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Preoperative grading of supratentorial gliomas using high or standard b-value diffusion-weighted MR imaging at 3T

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KEYWORDS
Glioma;
Diffusion-weighted MR imaging;
High b-value;
Tumor grading;
Normalized apparent diffusion coefficient (ADC)

Abstract
Purpose: The goal of this study was to compare diffusion-weighted magnetic resonance imaging (DW-MRI) using high b-value ($b = 3000\,s/mm^2$) to DW-MRI using standard b-value ($b = 1000\,s/mm^2$) in the preoperative grading of supratentorial gliomas.
Materials and methods: Fifty-three patients with glioma had brain DW-MRI at 3T using two different b-values ($b = 1000\,s/mm^2$ and $b = 3000\,s/mm^2$). There were 35 men and 18 women with a mean age of 40.5 ± 17.1 years (range: 18—79 years). Mean, minimum, maximum, and range of apparent diffusion coefficient (ADC) values for solid tumor ROIs (ADC_{mean}, ADC_{min}, ADC_{max}, and ADC_{diff}), and the normalized ADC (ADC_{ratio}) were calculated. A Kruskal—Wallis statistic with Bonferroni correction for multiple comparisons was applied to detect significant ADC parameter differences between tumor grades by including or excluding 19 patients with an oligodendroglioma. Receiver operating characteristic curve analysis was conducted to define appropriate cutoff values for grading gliomas.
Results: No differences in ADC derived parameters were found between grade II and grade III gliomas. Mean ADC values using standard b-value were $1.17 \pm 0.27 \times 10^{-3}\,mm^2/s$ [range: 0.63—1.61], $1.05 \pm 0.22 \times 10^{-3}\,mm^2/s$ [range: 0.73—1.33], and $0.86 \pm 0.23 \times 10^{-3}\,mm^2/s$ [range: 0.52—1.46] for grades II, III and IV gliomas, respectively. Using high b-value, mean ADC values were $0.89 \pm 0.24 \times 10^{-3}\,mm^2/s$ [range: 0.42—1.25], $0.82 \pm 0.20 \times 10^{-3}\,mm^2/s$ [range:

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0.56—1.10], and $0.59 \pm 0.17 \times 10^{-3}$ mm^2/s [range: 0.40—1.01] for grades II, III and IV gliomas, respectively. ADC_{mean}, ADC_{ratio}, ADC_{max}, and ADC_{min} were different between grade II and grade IV gliomas at both standard and high b-values. Differences in ADC_{mean}, ADC_{max}, and ADC_{diff} were found between grade III and grade IV only using high b-value.

Conclusion: ADC parameters derived from DW-MRI using a high b-value allows a better differential diagnosis of gliomas, especially for differentiating grades III and IV, than those derived from DW-MRI using a standard b-value.

Advanced magnetic resonance imaging (MRI) sequences, including diffusion-weighted (DW)-MRI, have had a limited role in the preoperative grading of glioma due to tissue heterogeneity associated with gliomas across different grades, within the same grade and even within a single tumor [1,2]. Several studies have reported that apparent diffusion coefficient (ADC), and fractional anisotropy (FA) images estimated from DW-MRI using a standard b-value did not help differentiate low from high-grade gliomas at 1.5T or 3T [3—7]. Higher field strength MRI scanners and stronger gradients with higher slew rates have enabled the acquisition of high b-value DW-MR images [8]. A higher b-value DW-MRI provides better contrast due to less T2 shine through effect and better reflects tissue characteristics [9]. Higher b-value DW-MRI has been reported to better identify the extent of acute cerebral infarction [10—12], and improve the lesion to normal contrast for Alzheimer's disease [13] and medulloblastomas [14]. High b-value DW-MRI has also been reported to provide better tumor delineation and detect additional lesions in primary central nervous system lymphomas [15]. More recently, Pramanik et al. stated that high b-value DW-MRI was more effective for the identification of hypercellular components of glioblastomas than standard b-value DW-MRI for radiation therapy target definition [16]. Additionally, minimum ADC values acquired from high b-value DW-MRI in peritumoral regions were reported to be effective in distinguishing high-grade gliomas from metastases [17].

High b-value DW-MRI has been reported to better discriminate between low and high-grade cerebral gliomas than standard b-value DW-MRI [9]. However, grades III and IV gliomas were grouped and designated as high-grade and the diffusion characteristics of these two grades were not differentiated in that study [9]. A recent study reported on several differentially expressed genes between grades III and IV gliomas [18], which indicates that their preoperative differentiation might be valuable for a more personalized therapy planning approach.

The goal of this study was to compare DW-MRI using high b-value ($b = 3000$ s/mm^2) to DW-MRI using standard b-value ($b = 1000$ s/mm^2) in the preoperative grading of supratentorial gliomas.

Materials and methods

Patients

This study was approved by the local institutional review board. All patients provided written informed consent prior to the study. A total of 53 patients with a supratentorial glioma were included in this study. There were 35 men and 18 women, with a mean age of 40.5 ± 17.1 years (range: 18—79 years). According to the World Health Organization (WHO), 12 patients had a WHO grade II oligodendroglioma, 10 had a WHO Grade II astrocytoma, 7 had a WHO Grade III oligodendroglioma, 4 had a WHO Grade III astrocytoma, and 20 had a WHO glioblastoma multiforme. The distribution of grades, age, gender, and the number of the patients diagnosed with an oligodendrioglioma within the study population are given in Table 1. MRI examinations were performed one to two days before surgery, and tumor grade of all the patients was defined after surgery through histopathological analysis conducted by a pathologist with 22 years of experience.

MRI data acquisition

MR imaging studies were performed on a 3T MR scanner (Intera Achieva®, Philips, Best, The Netherlands) using an eight-channel sensitivity encoding (SENSE) head coil. The system was equipped with high performance gradients (maximum gradient strength = 80 mT/m and maximum slew rate = 200 mT/m/ms). All patients underwent MRI using a routine tumor protocol that included T2-weighted fluid attenuated inversion recovery (FLAIR) (TR/TE = 11,000/125 ms) sequence in the transverse plane, T2-weighted turbo spin echo (TSE) (TR/TE = 3000/80 ms) sequence in the coronal plane, standard ($b = 1000$ s/mm^2) and high ($b = 3000$ s/mm^2) b-value DW-MRI, and pre-contrast and post-contrast (gadolinium-DTPA, Magnevist®, Bayer Pharma, Berlin, Germany) three-dimensional T1-weighted turbo field echo (TFE) (TR/TE = 9.9/4.5 ms) sequences. DW-MRI sequences were obtained by using a single shot spin echo echo-planar pulse sequence (TR/TE = 2678/53 ms for $b = 1000$ s/mm^2; TR/TE = 4306/68 ms for $b = 3000$ s/mm^2; echo-planar imaging (EPI) factor = 47, number of signal averages (NSA) = 1, field of view (FOV) = 230 mm, slice thickness = 4 mm, slice gap = 1 mm, number of slices = 28, data acquisition matrix = 112 × 89, image matrix = 256 × 256, scan time = 59 s for $b = 1000$ s/mm^2, and 1:35 min for $b = 3000$ s/mm^2).

MR image analysis

All DW-MRI examinations were transferred to a workstation (Philips View Forum® software system). ADC maps obtained at $b = 1000$ s/mm^2 and $b = 3000$ s/mm^2 were reconstructed using the DW image and the additional $b = 0$ s/mm^2 image. Two groups of region of interests (ROI) were defined on

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