Role of diffusion weighted MRI in differentiating typical from atypical meningiomas at 1.5 and 3T MRI

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Abstract Purpose: Atypical and malignant meningiomas are considered to have a higher rate of recurrence and show aggressive behavior compared to benign variety. The purpose of our study was to study the role of diffusion weighted imaging and determination of apparent diffusion coefficient (ADC) values and ADC ratios to differentiate typical meningiomas from atypical/malignant variety at 1.5 and 3T MRI.

Materials and methods: A total of 94 adult patients (48 patients at 3T and 46 patients at 1.5T) with pathologically proven meningiomas were retrospectively evaluated on conventional and diffusion weighted MRI. The signal intensity of the lesions on DW imaging was evaluated. ADC values and ADC ratios were calculated from lesion and contralateral normal white matter.

Results: 94 lesions comprising of 66 benign and 28 atypical meningiomas were evaluated. The mean ADC values at 3T MRI were 0.82 ± 0.12 × 10^{-3} in benign (typical) meningiomas and 0.68 ± 0.10 × 10^{-3} in atypical meningiomas. At 1.5T, the mean ADC values of benign meningiomas were 0.83 ± 0.11 × 10^{-3} and 0.70 ± 0.09 × 10^{-3} in atypical meningiomas. The mean ADC ratios were 1.08 ± 0.17 and 0.85 ± 0.15 for benign and atypical meningiomas respectively. There was a statistically significant difference between the mean ADC ratios and the mean ADC values of typical and atypical meningiomas (P < 0.001) at both 1.5T and 3T MRI.

Abbreviations: DWI, diffusion-weighted imaging; ADC, apparent diffusion coefficient

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1. Introduction

Meningiomas are considered to be the most common extra axial intracranial tumors (1). Histologically they are graded into three subtypes, benign, atypical and malignant (2,3). Atypical and malignant varieties have a high incidence of post operative recurrence and brain invasion (4). Although conventional MRI is helpful in diagnosing meningiomas, histological grading is not possible. Diffusion weighted imaging (DWI) with calculation of ADC values has been evaluated in preoperative grading of meningiomas. Although some studies have shown statistically significant results in differentiating typical from atypical/malignant meningiomas, other studies have contradicted these findings (4–8). The purpose of our study was to study the role of DWI with calculation of absolute ADC values and ADC ratios in differentiating benign meningiomas from atypical/malignant variety at 1.5 and 3T MRI.

2. Materials and methods

2.1. Patients

A database search through hospital and radiology information system was performed for this retrospective study. Patients who had a preoperative MR imaging with DW imaging between March 2010 and March 2012 and a final histopathological diagnosis of meningioma were included in this study. A total of 94 patients who had been diagnosed and operated for meningioma were included in the study. The exclusion criteria included patients with abundant calcification, necrosis and cyst on imaging. Tumor grading of the meningiomas was made based on the World Health Organization (WHO) classification (2007). 94 patients comprised of 31 males and 63 females (mean age of 48 years). Of all the meningiomas, 66 were typical while 28 were atypical. Approval of institutional review board was obtained for retrospective study.

2.2. Imaging

Out of 94, 46 patients underwent MR imaging study in a 1.5T clinical scanner (SIEMENS AVANTO) using standard head coil with 230 × 184 (AP X RL) FOV. Conventional MR images consisted of axial and coronal fast spin-echo T2-weighted images (TR/TE 4650/95 ms), axial and sagittal FFE T1-weighted images (1140/4.4), fluid attenuated inversion recovery sequence (FLAIR) (TR/TE 80900/89), contrast enhanced images T1-weighted images (TR/TE1110/4.4) after intravenous contrast injection (gadopentetate dimeglumine – 0.1 mmol/kg) with section thickness of 6 mm and inter slice gap of 0.6 mm.

DW MR imaging was acquired in the axial plane by using b-values of 0–1000 s/mm² with section thickness of 5 mm.

2.3. Statistical analyses

Statistical analyses were made by SPSS 17.0 version for Windows (SPSS, Chicago, IL). Levene’s sample test was used for calculating the overall statistical differences among the typical and atypical groups. Student’s T-test was conducted for calculating the differences in the mean ADC values and the mean ADC ratios between each pair. P < 0.05 was considered statistically significant.

3. Results

Out of 94, 46 patients underwent MR imaging study in a 3T clinical scanner (PHILIPS ACHIEVA) using standard head coil with 230 × 184 (AP X RL) FOV. Conventional MR images consisted of axial and coronal fast spin-echo T2-weighted images (TR/TE 3000/80 ms), axial and sagittal FFE T1-weighted images (8.4/3.8), fluid attenuated inversion recovery sequence (FLAIR) (TR/TE 11000/125), contrast enhanced images T1-weighted images (TR/TE8.4/3.8) after intravenous contrast injection (gadopentetate dimeglumine – 0.1 mmol/kg) with section thickness of 6 mm and interslice gap of 0.6 mm.

DW MR imaging was acquired in the axial plane by using b-values of 0–1000 s/mm² with section thickness of 5 mm.

Table 1 Diffusion weighted imaging characteristics of typical and atypical meningiomas at 3T and 1.5T MRI.

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<tr>
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<th>Typical</th>
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<tr>
<td>Hyperintense</td>
<td>19</td>
<td>13</td>
<td>22</td>
<td>12</td>
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<tr>
<td>Isointense</td>
<td>12</td>
<td>1</td>
<td>9</td>
<td>2</td>
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<tr>
<td>Hypointense</td>
<td>3</td>
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<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
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34 (71%) were typical. On 1.5T MRI of a total of 46 lesions imaged, 14 (30%) were atypical while 32 (70%) were typical. In total of 94 meningiomas, 28 (30%) were atypical (Grade 2), while 66 (70%) were typical (Grade 1).

The most common location for meningioma was parasagittal (28%) followed by sphenoid wing (11%). On T2-weighted images, 59 of the lesions were isointense, 28 were hyperintense, and 7 were hypointense. On T1-weighted images, 69 lesions were isointense and 35 were hypointense.

Lesions enhanced significantly after contrast material administration. There were no significant differences between the findings on T1- and T2-weighted images for atypical and typical meningiomas.

Diffusion-weighted MR imaging findings in meningiomas are shown in (Table 1).

Atypical meningiomas were hyperintense on trace diffusion-weighted MR images in 25 cases and isointense in three cases. On trace diffusion-weighted MR images of typical meningiomas, 41 were hyperintense, 22 were isointense and three were hypointense.

In summary, on trace diffusion-weighted images, the findings of atypical meningiomas and typical meningiomas were not significantly different both at 1.5 and 3T MRI.

3.1. ADC findings

At 3T MRI, the mean ADC value of atypical meningiomas was 0.68 ± 0.12 × 10⁻³ and the mean ADC value of typical meningiomas was 0.82 ± 0.12 × 10⁻³ (Figs. 1 and 2). At 1.5T, the mean ADC value of atypical meningiomas was 0.70 ± 0.09 × 10⁻³ and the mean ADC value of typical meningiomas was 0.83 ± 0.11 × 10⁻³. There was a statistically significant difference between the ADC values of typical and atypical meningiomas (P < 0.001) at both 1.5T and 3T MRI. The mean ADC value of normal white matter was 0.78 ± 0.73 × 10⁻³.

The calculated mean ADCTM/ADCWM ratios were 1.08 ± 0.17 for benign tumors, 0.85 ± 0.15 for atypical ones. There was a statistically significant difference between the ADC value of typical and atypical meningiomas (P < 0.001).

4. Discussion

Meningiomas are the third most common intracranial tumors in adults following gliomas and metastases (1). Based on the WHO classification they are classified as benign (WHO type I, 80% cases), atypical (WHO type II, 15–20%) and malignant (WHO type III, 1–3%) (2,3,7). Although meningiomas are easily diagnosed by conventional MRI, differentiation of histological types is usually not possible (7). Type II and III meningiomas are more aggressive and have a higher recurrence rate. The recurrence rate of atypical and malignant meningiomas is about 40% and 50–80%, respectively at 5 years of follow up (5). Patients with malignant meningioma have increased survival benefits if surgery is followed by fractionated external beam radiation therapy (EBRT) or stereotactic radiosurgery (SRS) (9). Therefore pre-operative characterization of meningiomas is of significant importance in deciding the therapy.

Diffusion-weighted MR imaging has been used to investigate primary brain neoplasms (10–14). Correlations between apparent diffusion coefficient (ADC) values and tumor grade have been made and diffusion-weighted imaging is being used to monitor treatment response (7). Only a few studies have evaluated the role of diffusion weighted imaging for grading meningiomas. Although some studies show that apparent diffusion coefficient (ADC) of atypical/malignant meningiomas is significantly lower than benign meningiomas, other studies have suggested that this difference is not statistically significant. (4–8).

Diffusion weighted imaging of brain tumors reveals that tumors with higher grades have lower ADC values when compared with low grade tumors. Several studies have shown that atypical meningiomas show lower ADC values compared to typical meningiomas (4,6,8). Histopathologically atypical and malignant meningiomas have increased areas of necrosis and show cells with a high nucleus to cytoplasmic ratio and prominent nuclei which explains the lower ADC levels found in them (15). Sasaki et al. noted that there is a significant variability in ADC values between 1.5 and 3.0T MRI scanners and that relative ADC values may be more suitable than absolute ADC values for comparison of studies involving different strength scanners (16). In our study, patients were grouped separately depending upon the scanner used to prevent fluctuation in the mean ADC values. In addition ADCTM/ADCWM ratios were used to eliminate the interscanner variability.

In our study on trace diffusion-weighted images most (87%) of the typical meningiomas were hyperintense and the remainder were iso- or hypointense. In addition all atypical/ malignant meningiomas were hyperintense on trace diffusion-weighted images. This made us conclude that typical and atypical meningiomas cannot be differentiated based on trace diffusion-weighted images. Similar results have been reported in previous studies (5,7). The hyperintensity is thought to be due to the T2 shine through effect.

On calculating the absolute ADC values we found that the ADC values of atypical meningiomas were significantly lower than those of normal white matter and typical meningiomas both at 1.5T and 3T MRI. Similar results have been noted by Filippi et al., Hakyemez et al., and Nagar et al. in their studies (4,6,8). In the study by Filippi et al. the mean ADC value was 0.52 ± 0.12 × 10⁻³ mm²/s in atypical/malignant tumors and 1.03 ± 0.29 × 10⁻³ mm²/s in benign meningiomas (4). In the study by Hakyemez et al. they found that the mean ADC value was 0.75 ± 0.21 × 10⁻³ mm²/s in atypical/malignant tumors and 1.17 ± 0.21 × 10⁻³ mm²/s in benign meningiomas (6). In a similar study by Nagar et al. the mean ADC value was found to be 0.88 ± 0.08 × 10⁻³ mm²/s in benign meningiomas and 0.66 ± 0.13 × 10⁻³ mm²/s in atypical/malignant lesions. The mean ADC ratio in their study was 1.28 ± 0.11 for benign tumors and 0.91 ± 0.18 for atypical/malignant lesions, a result which was found to be statistically significant (8). In all three studies the difference in the mean ADC values was found to be statistically significant (P < 0.0001).

The ADC values in our study closely matched results of study by Nagar et al. (8). In our study, mean ADC value at 3T MRI was 0.82 ± 0.12 × 10⁻³ in benign meningiomas and 0.68 ± 0.10 × 10⁻³ in atypical meningiomas. At 1.5T, the mean ADC value of benign meningiomas was 0.83 ± 0.11 × 10⁻³ and that of atypical meningiomas was 0.70 ± 0.09 × 10⁻³. The mean ADC ratio was found to be 1.08 ± 0.17 for benign tumors and 0.85 ± 0.15 for atypical ones. Both the results were found to be statistically significant (P < 0.001).
There have been limited studies studying the role of ADC in the evaluation of grade of meningiomas at 3T MRI (17,18). Watanabe et al. studied high b value DWI using a $b$ value of 4000 s/mm$^2$ and concluded that ADC values were useful in differentiating low grade from high grade meningiomas at high $b$ values (17).

To the best of our knowledge, ours is the first study in which both 1.5T and 3T MRI have been used in the evaluation of meningiomas. Fig. 1 MRI images of a patient with atypical meningioma (WHO Grade II) (A) Coronal T1-weighted image (1100/3.5) shows a well margined extraxial mass lesion in left high frontal convexity, (B) Axial fast spin-echo T2-weighted image (3000/80) shows a lesion appearing hyperintense to cortex, (C) Axial contrast enhanced spin-echo T1 weighted image (8.4/3.8) shows homogenous enhancement, (D) Diffusion-weighted image (2123/68), lesion is hyperintense, (E) Meningioma is hypointense on the ADC map and ADC of lesion was found to be $0.63 \times 10^{-3}$ cm$^2$/s.
Fig. 2  MRI images of a patient with typical meningioma (WHO Grade I) in left occipital convexity, (A) Coronal T1-weighted image (1110/4.14) shows a well marginated extraxial mass lesion in left occipital convexity, (B) Axial fast spin-echo T2-weighted image (4650/95) shows a lesion appearing isointense to cortex, (C) Axial contrast enhanced spin-echo T1 weighted image (1100/3.5) shows homogenous enhancement, (D) Diffusion-weighted image (3100/93), lesion is isointense to cortex, (E) Meningioma is hypointense on the ADC map and ADC of lesion was found to be $0.84 \times 10^{-3}$ cm$^2$/s.
of grade of meningiomas. Although the sample size of the patients studied under the individual scanners was small, the overall sample size for the study was sufficient to detect a difference in the ability to differentiate between typical and atypical meningiomas using ADC values. However, contrary to our findings, a previous study has shown that the calculation of ADC values has no role in preoperative grading of meningiomas. Further studies on a larger group of patients may be required before giving up on calculation of ADC ratios in evaluation of a common intracranial tumor. Also as noted in our study, the differences in mean ADC values of benign and atypical meningiomas were similar at both 1.5 and 3T MRI indicating that that mean ADC values from studies may be used in the evaluation of tumors despite the difference in scanner strength. Although there were no significant differences in mean ADC values between 1.5T or 3T machines using $b = 1000$ in our study, a previous study has shown the value of using higher $b$ values ($b = 4000$) in differentiating the subtypes of meningiomas. Our study was limited by the fact that we did not have any case of malignant meningioma.

5. Conclusion

Diffusion-weighted MR imaging findings of atypical and typical meningiomas differ. Atypical meningiomas have lower intratumoral ADC values than typical meningiomas. The use of ADC ratios while helpful in eliminating interscanner variability is capable of differentiating between typical and atypical meningiomas. The differences in mean ADC values between benign and atypical meningiomas were similar at both 1.5 and 3T MRI.

References


