Characteristics of typical and atypical meningiomas on ADC maps with respect to schwannomas

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Abstract

The differences in apparent diffusion coefficient (ADC) between typical and atypical meningiomas and schwannomas were investigated, with 41 patients included in the study. There were no significant differences in ADC values or ADC ratios between typical and atypical meningiomas. The discrimination between schwannomas and the typical and atypical meningiomas on ADC maps was reliable, with significant differences in ADC values and ratios and with the narrow range of ADC values in meningiomas.

Keywords: Typical meningioma; Atypical meningioma; Schwannoma; Apparent diffusion coefficient

1. Introduction

Meningiomas of various subtypes are the second most common group of primary intracranial tumors [1,2]. The diagnosis of these extra-axial neoplasms by imaging modalities such as CT and MRI is usually straightforward. However, the differentiation between meningiomas and other neoplastic processes, such as schwannomas, may be unreliable using conventional MRI techniques, especially in certain anatomic locations such as cerebellopontine angle. In this area, schwannomas are the most common lesions responsible for mass effect, although other processes may morphologically and clinically be similar [3]. Inflammatory or granulomatous lesions may also be included in the differential diagnosis of meningiomas [4]. Although the majority of meningiomas are benign tumors, in some cases, the shape of tumor margin, peritumoral rim, and the degree of edema [5] may cause diagnostic difficulties and confusion with more aggressive tumor types [6]. The differentiation of typical from atypical meningiomas is also extremely difficult in most cases, with a substantial impact on therapeutic approach and prognosis [7]. The recurrence rate of atypical meningiomas is 29–40%, as compared to 7–20% in typical meningiomas [1,8]. Typical meningiomas comprise 90% of all meningiomas, while 7.2% are atypical [9]. Advanced MRI techniques, such as diffusion-weighted imaging (DWI), provide insight into biological and histological characteristics of brain tumors [10,11] and may distinguish tumors from nonneoplastic space-occupying lesions [12]. There are confirmatory reports on differentiation of brain tumor types by DWI in conjunction with apparent diffusion coefficient (ADC) maps [10,11], as well as results in determination of tumor boundaries [13]. This imaging technique, in combination with conventional MRI, may provide discrimination between tumor grades [14–19], presumably mainly due to differences in tumor cellularity [20] and biochemical properties of extracellular space [21]. However, reports in this
field are conflicting, and all the studies do not support these findings [22–24]. There is a limited number of previous investigations focused on the diffusion properties of meningiomas and schwannomas, with differences in absolute ADC values and ranges of ADC values between studies [11,25–28]. The ADCs of meningiomas and schwannomas were also compared on a limited number of patients.

Our goal was to explore the ADC differences between typical and atypical meningiomas with respect to schwannomas—their most common morphological mimics. The histological assessment was based on the classification of CNS tumors provided by the World Health Organization (WHO) [29]. We analyzed the ADC of typical (WHO Grade I) and atypical meningiomas (Grade II). Further differentiation of subtypes of typical meningiomas was not performed, due to the same tumor prognosis, regardless of the histological subtype [8]. There were no patients with anaplastic (Grade III) tumors included in the study due to the small number of available patients.

We hypothesized that the ADC values may aid in the preoperative determination of meningioma grade, with a significant impact on the plan of treatment. The discrimination between meningiomas and schwannomas on the basis of ADC values, in cases where this cannot be performed by conventional MRI, may provide further insight into biological differences of these tumors and provide preoperative diagnosis.

2. Methods

2.1. Patients

We prospectively included 41 consecutive patients in the study (22 female and 19 male), with an age range of 18–83 years (mean age, 55 years). Examinations were performed between December 2004 and August 2006. There were 21 patients with typical meningiomas (WHO Grade I tumors), 5 patients with atypical meningiomas (WHO Grade II), and 15 patients with schwannomas (WHO Grade I). The mean age of patients with typical meningiomas was 59 years; for patients with atypical meningiomas and schwannomas, mean age was 61 and 44 years, respectively. All the patients had newly diagnosed tumors, and the diagnosis was based on histopathological examinations conducted after surgical resection or stereotactic biopsy. No therapy was administered prior to MRI examinations, and patients receiving corticosteroid treatment were excluded since this would affect the water content of the tissue and diffusion properties. The neuropathologist was blinded to the MRI findings and ADC values. We excluded patients with small tumors (<10 mm) because of a high possibility of the sampling error during ADC measurements; patients whose DW images were burdened by artifacts such as distortion, motion artifacts, and chemical shift or magnetic susceptibility artifacts; and patients with severe pathological changes on conventional images, which prevent the accurate measurements of control samples in the contralateral brain hemisphere. Examinations were performed after obtaining the written informed consent from all the patients, and the study was approved by the institutional review board.

2.2. MRI

MRI was performed in all cases on a 1.5-T system (Symphony, Siemens Medical Systems, Erlangen, Germany) with 30-mT/m gradients and a slew rate of 125 T/m/s. Single-shot echo-planar DW images were acquired in a transverse plain with the acquisition of a diffusion trace and
with the following parameters: FOV, 22.8×22.8 cm; matrix, 128×128; slice thickness, 5 mm; slice gap, 1.5 mm; three $b$ values (0, 500, and 1000 s/mm$^2$); TR, 3200 ms; TE, 94 ms; Nex, 1; TA, 1 min 12 s. ADC maps were automatically calculated, according to the following equation: $\text{ADC}=\ln \left(\frac{S_0}{S_1}\right)(b_1−b_0)×10^{-5}$ mm$^2$/s [30]. DWI was performed before the administration of gadolinium-DTPA in all cases. The imaging protocol also included conventional sequences: in all cases, axial FSE T2WI and axial nonenhanced and contrast-enhanced SE T1WI.

2.3. MRI evaluation and postprocessing

Two neuroradiologists separately reviewed conventional images and defined the following areas, with a consensus in cases of disagreement:

1. solid tumor, as an area with a mass effect and contrast enhancement;
2. normal contralateral brain parenchyma, as an area with normal signal intensities in all sequences, without mass effect;
3. cystic/necrotic area, as an area with a hypointense signal in T1WI and a hyperintense signal in T2WI, without contrast enhancement;
4. hemorrhage, as an area with a hyperintensity in nonenhanced T1WI; and
5. calcified tumors, as hypointense areas in $T_2^*$ images and/or hyperdensity in CT images.

Cystic/necrotic areas and areas containing hemorrhage and calcifications were excluded from further analysis. Cystic/necrotic areas generally do not have properties that would be specific for a tumor type or grade; therefore, the analysis of only solid tumor should result in more specific findings. In solid tumor areas and normal parenchyma, the ADC measurements were performed using a region-of-interest (ROI) method, with uniform ellipsoid ROIs of 2.0 cm$^2$, containing approximately 10 pixels. ADC measurements were performed using e-Film Workstation 2.1 (Merge Healthcare, Milwaukee, WI, USA), with a simultaneous display of contrast-enhanced T1WI, T2WI, isotropic DWI, and ADC map (Figs. 1, 2, and 3). The placement of ROIs was performed carefully to avoid volume averaging. We placed three ROIs in the areas corresponding to each tumor. The representative value used in data and statistical analysis was the mean value=SD. One control ROI was placed in the opposite hemisphere, in the normal brain parenchyma corresponding to the tumor site.

2.4. Data and statistical analysis

The mean intratumoral ADC values±SD. were compared to contralateral normal parenchyma, as well as between typical meningiomas, atypical meningiomas, and schwannomas. ADC ratio was calculated for each patient as a ratio between tumor ADC and normal control ADC. The mean ADC ratios were compared between typical and atypical meningiomas and schwannomas.

The comparison of differences in mean ADC values and mean ADC ratios was performed using the Mann–Whitney $U$ test. $P<.05$ was considered statistically significant.

3. Results

The prevalence of meningiomas was expectedly higher in female patients. There were 14 female and 7 male patients with typical meningiomas, 2 female and 3 male patients with atypical meningiomas, and 6 female and 9 male patients with schwannomas. The patients were grouped into three groups, according to the histological diagnosis of the tumor. The
mean intratumoral ADC values, the range of values, the
mean ADC of normal contralateral brain parenchyma, and
the mean ADC ratios are represented in Table 1.

The normal brain parenchyma had a mean ADC value of
79.9±7×10⁻⁵ mm²/s, and there were no significant differences
of these values between tumor groups. For all three
tumor groups, the mean intratumoral ADC values were
significantly different from the mean normal ADC values in
the contralateral brain parenchyma, with P<.0001 for
meningiomas, P<.028 for atypical meningiomas, and
P<.001 for schwannomas.

There were no significant differences in mean ADC
values or ADC ratios between typical and atypical
meningiomas. The mean ADC values of schwannomas
were significantly different from the ADC values of both the
typical (P<.0001) and atypical meningiomas (P<.0011). The
mean ADC ratio of schwannomas was also significantly
different from the mean ADC ratios of typical meningiomas
(P<.0001) and atypical meningiomas (P<.019).

The range of ADC values for each tumor group is
represented by a box plot (Fig. 4).

4. Discussion

DWI has a substantial role in the imaging of intracranial
tumors, especially in the determination of the glioma grade

![Fig. 3. Schwannoma: contrast-enhanced T1WI, T2WI, and DWI and the ADC map of a vestibular schwannoma.](image)

![Fig. 4. The range of ADC values in typical meningioma, atypical meningioma, and schwannoma.](image)

[11,15–17,31] and in the evaluation of response to treatment
[31,32]. The use of DWI and ADC maps in discriminating
between different histological types of intracranial tumors is
still controversial [17,18,24]. There are a limited number of
previous studies on diffusion properties of meningiomas and
schwannomas [11,27] and on discrimination between typical
and atypical meningiomas on the basis of DWI and ADC
maps [11,25,26]. Preoperative differentiation of meningio-
mas from schwannomas may have an important impact
regarding therapy and prognosis, especially at certain
locations [33].

We compared the ADC values and ADC ratios of typical
and atypical meningiomas and schwannomas. All three
tumor groups had significantly different ADC values from
contralateral normal brain tissue. The mean ADC value of
typical meningiomas, atypical meningiomas, and schwann-
omas was 79.9±5.9×10⁻⁵ mm²/s, 91.7±8.7×10⁻⁵ mm²/s,
and 133.4±21.1×10⁻⁵ mm²/s, respectively. The ADC
values and ADC ratios could not discriminate between
typical (Grade I) and atypical (Grade II) meningiomas but

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<td>ADC (×10⁻⁵ mm²/s)</td>
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were able to reliably differentiate meningiomas of both grades from schwannomas.

Our findings are in line with the results of Yamasaki et al. [11]. Their study found lower ADC values in atypical meningiomas than in typical meningiomas, with no significant difference. A number of studies found lower ADCs in atypical meningiomas than in typical meningiomas [11, 14, 17, 25, 26], but only some investigators [25, 26] found these differences to be statistically significant.

Atypical meningiomas, unlike typical meningiomas, exhibit increased mitotic activity and at least three of the following characteristics: small cells with high nuclear-to-cytoplasmic ratio, prominent nucleoli, uninterrupted growth pattern, and foci of necrosis [29]. The degree of contribution of intracellular environment to measurable diffusion is not entirely certain [34]. Diffusion is restricted by membranes, tight cell junctions, fibers [35], and, probably in a lesser degree, macromolecules and nuclear-to-cytoplasmic ratio [34]. High-grade brain tumors with increased cellularity have lower ADC values than low-grade tumors or normal brain [10, 16, 23, 31, 36–38], and cellularity is considered the main factor influencing water diffusion in living tissue. Atypical and typical meningiomas differ histologically mainly in their intracellular environment, and their relatively similar ADCs may be due to only moderately pronounced difference in cellularity, as reported in some cases [39]. Also, this may be the result of microscopic necrosis mixed with residual tumor cells, which would allow higher water diffusion than is expected on the basis of tumor cellularity. Similar findings have been described by Chen et al. [40] in two cases of atypical meningiomas. However, the results of the abovementioned studies and ours might be influenced by a relatively small number of investigated patients with atypical meningiomas.

The range of ADC values in typical meningiomas of our patients was narrow (87–105.4 × 10^{-5} \text{ mm}^2/\text{s}) and only slightly wider in atypical meningiomas (81.4–103.1 × 10^{-5} \text{ mm}^2/\text{s}). This finding is more pronounced than in previous studies [11, 17, 25, 26]. The narrow range probably indicates the homogenous texture of meningiomas, since there was no preselection of similar tumors, or other factors that would affect the result, such as mass effect in the measured regions. This may be important in preoperative assessment, with a higher probability of making the correct diagnosis.

Schwannomas in our study had significantly higher mean intratumoral ADC, as well as mean ADC ratio, than either typical or atypical meningiomas. There was no overlap in the range of ADC values in comparison to meningiomas, which is important in the discrimination between the two tumor types. The ADC values of schwannomas are in accordance with the report by Sener [27]. The higher ADC of schwannomas compared to meningiomas in our series is probably a feature of less densely cellular areas of the tumor. Elongated Schwann cells may contribute to a higher degree of water diffusion than meningiomas, and the extracellular matrix may also influence diffusion [21]. In larger schwannomas, there is a predominance of the loose textured and cystic areas (Antoni type B) [41–43], resulting in higher water diffusion. Microcystic tumor elements may partly be the cause of high ADC values.

The ADC values of normal brain tissue in our patients were in line with the results of previous studies [26, 27].

The principal limitation of our study is its relatively small number of patients with atypical meningiomas. Also, there is a lack of direct histopathological correlation with DW MRI regarding the presence of microscopic necrosis in atypical meningiomas or findings of Antoni A compact areas and Antoni B loose microcystic areas in schwannomas. We excluded macroscopically cystic/necrotic tumor parts from the analysis, and the measured ADC values should reflect the diffusion properties of solid tumor matrix. However, the ADC values may partly be due to the inclusion of cystic elements on a microscopic scale.

5. Conclusion

Our results indicate that ADC maps are not reliable in preoperatively discriminating between typical and atypical meningiomas, and a further investigation on a larger series of patients with atypical meningiomas is warranted. The ADC differences between meningiomas and schwannomas were significant, with the narrow range of ADC values in meningiomas, and in cases of such a diagnostic dilemma, ADC may be a predictor of histological type.

References