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FULL PAPER

3D turbo field echo with diffusion-sensitized driven-equilibrium preparation technique (DSDE-TFE) versus echo planar imaging in evaluation of diffusivity of retinoblastoma

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Objective: Compared with echoplanar (EP) diffusion-weighted imaging (DWI), three-dimensional (3D) turbo field echo with diffusion-sensitized driven-equilibrium (DSDE-TFE) preparation DWI obtains images with higher spatial resolution and less susceptibility artefacts. The purpose of this study was to evaluate the feasibility of DSDE-TFE to visualize retinoblastomas compared with EP imaging.

Methods: This retrospective study was approved by our institutional review boards. Eight patients with retinoblastomas (five males and three females; age range 0–87 months; median 21 months) were studied. For the DSDE-TFE, motion-probing gradients (MPGs) were conducted at one direction with b -values of 0 and 500 s mm^{-2} and a voxel size of $1.5 \times 1.5 \times 1.5 \text{ mm}^3$. For the EP imaging, MPGs were conducted at three directions with b -values of 0 and 1000 s mm^{-2} and a voxel size of $1.4 \times 1.8 \times 3 \text{ mm}^3$. The apparent diffusion coefficients (ADCs) of each lesion

were measured. Statistical analyses were performed with Pearson R and linear correlation coefficients.

Results: Intraocular lesions were clearly visualized on the DSDE-TFE without obvious geometrical distortion, whereas all showed deformity on EP images. On the DSDE-TFE, the ADCs of the lesions ranged from 0.83×10^{-3} to $2.93 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$ (mean $\pm$ standard deviation $1.73 \pm 0.73 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$). On the EP images, the ADCs ranged from 0.53×10^{-3} to $2.03 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$ ($0.93 \pm 0.53 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$). There was a significant correlation in ADC measurement between the DSDE-TFE and EP imaging ($r = 0.81$, $p < 0.05$).

Conclusion: With its insensitivity to field inhomogeneity and high spatial resolution, the 3D DSDE-TFE technique enabled us to assess diffusivity in retinoblastomas.

Advances in knowledge: DSDE-TFE could enable us to assess the ADC of retinoblastomas without obvious geometrical distortion.

INTRODUCTION

Retinoblastoma is a highly malignant tumour and is the most common intraocular tumour of childhood.^{1–5} Diagnoses of retinoblastoma are usually made by fundoscopy and ultrasound.^{1,2} However, MRI is recommended to evaluate extraocular extension and the presence of intracranial lesions.^{2,5}

Diffusion-weighted imaging (DWI) is widely used to diagnose tumours, inflammation and vascular disease in both intracranial and extracranial lesions.^{3,4,6–16} Previous studies also revealed the efficacy of DWI to evaluate orbital lesions including orbital tumours of adults^{8,9} and children,¹⁰ ocular adnexal lymphomas,^{9,11} immunoglobulin G4

(IgG4)-related disease,⁹ endophthalmitis¹² and optic nerve lesions.^{13,14} However, it is sometimes difficult to evaluate intraorbital structures with echoplanar (EP) imaging, which is the most common imaging technique for DWI. Therefore, de Graaf et al³ used single-shot turbo spin-echo sequences to evaluate retinoblastoma.

Compared with EP-DWI, three-dimensional (3D) turbo field echo with diffusion-sensitized driven-equilibrium (DSDE-TFE) preparation can produce images with higher spatial resolution and fewer susceptibility artefacts.^{9,15–17} DSDE-TFE itself was originally reported to be one of the nerve sheath imaging techniques that can be used to minimize image distortion while reducing B0 and B1

inhomogeneity and eddy current effects^{17,18} and was used to examine cholesteatoma,¹⁵ pituitary gland,¹⁶ orbital lymphoma and IgG4-related disease.⁹ However, to the best of our knowledge, there has been no report evaluating intraocular retinoblastomas using DSDE-TFE. Because of the image degradation with EP-DWI in the paediatric orbital region, DSDE-TFE might help to assess diffusivity without geometrical distortion. Therefore, the purpose of this study was to evaluate the feasibility of DSDE-TFE to visualize retinoblastomas compared with EP imaging.

METHODS AND MATERIALS

This retrospective study was approved by our institutional review boards, and written informed consent was waived.

Patients

The cases of eight consecutive patients with retinoblastomas (five males and three females; age range 0–87 months; median 21 months), who were treated between January 2011 and September 2013 at our institution, were studied. Orbital MRI including DSDE-TFE was routinely performed at our institution in this study period as a part of tumour staging. The paediatricians or ophthalmologists initially made the diagnosis clinically. Six patients were diagnosed histopathologically after MRI, without prior treatment. One patient received chemotherapy before surgery and was subsequently diagnosed histopathologically. Another patient was diagnosed clinically and treated with chemotherapy alone.

Imaging technique

All patients underwent MRI with a 3.0-T system (Achieva® Quasar Dual; Philips, Best, Netherlands) with an eight-channel head coil. The details of the DSDE-TFE are described elsewhere.^{9,15–17} The DSDE-TFE has two distinct components: the DSDE preparation and the segmented 3D TFE data acquisition.¹⁷ The DSDE preparation is an extension of a motion-sensitized driven-equilibrium (MSDE) preparation, which has been used for black-blood imaging of large vessels.^{19,20} MSDE preparations have also been applied to brain imaging for the detection of metastatic tumours.²¹

Compared with an MSDE preparation, the DSDE-prepared sequence has stronger motion-sensitizing gradients, which enables diffusion-weighting in the anteroposterior direction. The DSDE preparation was originally developed to reduce image distortion in the imaging of peripheral nerves,¹⁷ and it was then optimized for orbital imaging in the present study. Adiabatic refocusing pulses and additional gradients inserted in front of the sequence were used to reduce the sensitivity to B0 and B1 inhomogeneity as well as eddy current effects.^{17,18} Data acquisition using TFE was performed immediately after the DSDE preparation.

To eliminate T_1 effects in the acquired signal by TFE, we used a phase-cycling scheme.^{22,23} For the DSDE-TFE, motion-probing gradients were used in one direction with b -values of 0 and 500 s mm^{-2} . The other imaging parameters were as follows: repetition time/echo time = $6.2/3.0 \text{ ms}$, flip angle (FA) = 10° , echo train length (ETL) = 75, field of view = 240 mm , voxel size = $1.5 \times 1.5 \times 1.5 \text{ mm}^3$, number of excitations = 2, imaging

time = $5 \text{ min } 22 \text{ s}$. For the EP imaging, motion-probing gradients were conducted in three directions with b -values of 0 and 1000 s mm^{-2} . The other imaging parameters were as follows: repetition time/echo time = $3000/57 \text{ ms}$, sensitivity encoding (SENSE) factor = 2.5, field of view = 230 mm , matrix = 160×128 , slice thickness/gap = $3/0 \text{ mm}$, voxel size = $1.4 \times 1.8 \times 3 \text{ mm}^3$, number of sample overaged (NSA) = 2 and acquisition time = $2 \text{ min } 12 \text{ s}$.

Axial T_1 weighted images, T_2 weighted images with fat suppression and post-contrast T_1 weighted images with fat suppression were also obtained. The contrast material was injected at 0.1 mmol kg^{-1} [gadopentetate dimeglumine (Magnevist®; Bayer, Osaka, Japan), gadodiamide (Omniscan; Daiichi Sankyo, Tokyo, Japan) or gadoteridol (Prohance®; Eisai, Tokyo, Japan)].

Analysis

The DSDE-TFE data set was reformatted to the axial plane (3 mm thick) and saved in digital imaging and communications in medicine format. Apparent diffusion coefficient (ADC) maps were calculated on a personal computer using ImageJ v. 1.44p, for Windows software (<http://rsb.info.nih.gov/ij/>). All other MR images were transferred to picture archiving and communication systems (SYNAPSE®; Fujifilm Medical, Tokyo, Japan). Regions of interest (ROIs) were placed at the intraorbital lesions by a neuroradiologist (AH with 17 years' experience in neuro-radiology). All ROIs were placed to cover the solid portions of the lesions on the axial plane at the level of the maximum diameter of each lesion. Pathological specimens were used as references during the ROI placements. The statistical analyses were all performed by the same author using JMP software v. 9.0.2 (SAS Institute, Cary, NC). Statistical analyses were performed with Pearson R and linear correlation coefficients. A p -value < 0.05 was considered significant.

RESULTS

Intraocular lesions were clearly visualized on the DSDE-TFE without obvious geometrical distortion (Figure 1), whereas all eight eyeballs showed deformity on the EP images. On the DSDE-TFE, the ADCs of the lesions ranged from 0.83×10^{-3} to $2.93 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$ (mean $\pm$ standard deviation; $1.73 \pm 0.73 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$). On the EP imaging, the ADCs ranged from 0.53×10^{-3} to $2.03 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$ ($0.93 \pm 0.53 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$). There was a significant correlation in ADC measurement between the DSDE-TFE and EP ($r = 0.81$, $p < 0.05$) (Figure 2).

There was one case of presumed optic nerve involvement; the patient had received pre-operative chemotherapy resulting in a lack of it in the surgical specimen. This case showed the highest ADC ($2.03 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$), probably owing to tumour necrosis.

DISCUSSION

In this study, we evaluated the diffusivity of retinoblastomas using DSDE-TFE. We found that with DSDE-TFE, there was no obvious image distortion in the eyeballs as there was with EP imaging. DSDE-TFE originally has a high spatial resolution ($1.5 \times 1.5 \times 1.5 \text{ mm}^3$). TFE acquisition can achieve less susceptibility artefacts compared with EP.

Figure 1. A 22-month-old female with retinoblastoma in the right eye: there is a hypointense mass (arrow) in the right eyeglobe on the fat-suppressed T_2 weighted image (a). There is a heterogeneous enhancement in the lesion (arrow) (b). The apparent diffusion coefficient (ADC) map derived from the turbo field echo with diffusion-sensitized driven-equilibrium (c) is showing restricted diffusivity in the lesion (arrow) ($1.57 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$) compared with the vitreous ($3.92 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$) without geometrical deformity. The ADC map derived from the echoplanar imaging (d) is also showing restricted diffusivity in the lesion (arrow) ($0.71 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$) compared with the vitreous ($2.67 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$), but there is a severe geometric deformity.

In this study, we observed a significant correlation in ADC measurement between DSDE-TFE and EP imaging ($r = 0.81$, $p < 0.05$). However, the ADCs derived from the DSDE-TFE

Figure 2. The relationship of apparent diffusion coefficient (ADC) between the turbo field echo with diffusion-sensitized driven-equilibrium (DSDE-TFE) and echoplanar (EP) imaging: there is a significant correlation in ADC measurements between the DSDE-TFE and EP imaging ($r = 0.81$, $p < 0.05$). $\text{ADC}_{\text{DSDE-TFE}} = \text{ADC}_{\text{EP}} \times 1.05 + 0.88$.

tended to be higher than those derived from the EP imaging. For the DSDE-TFE, we used adiabatic refocusing pulses and additional gradients inserted in front of the sequence to reduce the sensitivity to B0 and B1 inhomogeneity and the eddy current effects.^{17,19} However, further development is required to verify the ADC measurements.

DWI has been reported to be beneficial for evaluating tumour grade and response to treatment.^{7–11} Previous reports showed variable DWI intensities and ADCs in retinoblastomas, depending on their histology and cellularity.³ Abdel Razek et al⁴ reported that the mean ADC was $0.49 \pm 0.12 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$ on EP imaging, which is lower than the mean ADC of the present study. They mentioned that the ADC values were significantly lower in their patients with optic nerve invasion.⁴ Our study population included one patient with optic nerve involvement showing a high ADC ($2.03 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$). This patient underwent pre-operative chemotherapy, and we could not verify the optic nerve invasion histopathologically. Abdel Razek et al⁴ also reported that the ADC value of retinoblastoma was well correlated with the degree of differentiation of the tumour ($r = 0.87$, $p = 0.007$). In our present retrospective case series, we could not examine the radiologic–histopathologic correlation.

Contrary to the findings described by Abdel Razek et al,⁴ Sepahdari et al⁸ reported that retinoblastomas had an ADC of

$0.93 \pm 0.3 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$, which is in line with our results. They also mentioned that the ADCs of the retinoblastomas were strongly inversely correlated with the lesion thickness, likely representing the effect of partial volume averaging.⁸ The high spatial resolution of DSDE-TFE might solve this problem.

A limitation of the present study is the small number of cases examined (eight). We will continue to gather similar cases. Low *b*-values and the unidirectional diffusion weighting are technical limitations of this study. We were able to obtain DW images with DSDE-TFE with *b*-values $>500 \text{ s mm}^{-2}$, but it was sometimes difficult to obtain ADC maps, probably owing to insufficient eddy current corrections. In addition, we are trying to apply diffusion weighting in more than three directions. Further

technical developments are required. We included the patient who received treatment before MRI. The presence of treatment effect might alter the results. The results of this study might not play a role in the diagnosis of retinoblastoma; however, we hope it might represent treatment response in the future.

CONCLUSION

With its insensitivity to field inhomogeneity and high spatial resolution, the 3D DSDE-TFE technique enabled us to assess diffusivity in retinoblastomas.

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