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Original Article

Improve the image quality of orbital 3 T diffusion-weighted magnetic resonance imaging with readout-segmented echo-planar imaging☆

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ABSTRACT

The aim of our study is to compare the image quality of readout-segmented echo-planar imaging (rs-EPI) and that of standard single-shot EPI (ss-EPI) in orbital 3 T diffusion-weighted (DW) magnetic resonance (MR) imaging in healthy subjects. Forty-two volunteers underwent two sets of orbital DW imaging scan at a 3 T MR unit, and image quality was assessed qualitatively and quantitatively. As a result, we found that rs-EPI could provide better image quality than standard ss-EPI, while no significant difference was found on the apparent diffusion coefficient between the two sets of DW images.

1. Introduction

Diffusion-weighted imaging (DWI) which can evaluate microscopic water motion within tissue in vivo, promises increased diagnostic accuracy for the orbital abscess, the characterization of retinoblastoma in pediatric patients, the differentiation between benign and malignant orbital tumors [1–5]. Mainly due to its resistance to patient motion and scanning speed, single-shot echo-planar imaging (ss-EPI) is the sequence used mostly in current clinical DWI related studies. However, ss-EPI DWI is prone to susceptibility artifacts which manifests as geometric distortion, signal-intensity drop-out, and overall T2*-induced image blurring. These detrimental effects are more severe at high field strengths and particular pronounced in regions with poor magnetic field homogeneity [6,7]. Thus, orbital DWI is particular challenging because it is adjacent to nasal sinus, bone and skin. Nearly 6% of the study population were excluded due to the inadequate image quality of DWI in one previous study [4].

One approach to overcome these disadvantages is the introduction of parallel imaging. However, ss-EPI DWI in combination with parallel imaging can only reduce distortion to a certain content. Because distortion is proportional to the matrix size in EPI, distortion and blurring artifacts can become increasingly prohibitive at higher resolutions [8]. Another approach to reduce distortion is the use of interleaved (or multishot) EPI DWI. Despite the absence of geometric distortion artifacts, the long scanning time and the ghosting artifacts in the presence of motion limit its clinical practice [9].

Recently, DWI based on read-out segmented EPI (rs-EPI), in which k-space is divided into several segments along the direction of the readout, has attracted increasing attention [6–14]. It permits the useage of shortened echo spacing in each segment, and can reduce geometric distortion and susceptibility artifacts by accelerating the k-space traversal along the direction of the readout. This technique has be proven to be useful to reduce geometric distortions, image blurring and ghosting artifacts in various organs at 3 T magnetic resonance (MR) imaging, including pediatric and adult brain, breast, kidney and neck region [6–14]. However, few studies have applied the rs-EPI in the orbital DWI till now.

Therefore, the purpose of our study is to evaluate the clinical usefulness of rs-EPI in the orbital DWI, and to compare its image quality with that of ss-EPI DWI at 3 T MR imaging unit in healthy adults.

2. Materials and methods

2.1. Patients

The institutional review board of our hospital approved our study protocol, and the requirement for written informed consents was waived due to the retrospective nature of analysis. Siemens Healthcare (Erlangen, Germany) provided the DW imaging sequence based on rs-EPI. We included the volunteers based on the following inclusion criterions: 1) 18 years or older; 2) no history of orbital disease; 3) no systematic disease that would influence the orbital morphology. Finally, forty-two consecutive volunteers (20 males and 22 females; mean age,

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51.3 ± 16.5 years; range, 24–88 years) were included in our study from March 2015 to September 2015.

2.2. Image acquisition

MR examinations were performed using a 3 T MR unit (Verio; Siemens, Erlangen, Germany) with a twelve-channel head coil, with patients resting in the supine position. Conventional imaging protocols contained an unenhanced axial T1-weighted imaging (repetition time [TR]/echo time [TE], 600/10 msec) and axial T2-weighted imaging (TR/TE, 4700/79 msec) with fat saturation.

Two sets of EPI DW imaging sequences (ss-EPI and rs-EPI) were performed with comparable imaging parameters. Detailed imaging parameters of the two imaging sequences were summarized in Table 1. To account for the number of readout-segmented (n = 5) in rs-EPI, and to keep the scanning time constant, five signals were acquired for the ss-EPI sequence.

2.3. Qualitative comparisons of image quality

We performed the qualitative comparisons of image quality based on five criteria: distinction of normal anatomical structure, degree of ghosting artifact, uniformity of fat suppression, and the overall image quality. Detailed criteria about the qualitative comparisons of image quality are shown in Table 2.

2.4. Quantitative comparisons of image quality

All data were transferred in Digital Imaging and Communication in Medicine (DICOM) format and post-processed off-line with in-house software (FireVoxel; CAI^{2}R; New York University, USA) [15].

Geometric distortion was evaluated by comparing the lengths of vitreous body at the level of lens on both T2 weighted images and the corresponding DW images. Both anterior–posterior (AP) length and right–left (RL) width of the vitreous body were measured and calculated. The geometric distortion ratio (GDR) in both AP and RL direction was calculated using following formula:

$$GDR = (length_{T2} - length_{DWI}/length_{T2}) \times 100\%$$

For comparing the absolute apparent diffusion coefficient (ADC) value between two sets of DW images, three circular ROIs were drawn on the vitreous body at the level of lens and the pons at the level of olivary nucleus. As previously mentioned, the ADC value was given by the following formula:

$$ADC = -\ln(S_b/S_0)/b$$

Where b represents the diffusion sensitivity coefficients, S_b and S_0 represent the corresponding signal values of the given ROIs.

Signal-to-noise ratio (SNR) was determined by the ratio between the mean signal intensity inside the ROI (S_{ROI}) in the vitreous body at the level of lens and the standard deviation of the background noise (σ_{BG}) ($SNR = S_{ROI}/\sigma_{BG}$). All the quantitative measurements were repeated three times, and the average value was adapted into further analysis.

All the qualitative and quantitative assessments were determined by two neuro-radiologists (reader 1: with 14 years of experience; reader 2: with 4 years of experience), who were blinded to the study design and image sequence type. Meanwhile, to assess the intra-reader reproducibility of qualitative and quantitative assessments, all the imaging data were processed again by reader 1, spaced by at least one month. The average value of the two time measurements from reader 1 was adopted for analysis.

2.5. Statistical analysis

All statistical analyses were carried out using two software packages (SPSS version 19.0, IBM Corp., Armonk, NY; MedCalc 9.0, Mariakerke, Belgium). Wilcoxon signed rank test was used to compare the differences of qualitative parameters about the image quality. Paired t test was used to compare the differences of quantitative parameters between two DW images. The inter-reader and intra-reader agreements for the assessment of qualitative parameters were evaluated using Kappa analysis, and the agreements for the assessment of quantitative parameters were evaluated using intraclass correlation (ICC) coefficient with 95% confidence interval (CI). The Kappa value and ICC coefficient

Table 1
Sequence parameters for single-shot and readout-segmented EPI

Sequence parameter	Single-Shot EPI	Readout-segmented EPI
Diffusion direction	Three-direction trace	Three-direction trace
Diffusion schema	Stejskal-Tanner	Stejskal-Tanner
b value (sec/mm^2)	0, 1000	0, 1000
Fat suppression	Frequency selective	Frequency selective
Repetition time (msec)	4000	4000
Echo time (msec)	85	69
Field of view (mm)	220	220
Matrix	130 × 130	224 × 224
Numbers of sections	9	9
Section thickness (mm)	4	4
Intersection gap (%)	30	30
Phase-encoding direction	Anteroposterior	Anteroposterior
Echo-spacing (msec)	1.07	0.4
Number of readout segments	1	5
Number of signals acquired	5	1
Acquisition time (min: sec)	1:34	1:50

Note: EPI indicates echo-planar imaging.

Table 2
Criteria for qualitative comparison of image quality

Clear distinction of normal anatomical structure
0–4: Number of distinguishable structures
(lens, vitreous body, optic nerve, medial or lateral rectus)
Fat suppression
1: No suppression
2: Heterogeneous fat suppression
3: Homogeneous fat suppression
Ghosting artifact (the interface of the orbital apex and petrous bone)
1: Severe artifact
2: Moderate artifact
3: Mild artifact
4: None artifact
Overall image quality
1: Poor
2: Fair
3: Good
4: Excellent

Table 3
Qualitative comparison of image quality between rs-EPI and ss-EPI DWI of the orbit in healthy volunteers

Parameter	ss-EPI	rs-EPI	P value	Kappa value	
				Inter-reader	Intra-reader
Anatomical structure distinction	2.52 ± 0.08	3.19 ± 0.67	0.0090	0.7198	0.7264
Fat suppression	2.86 ± 0.35	2.90 ± 0.30	0.7539	0.9179	0.9318
Ghosting artifact	1.62 ± 0.66	2.67 ± 0.48	<0.0001	0.8022	0.8345
Overall image quality	1.95 ± 0.79	2.86 ± 0.72	<0.0001	0.7303	0.8117

Note: Numbers show mean ± standard deviation except for P value and Kappa value. ss-EPI indicates single-shot echo-planar imaging; rs-EPI, readout-segmented echo-planar imaging. DWI, diffusion weighted imaging.