Parallel Line Scan Diffusion Imaging

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Introduction: Line scan imaging (LSI) [1] and line scan diffusion imaging (LSDI) [2,3] have interesting features compared to standard 2D Fourier encoding. In particular, the absence of phase encoding in LSI/LSDI allows for high-resolution imaging of inner volumes with considerable robustness against motion, while avoiding any aliasing artifact. LSI/LSDI is mostly immune to off-resonance effects, e.g., magnetic field inhomogeneities and susceptibility. Moreover, a reduction of the FOV in the line direction is without additional cost in SNR. In recent years, parallel imaging has achieved significant success in 2D/3D Fourier imaging due to its considerable imaging speed, but with the penalty of reduced SNR. Combining LSDI and parallel imaging techniques, we propose a novel parallel line scan diffusion imaging (pLSDI) technique with multiple slice acquisition scheme. The prominent advantage of pLSDI is not only its acceleration acquisitions for LSDI, but also the fact that this can be done with no cost in SNR.

Methods: Our pLSDI pulse sequence is shown in Fig. 1. A cosine modulated 90° pulse for double slice selection along one axis, e.g. y, and a conventional 180° refocused pulse along the z axis excites a pair of columns. A 1D-FT yields one line of data for the acquired aliased image. Diffusion gradient amplitudes are alternated to obtain images that are diffusion-weighted along different directions, and/or with different b-factor. To avoid interference from earlier excitations with the 90° and 180° RF pulses, sequential acquisition of columns is performed along the diagonal of the scan volume, as shown in Fig. 2. The first sweep excites odd columns (white squares) and the second sweep excites even columns (dark squares). In order to maintain a steady state, for every diagonal scanning route, a "dummy sweep" was added before the first sweep scan and one "idle scan" was added at the end of every even. The scan scheme for a 7-slice acquisition is shown in Fig. 3. After performing 1D-FT to the raw column data and separating aliased column data using SENSE, multi-slice images are obtained.

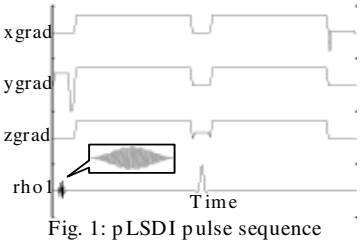

Fig. 1: pLSDI pulse sequence

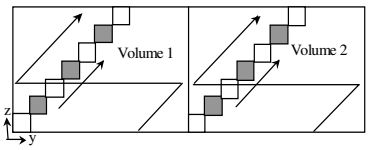

Fig. 2: Diagonal scan scheme

Results: The pLSDI sequence was implemented on a 3T GE Signa EXCITE 14.0 scanner with an 8-channel GE head coil. A GE distributed MRS sphere phantom with solution (Model: 212220) was used to test the pulse sequence and estimate SNR between pLSDI and LSDI. 47 slices were acquired with a slice thickness of 2.5mm, FOV 32x24cm, Matrix 128x128, TE=49.4ms, TR_{eff}=89*24 =2136ms where 89 is the scan time between column and 24 is the number of column per sweep. High and low diffusion b-factor value are 750 s/mm^2 and 5 s/mm^2 respectively. The overlapping and reconstructed images are shown in Fig. 4, for one low b-factor slice. For this slice, 4 areas of 276 mm^2 each (see circles in Fig.4) were used to estimate signal intensity and standard deviation, with and without parallel imaging. SNR was measured as the relative standard deviation of the signal within the area. The results are shown in Table 1. A human brain study with the same parameters as in the phantom study is shown in Fig. 5 and its location is shown in Fig 6.

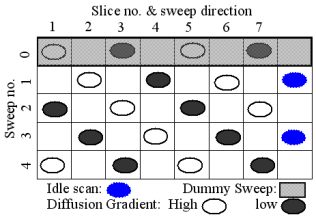

Fig. 3: Interleaved acquisition

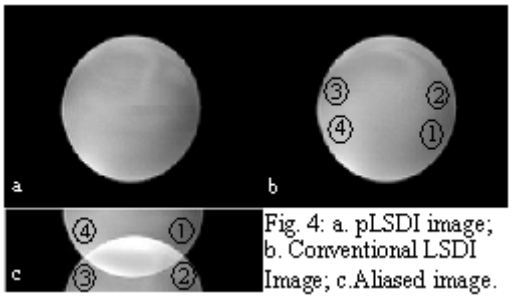

Fig. 4: a. pLSDI image; b. Conventional LSDI Image; c.Aliased image.

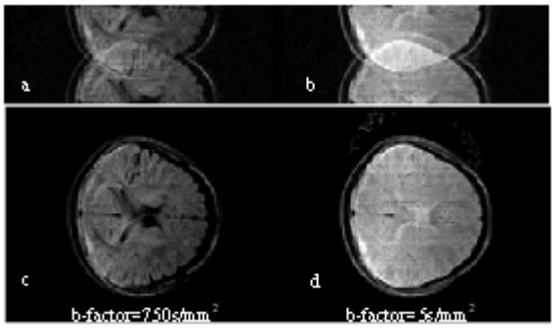

Fig. 5. pLSDI reconstructed images (c ,d) from aliased images (a, b)

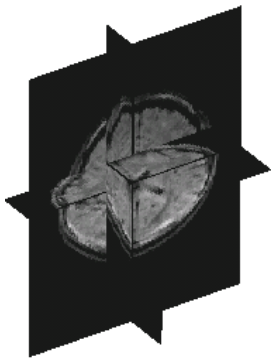
Fig. 6 pLSDI images in 3 planes

Discussion: In theory, pLSDI is not expected to reduce SNR. This can be understood through an analogy with the phase-offset multi-planar (POMP)[4] method, whereby SNR is improved by √n when *n* slices are excited simultaneously. Similarly, the gain in SNR obtained by exciting *n* lines simultaneously offsets the usual loss of SNR associated with parallel imaging. Comparing results from 4 ROIs, SNR is slightly higher with pLSDI in 2 ROIs (#3 and #4), slightly lower in one ROI (#1) and significantly lower in one (#2).

Fig. (ROI)	b(1)	c(1)	b(2)	c(2)	b(3)	c(3)	b(4)	c(4)
Mean	7781	7266	8401	8572	9590	9722	11885	10817
STD	288	322	443	633	584	521	427	364
SNR	27.0	22.6	19.0	12.9	16.4	18.7	27.9	29.7

Conclusion: LSDI images do not suffer from the susceptibility-induced signal loses and geometric image distortions that often plague EPI, especially in critical regions such as the frontal lobe, near major air cavities. Our proposed pLSDI approach preserves these significant advantages of the LSDI approach, and reduces scan time at particularly no cost in SNR.

[1] Ailion *et al.* MRI 1992;10:747 [2] Gudbjartsson *et al.* MRM 1996;36:509 [3] Maier. MRM 2001;46:1136 [4] Glover. JMRI 1991;1:457

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