Evaluation of the Effects of K-Space Under-Sampling in PROPELLER Imaging.

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Introduction: PROPELLER acquisitions were recently introduced in diffusion tensor imaging (DTI) of the brain[1]. A significant advantage of PROPELLER-DTI over EPI-based DTI is the fact that data acquired with PROPELLER have significantly less B_0-related artifacts. However, being a fast spin echo technique, PROPELLER-DTI acquisitions are slower than conventional EPI-based DTI acquisitions. Often in MRI, imaging time is reduced by under-sampling k-space. In this work, the effects of under-sampling on the raw PROPELLER images were evaluated. Under-sampling by reducing the number of samples/line, the number of lines/blade, or the number of blades/acquisition, while maintaining uniform sampling at the outer circle formed in k-space, reduces imaging time but may lead to a reduction of signal intensities and severe image artifacts. In contrast, under-sampling by means of removing whole blades from a PROPELLER sampling pattern that sufficiently samples k-space, may lead to minimal image artifacts, mainly manifested as blurring in directions perpendicular to the blades removed, even at a 50% reduction of imaging time.

Methods: Simulations of data acquisitions with different PROPELLER k-space sampling patterns were performed. The simulated object being imaged was the Shepp-Logan phantom[2], since its k-space image is known analytically, and the exact values of any sample, in any k-space sampling pattern, can be estimated. The FOV in image space was 24cm x 24cm, and an image matrix of 128x128 was selected. No noise was added to the data. If b, l, s, stand for the number of blades, lines and samples respectively, then the k-space sampling patterns that were simulated were (P={b, l, s}): P1={12, 16, 128}, P2={12, 16, 64}, P3={12, 8, 128}, P4={8, 16, 128} (Fig.1F, 1G, 1H, 1I). Also, sampling pattern M1 was created by removing blades 2, 3 and 4 from P1, and pattern M2 was created by removing blades 2, 4, 6, 8, 10, 12 from P1 (Fig.2ii, 2iv). The samples from all patterns covered the same circular region of k-space. Pattern P1 contained the most samples. All other patterns were considered to under-sample k-space. The type of under-sampling in P2, P3, P4 differed from that in M1, M2, in the sense that the former uniformly sampled the periphery of k-space, while the latter contained "blade-gaps". Image reconstruction involved (in the following order): weighting the k-space data to compensate for non-uniform sampling, interpolation onto a Cartesian grid, and Fourier transform (FT) to image space[3].

Results & Discussion: Figures 1 and 2 show the different sampling patterns and the corresponding images that were reconstructed. The reconstructed image based on P1 closely resembled the original object. Under-sampling in PROPELLER did not result in image fold-over similar to conventional sampling on a grid, since eventually all sampled data were interpolated on the same Cartesian grid before FT to image space. Images reconstructed using P2, P3 and P4 were characterized by reduced signal intensities compared to those using P1 (Fig.1). This was probably due to the fact that in patterns P2, P3, P4, the samples in the lowest spatial frequencies were further away from the center of k-space than in P1, therefore leading to larger errors in the center of k-space when interpolating onto the Cartesian grid. Also, images reconstructed using P2, P3 and P4 contained image artifacts that resembled ghosting along several different axes (Fig.1). For patterns M1 and M2 there was no significant reduction in signal intensities in the reconstructed images when compared to that obtained with P1, since low spatial frequencies were sampled similar to P1 (Fig.2). Also, images reconstructed from data sampled with M1 and M2 did not contain the severe ghosting artifact that was observed in the images obtained from P2, P3, and P4. Instead, sampling patterns M1, M2 introduced image smoothing along directions perpendicular to the missing blades. This can be explained using theory from limited angle tomography[4]. This result is also a demonstration of the effects of removing blades contaminated by motion[1]. Acquisition time for patterns P2, P3 and P4 is lower than that using P1, but still higher than 50% of that in P1. In contrast, imaging time with sampling pattern M2 is half of that with P1, and yet the images reconstructed from M2 were of superior quality to those reconstructed from P2, P3, P4, and very similar to the images reconstructed from P1. This finding is of significant importance for PROPELLER imaging, since it suggests that with only a small compromise in spatial resolution along predicted directions, acquisition time can be reduced to half of that with no under-sampling.

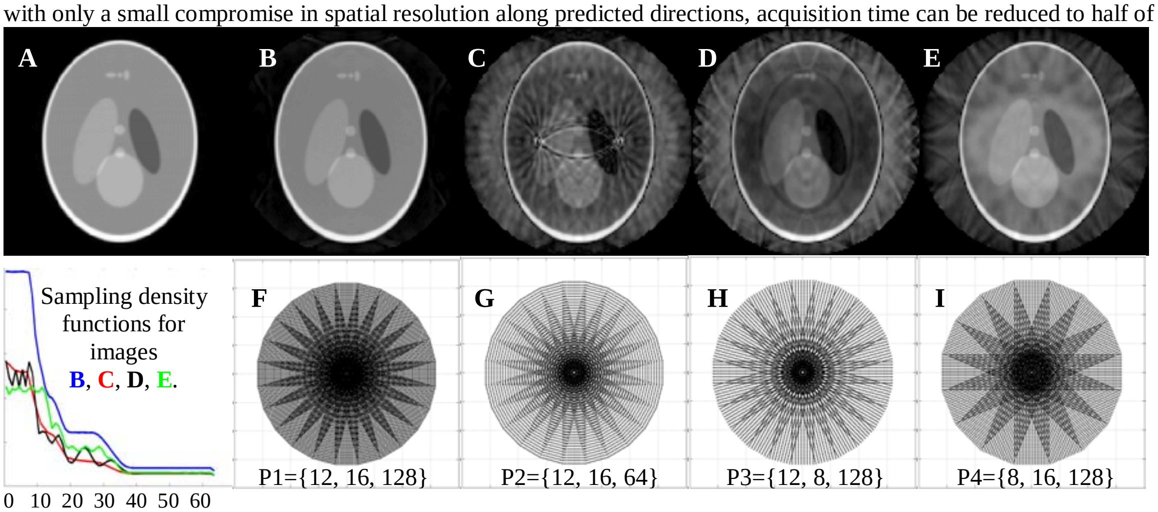

Figure 1. Image of the original object (A), and reconstructed images of the same object (B, C, D, E) using sampling patterns P1, P2, P3, P4 respectively. These patterns are shown in (F, G, H, I). Also shown, is the sampling density functions, along the k_x-axis, that correspond to sampling patterns P1 (blue), P2 (red), P3 (black), P4 (green).

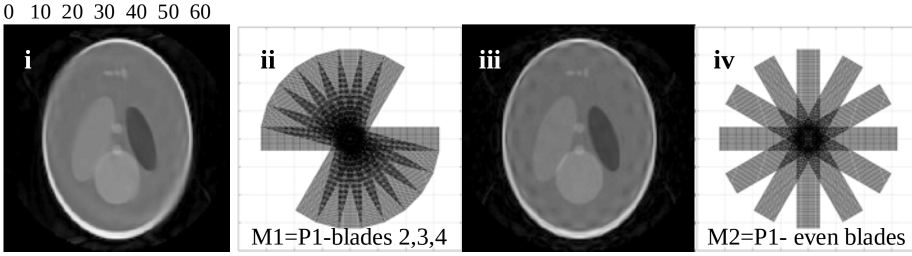

Figure 2. Reconstructed image (i) using sampling pattern M1 (ii), and the same object reconstructed (iii) from sampling pattern M2 (iv).

References: 1) Pipe JG, Farthing VG, Forbes KP, Magn Reson Med 47:42 (2002). 2) Shepp LA, Logan BF, IEEE Trans Nucl Sci NS-21:21 (1974). 3) Pipe JG, Menon P, Magn Reson Med 41:179 (1999). 4) Natterer F, John Wiley & Sons Ltd., Stuttgart (1989).