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Apparent Diffusion Coefficient Values and Intra-tumoral Susceptibility Signals in Meningiomas and Schwannomas: Useful Tools for Challenging Cases

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Abstract

Background: We aimed to estimate the diagnostic accuracy of apparent diffusion coefficient values (ADC) and intra-tumoral susceptibility signals (ITSS) in differentiating meningiomas and schwannomas.

Methods: This retrospective study included 41 patients with 23 histopathologically proven meningiomas (20 patients with benign meningioma and 3 patients with high-grade meningioma) and 18 schwannomas. We calculated the mean ADC values and ADC ratio from ADC maps and intratumoral susceptibility signals (ITSS) in susceptibility-weighted imaging (SWI) for all patients. The quantitative variables were compared between the tumor groups using *t* test and the qualitative variables were compared between them using Chi-square test.

Results: In this study, the mean ADC value of meningiomas ($0.86 \pm 0.11 \times 10^{-3}$ mm^2/s, range 0.67-1.04) was lower than schwannomas ($1.32 \pm 0.16 \times 10^{-3}$ mm^2/s, range 1.10-1.65) with no overlap in the range of ADC values. The mean ADC ratio of schwannomas (2.0 ± 0.29, range 1.45- 2.58) was higher than meningiomas (1.24 ± 0.17, range 0.83-1.64) with some overlap. We found significant difference in mean ADC value and ADC ratio between meningiomas and schwannomas. The presence of intratumoral microhemorrhages (ITSS-H) in SWI was more suggestive of schwannomas and the presence of calcification was in favor of benign meningiomas. We did not find any significant difference in mean ADC value and ADC ratio between benign and high-grade meningiomas with considerable overlap in their range.

Conclusion: Additional magnetic resonance imaging findings such as ADC values and ITSS in SWI can help better pre-operative diagnosis of meningiomas and schwannomas, particularly in challenging patients.

Keywords: Meningiomas; Schwannomas; Apparent diffusion coefficient; Susceptibility-weighted imaging; intratumoral susceptibility signals.

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Introduction

Meningiomas comprise 20%-30% of all major intracranial masses, originating from arachnoid cap cells and are more commonly seen in middle-aged adults.[1] Meningiomas are generally benign but they have a wider range of clinically and histologically different subgroups which have higher chances of recurrence and can also be malignant.[1] The World Health Organization (WHO) 2016 classification has depicted them as (a) benign (grade I), (b) atypical (grade II), and (c) malignant (grade III).[2,3] Atypical and malignant meningiomas (high grade) have poorer prognosis as compared to the benign type (low grade).[2,4]

The most important treatment for meningiomas is surgical removal.[5] Surgical planning and outcome depends on many factors such as size, location, invasion or encasement of adjacent blood vessels and cranial nerves, internal vascularity, and tumor consistency.[1,6] Magnetic resonance imaging (MRI) is a very important means to decide on surgical approach, perioperative risk, timing of surgery and resectability of meningiomas.[1] Meningiomas commonly appear isointense on T1W and T2W images as compared to brain with bright homogeneous contrast enhancement.[6,7] There can be calcifications, cystic changes, flow voids and enclosed cerebrospinal fluid spaces within them.[1]

Cerebellopontine angle (CPA) tumors constitute around 5%-10% of adult intracranial tumors and 1% of pediatric intracranial tumors.[8] The most common CPA tumor is vestibular schwannoma comprising 80%-90% of all CPA tumors. It is followed by meningioma which occurs in 10%-15% of cases. Schwannomas appear iso-to-hypointense in T1W and hyperintense in T2W sequences as compared with the brain and may have cystic changes and microhemorrhages. Vestibular schwannomas arise from internal auditory canal causing widening of porus acusticus and form a round lesion in CPA cistern with an 'ice cream cone appearance'.[7]

Conventional MRI sequences may not always be accurate in discrimination between meningiomas and schwannomas particularly when lesions appear heterogeneous and atypical in locations such as cerebellopontine cistern because of diverse histological tumor types. However, precise imaging diagnosis is utmost important since surgical planning and prognosis

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is different for these lesions with meningiomas having higher chances of hearing preservation.[7-9] There are also less specific conventional MRI findings that distinguish benign meningiomas from high-grade meningiomas.[2,10] Advanced MRI sequences such as diffusion-weighted imaging (DWI) are used for improving evaluation of intracranial lesions and tumor grading.[8,9,11,12] DWI imaging is done using two optimized b values to attain apparent diffusion coefficient (ADC) values.[13] It has been shown that primary intracranial masses with relatively high cellularity and a high grade usually display low ADC relative to the normal brain parenchyma.[8,11]

Susceptibility-weighted imaging (SWI) utilizes a gradient echo sequence combining T2*-weighted "magnitude" image and filtered "phase" images.[14] It is based on magnetic property of tissues and displays blooming (intratumoral susceptibility signals, ITSS) in tissues with tiny hemorrhages and calcifications.[8] The role of ADC and SWI in distinguishing meningiomas and schwannomas is still unclear. Therefore, we aimed to assess the utility of ADC values and ITSS for differentiation of meningiomas and schwannomas in our population.

Materials and Methods

We conducted a retrospective study in the radiology department of a tertiary care hospital from February 2020 to July 2022. All patients who were operated in our hospital with histopathologically proven intracranial meningioma and schwannoma and had undergone preoperative MRI (along with DWI and SWI sequences) were included. We excluded patients who had undergone prior intracranial surgery, imaging performed at an outside institution, had artifacts in DWI or SWI images (motion artifacts, susceptibility artifacts etc) or had a lesion size of less than 1 cm. This study was performed after approval by the institutional review board. Ultimately, 41 patients with meningioma or schwannoma on histopathology were included. MRI was done using a 1.5 Tesla scanner (Ingenia, Philips Healthcare) with head coil. Routine MRI brain protocol included axial T1-weighted (T1W) image, multiplanar T2-weighted (T2W) images, fluid-attenuated inversion recovery (FLAIR) in axial plane, DWI, and SWI. Then contrast-enhanced fat-suppressed T1W sequence (using gadolinium-based contrast agents at bolus dose of 0.1 mg/kg) was obtained in multiple planes. DWI employs single-shot echo-planar spin-echo technique with application of gradients in three directions, having TR 4.1 sec, matrix 184×109, FOV 220 mm, TE 89 msec, NSA 2, thickness of slice 4.5 mm, flip angle 90°, inter-slice interval 1mm, and three diffusion sensitivities having 0, 500, and 1000 s/mm^2 b values. ADC maps are customarily acquired from DWI sequence and analyzed in a separate workstation using dedicated software package installed by the vendor. SWI parameters were TR 52 msec, matrix 232×197, FOV 230 mm, TE 12 msec, NSA 1, inter-slice gap 1mm, thickness of slice 2 mm, and flip angle 20°. SWI sequence was used to generate the combined SWI processed magnitude and filtered-phase images.

Assessment of the images was performed by a neuroradiologist (S.S.) with more than 8 years of experience in reporting MRI studies, without prior knowledge of histopathological diagnosis of the included cases. At least three regions-of-interest each of diameter 12-18 mm were placed on ADC maps within the solid enhancing part of tumor (excluding cystic, necrotic, calcific and microhemorrhagic areas) and in contralateral normal appearing white matter (without edema and mass effect) and mean ADC values were ascertained for tumor and normal white matter (measured in 10^{-3} mm^2/s). The mean tumor ADC was divided from mean white matter (WM) ADC to estimate ADC ratio.

The ITSS in SWI images were analyzed and classified into ITSS-present and ITSS-absent. ITSS appear as areas of blooming (low signal foci) on SWI images. The areas with ITSS (ITSS-present) were further evaluated on filtered phase images which show high signal foci in areas of calcification, low signal foci in areas of microhemorrhage and low signal vascular structures if vessels are present on our right-handed MRI machine. In our study, ITSS-present were categorized into (a) calcification appearing as high signal (ITSS-C), (b) microhemorrhage appearing as low signal (ITSS-H), and (c) vessels within (ITSS-V). We also measured the maximum tumor diameter in contrast-enhanced T1W images and noted the presence of peritumoral edema in T2W images in all cases. Meningiomas were further graded based on WHO classification – (a) benign (b) high-grade and tumor location was also noted.

Statistical Package for Social Sciences (SPSS) 20 of IBM (USA) was utilized for data evaluation. $P<0.05$ was considered as statistically significant. We ascertained mean with standard deviation (SD) for quantifiable variables including age, maximum tumor size, symptom duration, mean tumor ADC, mean WM ADC and mean ADC ratio and *t* test was used for analysis. Frequency and percentage were determined for remaining data including sex, symptoms, peritumoral edema, ITSS positivity. Chi-square test was used as appropriate. We used receiver operating characteristic (ROC) curve to ascertain cut-off value for mean tumor ADC and ADC ratio for differentiation of meningiomas and schwannomas.

Results

In this study, there were 23 meningiomas, of which 20 (86.96%) had benign meningioma (Figure 1) and 3 (13.04%) had high-grade meningioma (two with atypical meningioma and one with malignant meningioma, Figure 2) with a mean±SD age of 44.61±12.53 years (range: 24-66 years). The patients with benign and high-

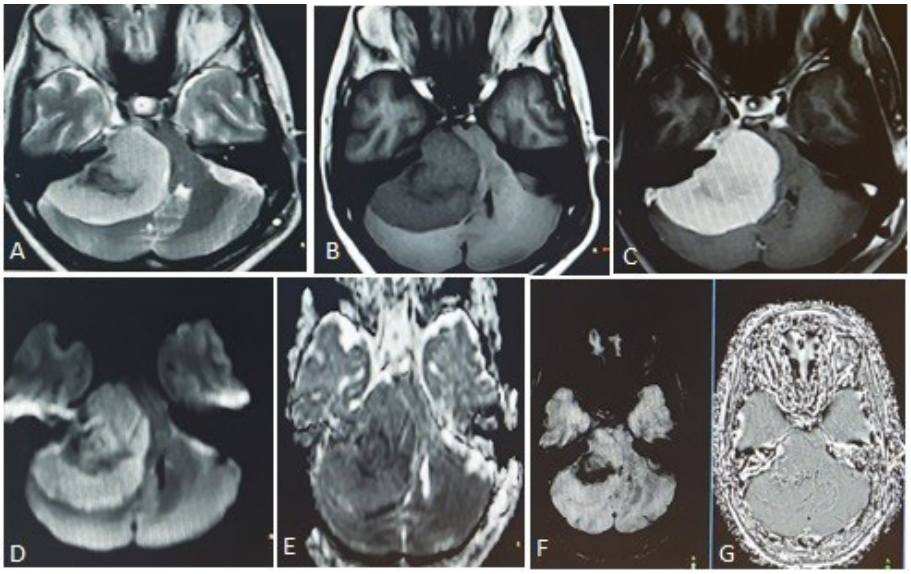

Figure 1. Benign Meningioma. (A) axial T2W, (B) axial T1W, (C) contrast-enhanced T1W, (D) DWI, (E) ADC map, (F) ITSS in SWI and (G) SWI phase images show a benign meningioma in right cerebellopontine angle

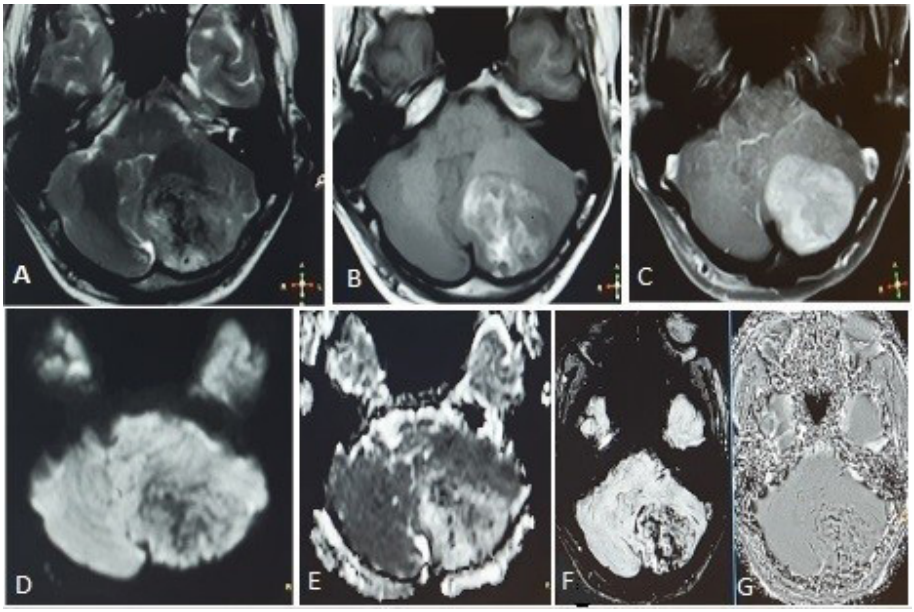

Figure 2. High-Grade Meningioma. (A) axial T2W, (B) axial T1W, (C) contrast-enhanced T1W, (D) DWI, (E) ADC map, (F) ITSS in SWI and (G) SWI phase images show a high-grade meningioma in left side of posterior fossa

grade meningiomas had mean ± SD age of 44.2 ± 12.94 years (range: 24-66 years) and 47.33 ± 11.02 years (range 40-60 years), respectively, with no significant difference in age between benign and high-grade meningiomas. There were 19 women (82.61%, 18 with benign meningioma and one with high-grade meningioma) and 4 men (17.39%, two each with benign and two with high-grade meningioma) with overall female predominance in meningiomas and male predominance in high-grade meningiomas. The mean ± SD age was higher in women (46.95 ± 12.1 years, range: 27-66 years) compared with men (33.5 ± 8.85 years, range: 24-42 years) in meningiomas ($P = 0.048$).

We had 18 patients with schwannomas (Figure 3) with mean ± SD age of 40.83 ± 14.66 years (range: 8-63 years). In this group, there were 14 (77.78%) women and four (22.22%) men with a mean ± SD age of 41.21 ± 12.82 years (range 21-63 years) in women and 39.5 ± 22.43 years (range 8-61 years) in men ($P = 0.84$). There was overall female predominance within schwannomas. We noted insignificant difference in age and sex distribution upon comparing meningiomas with schwannomas ($P = 0.38$ and $P = 0.71$, respectively, Table 1). We found headache as the most common symptom in meningiomas and schwannomas followed by vertigo with no significant difference in symptoms and symptom duration between the tumor groups ($P = 0.45$ and $P = 0.74$, respectively, Table 1).

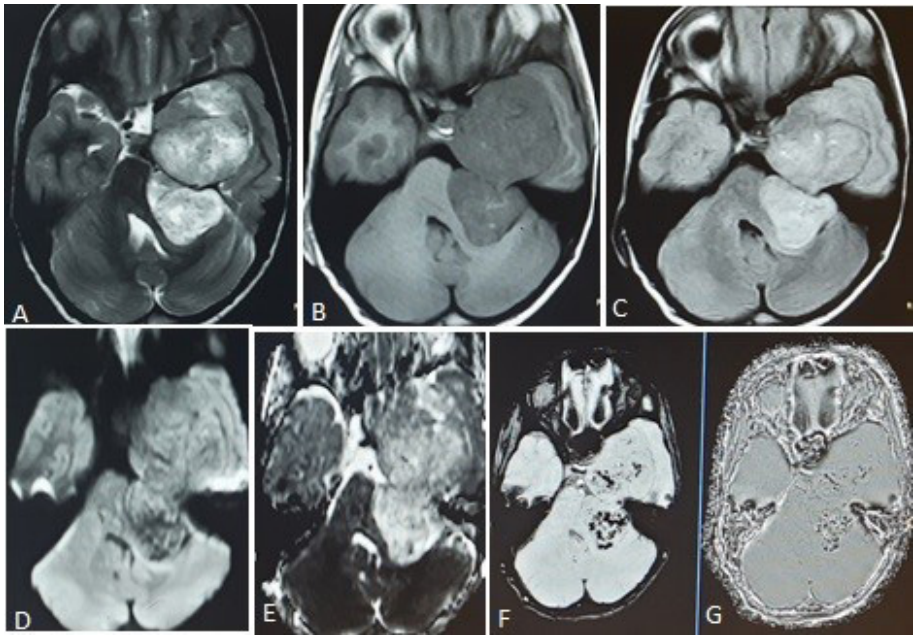

Figure 3. Schwannoma. (A) axial T2W, (B) axial T1W, (C) axial FLAIR, (D) DWI, (E) ADC map, (F) ITSS in SWI and (G) SWI phase images show a large left trigeminal schwannoma

Table 1. Comparison of the Demographic and Clinical Data of Meningiomas With Schwannomas

Variable	Meningiomas	Schwannomas	*P* Value*
Age (mean ± SD, years)	44.61 ± 12.53	40.83 ± 14.66	0.38
Gender (Male: Female)	4: 19	4: 14	0.71
Most common symptom	Headache (60%)	Headache (72%)	0.45
Symptom duration (mean ± SD, months)	9.02 ± 14.39	10.42 ± 11.84	0.74

* P < 0.05 was considered significant.

We found a higher incidence of meningioma in supratentorial location (15, 65.22%) of which eight were located at convexity, six at falx and one at skull base. Eight meningiomas were in infratentorial location (34.78%). Multiple meningiomas were found in one patient in whom the largest lesion was included in this study. The most common histopathological subtype of benign meningiomas was meningothelial (n = 9, 45%) followed by transitional type (n = 5, 25%), fibrous (n = 3, 15%), psammomatous (n = 2, 10%) and angiomatous (n = 1, 5%). Among the schwannomas, 16 (88.89%) were vestibular schwannomas and two (11.11%) were trigeminal schwannomas. The mean ± SD maximum diameter of meningiomas was 51.74 ± 12.41 mm (range: 26-67 mm) and 38 ± 14.56 mm (range: 16-78 mm) in schwannomas ($P = 0.003$). We observed presence of peritumoral edema in 19 (82.61%) meningiomas and 11 (61.11%) schwannomas ($P = 0.12$).

Mean ± SD tumor ADC (Figure 4) in meningiomas was calculated to be $0.86 \pm 0.11 \times 10^{-3}$ mm²/s (range: 0.67 to 1.04) and in schwannomas to be $1.32 \pm 0.16 \times 10^{-3}$ mm²/s (range: 1.1-1.65). The mean ± SD ADC ratio was 1.24 ± 0.17 (range: 0.83-1.64) in meningiomas and 2.0 ± 0.29 (range: 1.45-2.58) in schwannomas (Figure 5). We found significant difference in mean tumor ADC ($P = 0.001$) and ADC ratio ($P < 0.01$) between meningiomas and schwannomas (Table 2) and between mean tumor ADC value and mean white matter ADC value in both tumor groups (both with $P < 0.01$). There was insignificant disparity ($P = 0.09$) in mean white matter ADC between meningiomas and schwannomas (Table 2). The ROC curve analysis showed a cut-off value of 1.07×10^{-3}mm²/s for mean tumor ADC (with 100% accuracy, sensitivity, and specificity) and 1.435 for ADC ratio (97.56% accuracy, 100% sensitivity, and 95.65% specificity) for differentiation of meningiomas from schwannomas. We found considerable variation in mean tumor ADC (each with $P < 0.01$) and mean ADC ratio (each with $P < 0.01$) when comparing meningioma subgroups (benign and high-grade meningiomas) with schwannomas and insignificant disparity in mean white matter ADC value upon comparing meningioma subgroups and schwannomas.

ITSS in SWI images were found in 17 (94.44%) schwannomas and all showed microhemorrhages (ITSS-H). ITSS was seen in 16 (69.5%) meningiomas with calcifications in 5, vessels in 9 and microhemorrhages in 2 patients. We noted significant disparity in ITSS ($P = 0.046$) between meningiomas and schwannomas with presence of microhemorrhages more suggestive of schwannomas ($P < 0.001$) and presence of calcification and vascularity in favor of meningiomas (Table 2). Out of the two meningiomas with microhemorrhages, one had transitional subtype of benign meningioma and another was grade III meningioma.

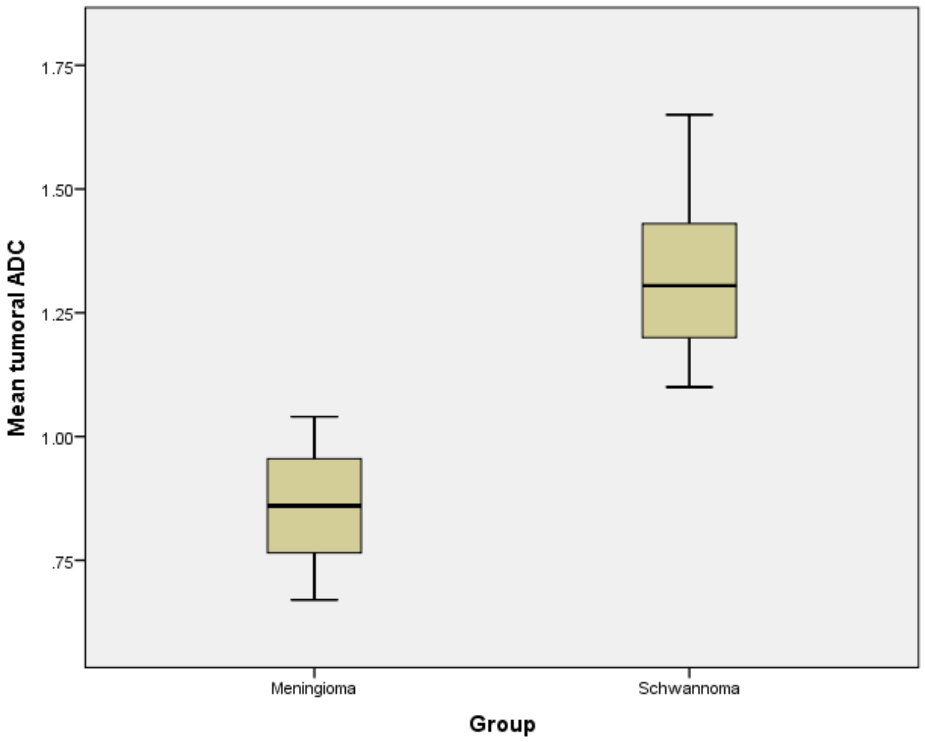

Figure 4. Box-Plot Figure Showing Distribution of Mean Tumor ADC Values of Meningiomas and Schwannomas

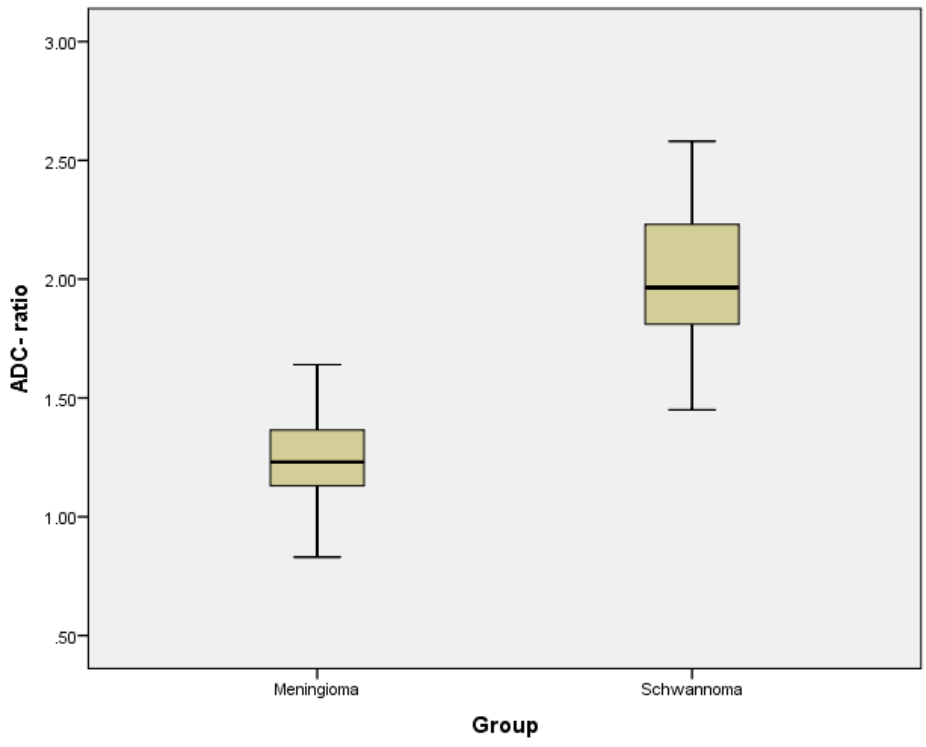

Figure 5. Box-Plot Figure Showing Distribution of Mean ADC Ratio of Meningiomas and Schwannomas

We estimated mean ± SD tumor ADC value in benign and high-grade meningiomas to be $0.85 \pm 0.11 \times 10^{-3}$ mm^2/s (range: 0.67 to 1.04×10^{-3} mm^2/s) and $0.91 \pm 0.09 \times 10^{-3}$ mm^2/s (range: 0.84-1.02×10^{-3} mm^2/s), correspondingly. Mean ± SD ADC ratio in benign and high-grade meningiomas was 1.22 ± 0.16 (range: 0.83-1.42) and 1.38 ± 0.24 (range: 1.17-1.64), respectively. There was insignificant discrepancy of mean tumor ADC and ADC ratio ($P = 0.76$ and $P = 0.502$ respectively) between benign and high-grade meningiomas (Table 3).

Table 2. MRI Parameters of Meningiomas and Schwannomas

Parameter	Meningiomas	Schwannomas	*P* Value
Mean tumor ADC value ($x10^{-3}mm^2/s$)	0.86 ± 0.11	1.32 ± 0.16	0.001
Mean WM ADC value ($x10^{-3}mm^2/s$)	0.69 ± 0.06	0.66 ± 0.05	0.09
Mean ADC ratio	1.24 ± 0.17	2.0 ± 0.29	<0.01
SWI (ITSS) positivity	16 (69.5%)	17 (94.44%)	0.046
ITSS-H	2 (12.5%)	17 (100%)	<0.001
ITSS-C	5 (31.25%)	-	-
ITSS- V	9 (56.25%)	-	-
Mean tumor size	51.74 ± 12.41	38 ± 14.56	0.003
Peritumoral edema	19 (82.61%)	11 (61.11%)	0.123

Abbreviations: ADC, apparent diffusion coefficient; WM, white matter; SWI, susceptibility weighted imaging; ITSS, intra-tumoral susceptibility signals; ITSS-H, microhemorrhage; ITSS-C, calcification, ITSS-V, vascular channels. *$P<0.05$ was considered significant.

Table 3. Comparison of MRI Findings of Benign Meningiomas With High-Grade Meningiomas

Parameter	Benign Meningiomas	High-Grade Meningiomas	*P* Value
Mean tumor ADC value	0.85 ± 0.11	0.91 ± 0.09	0.76
Mean WM ADC	0.7 ± 0.06	0.67 ± 0.05	0.86
Mean ADC ratio	1.22 ± 0.16	1.38 ± 0.24	0.502
SWI (ITSS) positivity	13 (65%)	3 (100%)	0.22
ITSS-H	1(7.7%)	1 (33.3%)	0.249
ITSS-C	5 (38.5%)	-	-
ITSS- V	7(53.8%)	2 (66.7%)	0.54
Mean tumor size	51.1 ± 13.2	56 ± 4.4	0.54
Peritumoral edema	16 (80%)	3 (100%)	0.39

Abbreviations: ADC, apparent diffusion coefficient; WM, white matter; SWI, susceptibility weighted imaging; ITSS, intra-tumoral susceptibility signals; ITSS-H, microhemorrhage; ITSS-C, calcification, ITSS-V, vascular channels.

There was insignificant disparity ($P=0.86$) of mean white matter ADC between benign ($0.7 \pm 0.06 \times 10^{-3}$ mm^2/s) and high-grade meningiomas ($0.67 \pm 0.05x10^{-3}$ mm^2/s). ITSS was found in 13 benign meningiomas (65%) and three (100%) high-grade meningiomas (Table 3). There was insignificant variation in peritumoral edema ($P=0.39$) and mean tumor size ($P=0.54$) between benign and high-grade meningiomas.

Discussion

Meningiomas and schwannomas are common extra-axial tumors which need accurate preoperative diagnosis as it determines the surgical planning and prognosis.[7] DWI, ADC, and SWI are advanced MRI techniques which have been used in intracranial tumor imaging. We found insignificant disparity in mean age and sex distribution between meningiomas and schwannomas in this study. However, we found male predominance in high-grade meningiomas similar to previous studies.[15,16]

In this study, mean tumor ADC of meningiomas ($0.86 \pm 0.11 \times 10^{-3}$ mm^2/s, range: 0.67- 1.04) was lower than schwannomas ($1.32 \pm 0.16 \times 10^{-3}$ mm^2/s, range: 1.1-1.65). The mean ADC ratio of schwannomas (2.0 ± -0.29, range: 1.45-2.58) was higher than meningiomas (1.24 + /-0.17, range: 0.83- 1.64). We found noteworthy disparity in mean tumor ADC and ADC ratio on comparing meningiomas and schwannomas. These findings are comparable to those reported by Pavlisa and colleagues,[9] who found mean ADC value of these tumors close to our study. Schwannomas have loosely packed elongated Schwann cells with cystic areas which may explain higher ADC values compared to meningiomas.[9]

We found that presence of intratumoral microhemorrhages was more suggestive of schwannomas similar to previous studies.[7,17] ITSS-H was absent in one case of vestibular schwannoma in our study which was smallest in size. In this study, presence of calcification and vascularity were in favor of meningiomas. The presence of ITSS-H with a mean ADC value of $> 1.07 \times 10^{-3} mm^2/s$ were more indicative of schwannomas in our study, consistent with another study.[8]

We did not find any considerable variation in mean tumor ADC and ADC ratio between benign and high-grade meningiomas, similar to previous studies.[9,18-20] This finding may be attributed to the fact that high-grade meningiomas have microscopic necrosis along with moderately increased cellularity which results in overlapping ADC values and ratios.[9] There are however, other studies showing considerable distinction in intra-tumoral ADC values between benign and high-grade meningiomas.[21-25] This could be related to disparity in histological subtypes, sample size, imaging protocols etc. among these studies.[6] Bozdag and Er[14] reported that calcification occurs more frequently in benign meningiomas in SWI as compared to high-grade meningiomas, which is similar to our results.

Our study had small sample size with few high-grade meningiomas which remains the chief limitation and entails further study with more cases. We could not assess inter-observer variability as the ADC values and ITSS in SWI were evaluated by a single radiologist. We included histopathologically proven tumors in the study; however, we could not directly correlate the tumor areas evaluated for ADC values and ITSS with histological findings as this was a retrospective study.

Conclusion

Additional MRI findings like ADC values and ITSS in SWI can help in better pre-operative diagnosis of meningiomas and schwannomas, particularly in challenging cases. The presence of microhemorrhages with a mean ADC value of > 1.07 × 10-3mm2/s is more indicative of schwannomas.

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Competing Interest
None.

Ethical Approval
Our study was permitted by institutional review board (1161/IEC-GRMC/2022).

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References
1. Alyamany M, Alshardan MM, Jamea AA, ElBakry N, Soualmi L, Orz Y. Meningioma consistency: correlation between magnetic resonance imaging characteristics, operative findings, and histopathological features. Asian J Neurosurg. 2018;13(2):324-8. doi: 10.4103/1793-5482.228515.
2. Abdel-Kerim A, Shehata M, El Sabaa B, Fadel S, Heikal A, Mazloum Y. Differentiation between benign and atypical cranial Meningiomas. Can ADC measurement help? MRI findings with hystopathologial correlation. Egypt J Radiol Nucl Med. 2018;49(1):172-5. doi: 10.1016/j.ejrnm.2017.10.004.
3. Zhang S, Chiang GC, Knapp JM, Zecca CM, He D, Ramakrishna R, et al. Grading meningiomas utilizing multiparametric MRI with inclusion of susceptibility weighted imaging and quantitative susceptibility mapping. J Neuroradiol. 2020;47(4):272-7. doi: 10.1016/j.neurad.2019.05.002.
4. Tsai YT, Hung KC, Shih YJ, Lim SW, Yang CC, Kuo YT, et al. Preoperative apparent diffusion coefficient values for differentiation between low and high grade meningiomas: an updated systematic review and meta-analysis. Diagnostics (Basel). 2022;12(3):630. doi: 10.3390/diagnostics12030630.
5. Salles D, Santino SF, Malinverni ACM, Stávale JN. Meningiomas: a review of general, histopathological, clinical and molecular characteristics. Pathol Res Pract. 2021;223:153476. doi: 10.1016/j.prp.2021.153476.
6. Huang RY, Bi WL, Griffith B, Kaufmann TJ, la Fougère C, Schmidt NO, et al. Imaging and diagnostic advances for intracranial meningiomas. Neuro Oncol. 2019;21(Suppl 1):i44-i61. doi: 10.1093/neuonc/noy143.
7. Saravanan K, Parthasarathy EA, Farook AS, Sridharan P, Gopalakrishnan, Anand R. Role of susceptibility weighted imaging in cerebellopontine angle schwannoma vs meningioma. International Journal of Contemporary Medicine, Surgery and Radiology. 2018;3(2):B20-B23.
8. Khaled M, Moghazy K, Elsaadany W, Eissa L. Additional diagnostic role of MRI spectroscopy, diffusion and susceptibility imaging in differentiation of CPA masses: our experience with emphasis on schwannomas and meningiomas. Egypt J Radiol Nucl Med. 2020;51(1):137. doi: 10.1186/s43055-020-00256-5.
9. Pavlisa G, Rados M, Pazanin L, Padovan RS, Ozretic D, Pavlisa G. Characteristics of typical and atypical meningiomas on ADC maps with respect to schwannomas. Clin Imaging. 2008;32(1):22-7. doi: 10.1016/j.clinimag.2007.07.007.
10. Zikou A, Alexiou GA, Goussia A, Kosta P, Xydis V, Voulgaris S, et al. The role of diffusion tensor imaging and dynamic susceptibility perfusion MRI in the evaluation of meningioma grade and subtype. Clin Neurol Neurosurg. 2016;146:109-15. doi: 10.1016/j.clineuro.2016.05.005.
11. Khedr SA, Hassaan MA, Refaat A. The diagnostic value of diffusion weighted imaging in patients with meningioma. Egypt J Radiol Nucl Med. 2012;43(2):249-56. doi: 10.1016/j.ejrnm.2012.01.003.
12. Shiroishi MS, Cen SY, Tamrazi B, D'Amore F, Lerner A, King KS, et al. Predicting meningioma consistency on preoperative neuroimaging studies. Neurosurg Clin N Am. 2016;27(2):145-54. doi: 10.1016/j.nec.2015.11.007.
13. Miyoshi K, Wada T, Uwano I, Sasaki M, Saura H, Fujiwara S, et al. Predicting the consistency of intracranial meningiomas using apparent diffusion coefficient maps derived from preoperative diffusion-weighted imaging. J Neurosurg. 2020;135(3):969-76. doi: 10.3171/2020.6.jns20740.
14. Bozdag M, Er A. Relation of susceptibility-weighted imaging findings with histological grade in intracranial meningiomas. Ann Med Res. 2021;28(4):806-11.
15. Kasuya H, Kubo O, Tanaka M, Amano K, Kato K, Hori T. Clinical and radiological features related to the growth potential of meningioma. Neurosurg Rev. 2006;29(4):293-7. doi: 10.1007/s10143-006-0039-3.
16. Kane AJ, Sughrue ME, Rutkowski MJ, Shangari G, Fang S, McDermott MW, et al. Anatomic location is a risk factor for atypical and malignant meningiomas. Cancer. 2011;117(6):1272-8. doi: 10.1002/cncr.25591.
17. Mishra A, Thomas B, Kapilamoorthy TR. Susceptibility weighted imaging - a problem-solving tool in differentiation of cerebellopontine angle schwannomas and meningiomas. Neuroradiol J. 2017;30(3):253-8. doi: 10.1177/1971400916689804.
18. Sanverdi SE, Ozgen B, Oguz KK, Mut M, Dolgun A, Soylemezoglu F, et al. Is diffusion-weighted imaging useful in grading and differentiating histopathological subtypes of meningiomas? Eur J Radiol. 2012;81(9):2389-95. doi: 10.1016/j.ejrad.2011.06.031.
19. Santelli L, Ramondo G, Della Puppa A, Ermani M, Scienza R, d'Avella D, et al. Diffusion-weighted imaging does not predict histological grading in meningiomas. Acta Neurochir (Wien). 2010;152(8):1315-9. doi: 10.1007/s00701-010-0657-y.
20. Meyer HJ, Wienke A, Surov A. ADC values of benign and high grade meningiomas and associations with tumor cellularity and proliferation - a systematic review and meta-analysis. J Neurol Sci. 2020;415:116975. doi: 10.1016/j.jns.2020.116975.
21. Hakyemez B, Yildirim N, Gokalp G, Erdogan C, Parlak M. The contribution of diffusion-weighted MR imaging to distinguishing typical from atypical meningiomas. Neuroradiology. 2006;48(8):513-20. doi: 10.1007/s00234-006-0094-z.
22. Tang Y, Dundamadappa SK, Thangasamy S, Flood T, Moser R, Smith T, et al. Correlation of apparent diffusion coefficient with Ki-67 proliferation index in grading meningioma. AJR Am J Roentgenol. 2014;202(6):1303-8. doi: 10.2214/ajr.13.11637.
23. Toh CH, Castillo M, Wong AM, Wei KC, Wong HF, Ng SH, et al. Differentiation between classic and atypical meningiomas with use of diffusion tensor imaging. AJNR Am J Neuroradiol. 2008;29(9):1630-5. doi: 10.3174/ajnr.A1170.
24. Yin B, Liu L, Zhang BY, Li YX, Li Y, Geng DY. Correlating apparent diffusion coefficients with histopathologic findings on meningiomas. Eur J Radiol. 2012;81(12):4050-6. doi: 10.1016/j.ejrad.2012.06.002.
25. Surov A, Gottschling S, Mawrin C, Prell J, Spielmann RP, Wienke A, et al. Diffusion-weighted imaging in meningioma: prediction of tumor grade and association with histopathological parameters. Transl Oncol. 2015;8(6):517-23. doi: 10.1016/j.tranon.2015.11.012.