3 phase cycle diffusion prepared 3D FSE to eliminate diffusion weighted image distortion

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Target Audience: Scientists, engineers and radiologists who have an interest in distortion free diffusion weighted imaging

Purpose: Echo planner imaging (EPI) is normally used for Diffusion Weighted Imaging (DWI). However, B0 inhomogeneity and eddy current of Motion Probing Gradient (MPG) pulse produce distortion in DW-EPI. Dual Echo type DW-EPI can reduce the influence of eddy current. But influence of inhomogeneous B0 cannot be eliminated. In this study, Diffusion Prepared 3D FSE (DP-Cube) was developed for distortion-free DWI. Phase cycle [ref. 1] was used to eliminate banding artifacts of DP pulse sequence. The image distortion and Apparent Diffusion Coefficient (ADC) were compared between DP-Cube and DW-EPI.

°**Methods:** *DP pulse sequence:* Dual echo type DP pulse sequence (Fig.1) was used in this study. 90° RF pulse was followed by two adiabatic 180° RF pulses. The phase θ of last -90° RF pulse was modified to be 0° or ±120° and 3 phases were acquired for one DWI. Although B0 inhomogeneity and eddy current do not produce distortion in DP-Cube, they produce banding. The number of phase in a cycle was 3 and Root Mean Square (RMS) of 3 phases was calculated to eliminate the banding. To make the sequence insensitive to motion, Flow compensated MPG pulses were used to cancel the 1st order moment of the coherent motion and DP pulse sequence was synchronized to the diastolic phase of cardiac cycle that was 400ms after peripheral trigger. Tetrahedral MPG [ref. 2] was used for isotropic DWI. *Data acquisition:* Variable Refocus Flip Angle 3DFSE (Cube) was used for data acquisition. Hardwares were 8ch brain coil and GE 1.5T Signa HDxt (GE Healthcare, Waukesha, WI, USA). Protocol was as follows; TE 96ms (including Diffusion Preparation time), TR 5RR, Echo Train 60, BW 62.5 kHz, FOV 250mm, thick 6mm, #slice 14, matrix 192x160, acceleration 2, Fat Saturation, Peripheral Trigger, Trigger delay 400ms, b value 3 or 1000s/mm^2, scanning time 1:11 for one dataset. 3 (3 phases) and 12 (3 phases * 4 MPG directions) datasets were acquired for b=3 and 1000, respectively. Total scanning time was around 18:00, which depended on cardiac cycle. DW-EPI was acquired for a comparison. Protocol was; TE 91ms, TR 6000ms, BW 250kHz, FOV 280mm, thick 5mm, matrix 128x128, acceleration 2, Dual Echo, Tetrahedral isotropic diffusion, scanning time 3:24. Water phantom and one volunteer were scanned and images were compared between DP-Cube and DW-EPI. IRB approval and written informed consent were obtained for human scanning.

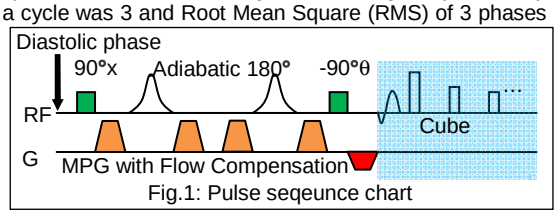

Fig.1: Pulse seqeunce chart

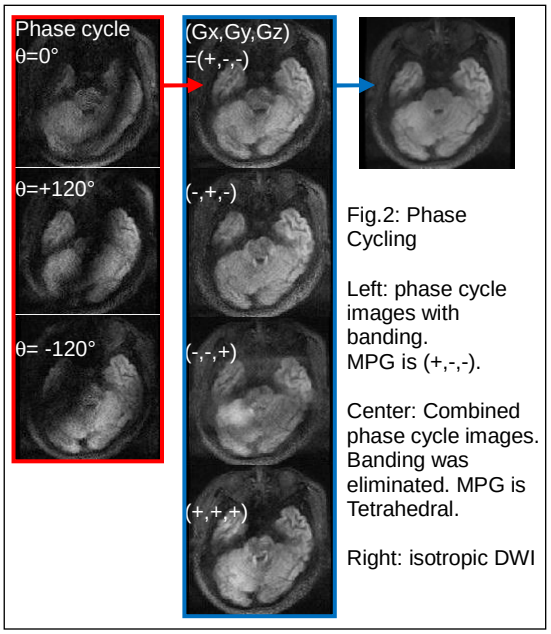

Fig.2: Phase Cycling

Left: phase cycle images with banding. MPG is (+,-,-).

Center: Combined phase cycle images. Banding was eliminated. MPG is Tetrahedral.

Right: isotropic DWI

Results: ADC of Water phantom in DP-Cube and DW-EPI are in Table 1. Room temperature was 25°C. They were within the margin of error bar. Volunteer images of DP-Cube are shown in Fig.2. Left column is the phase cycle images. Banding was depicted but distortion was not depicted. Center column is RMS of phase cycle images and banding was eliminated. There were some ghosting artifacts in each images and the (-,-,+) MPG image had the strongest ghost. Right column is isotropic DWI. The DP-Cube and DW-EPI images with low b, b=1000 and ADC are shown in Fig.3. Because of the B0 inhomogeneity near the sinus (red circle), DW-EPI image had distortion. DP-Cube was distortion-free. ADC of the DP-Cube was around 20 to 40% higher than DW-EPI in Pons and Cerebellum (Table 1). ADC of DP-Cube was lower in CSF. The literature of ADC [ref. 3] is also shown.

Discussion: Distortion in DW-EPI was not depicted in DP-Cube because DP-Cube was insensitive to B0 inhomogeneity and eddy current. In the same reason, higher resolution DWI was available in DP-Cube. Although ADC of static water phantom was similar, ADC of brain matter with DP-Cube was larger than DW-EPI. DP-Cube image had ghosting artifacts in Fig.2 and 3. The ghost signal intensity in b=1000 image (yellow circle) was around 20% of cerebellum signal. Because DP-Cube uses multi shot data acquisition and its signal is sensitive to motion, a small signal difference between TR might have caused ghost and ADC error.

Conclusion: 3 phase cycle DP-Cube eliminated the distortion of DWI. Ghost reduction was required for accurate ADC measurement.

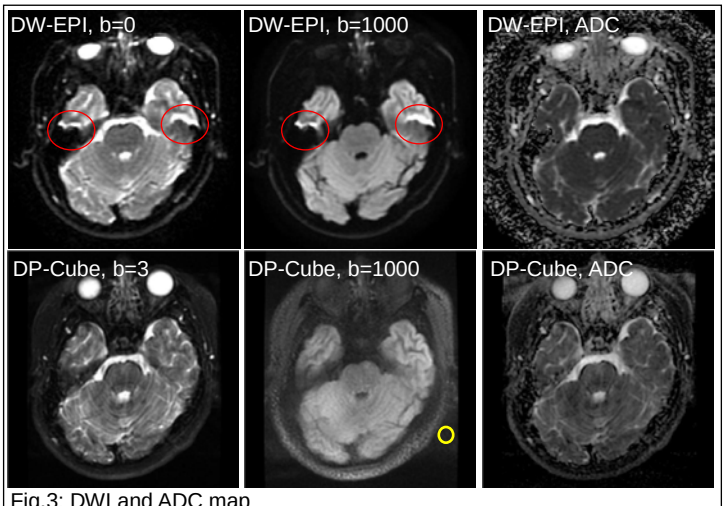

Fig.3: DWI and ADC map

References: 1. Thomas DL, Pell GS, Lythgoe MF, Gadian DG, Ordidge RJ. A Quantitative Method for Fast Diffusion Imaging Using Magnetization-Prepared TurbeFLASH. Magn Reson Med. 39:950-960 (1998).

2. Conturo TE, McKinstry RC, Akbudak E, Robinson BH. Encoding of Anisotropic Diffusion with Tetrahedral Gradeints: General Mathematical Diffusion Formalism and Experimental Results. Magn Reson Med. 35:399-412 (1996).

3. Helenius J, Soinne L, Perkio J, et al: Diffusion-weighted MR imaging in normal human brains in various age groups. AJR 23: 194-199, 2002.

Table 1: Measured and literature ADC value (10^{-3}mm^2/s)

	Literature	DW-EPI	DP-Cube
Water Phantom	2.04	1.98±0.02	2.04±0.07
Pons	0.6	0.75±0.12	1.03±0.22
Cerebellum	0.59-0.82	0.76±0.10	0.99±0.13
CSF	2.9	3.69±0.50	2.72±0.11