Parameters of Fractional Anisotropy and Mean Diffusivity in DTI with Intracranial Meningioma Subtypes

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Abstract

Background: Meningioma is the most common primary intracranial tumor, divided into three grades and 15 subtypes. MRI and one of its advanced techniques, DTI, have been proven helpful in patient management. The aim of this study was to find the characteristics of FA and MD values in DTI and their association with intracranial meningioma subtypes.

Method: In this retrospective study, the researcher examined the medical records of surgically treated intracranial meningioma patients at Dr. Soetomo Hospital, dated January 2020 to December 2022. Intratumoral and peritumoral FA and MD values of all subjects were obtained and then statistically analyzed using the Mann-Whitney test.

Result: Eighteen subjects were eligible for the study, of whom 15 had grade 1 meningioma (8 transitional, four fibroblastic, one meningothelial, one microcystic, one metaplastic), two had grade 2 meningioma (2 atypical), and one had grade 3 meningioma (anaplastic). Both HGM and fibroblastic meningiomas had significantly higher intratumoral FA compared to other meningiomas ($p < 0.05$), but no statistically significant difference when compared to each other. Also, no significant differences were found in other FA and MD parameters.

Conclusion: Intratumoral FA values were able to differentiate fibroblastic subtype meningioma and high-grade meningioma from other typical meningioma, both of which had significantly higher FA values.

Keywords:

MRI, DTI, meningioma, intracranial, fractional anisotropy (FA), mean diffusivity (MD)

1. Introduction

Meningioma is the most common primary brain tumor, accounting for 35% of all primary brain tumors. According to 2008-2012 data from the Central Brain Tumor Registry of the United States, meningioma has an incidence rate of 7.75 per 100,000, and the median age at diagnosis is 65 years (1).

WHO divides meningioma into three grades: meningioma grade 1 is benign, while grades 2 and 3 are more aggressive (2). The morphological spectrum of meningioma is further divided into 15 subtypes (3). Variants included in WHO degree 1 are meningothelial, fibrous, transitional, psammomatous, angiomatous, microcystic, secretory, lymphoplasmacyte rich, and metaplastic. Those in the WHO grade 2 category include chordoid, clear cell, and atypical variants. WHO grade 3 meningiomas include the papillary, rhabdoid, and anaplastic variants. (4).

MRI is the primary modality for assessing brain tumors and is an integral part of preoperative diagnosis, surgical and therapeutic planning, evaluation of therapeutic outcomes, and detection of recurrence (5, 6). From a radiological point of view, determining the presence of brain tissue infiltration is paramount in evaluating the degree of malignancy. In many cases of malignant tumors, structural tumor margins may not reflect the actual tumor boundaries due to infiltration at the cellular level. However, conventional MRI techniques for structural evaluation, such as T1, T2, and FLAIR, cannot detect infiltration at the microscopic level (5, 7). Other methods are required to detect tumor cell infiltration in tissue at the microscopic level. DTI, with FA and MD as its metric, has been proposed by some of the recent literature to allow better determination of tumor boundaries than

conventional MRI techniques. DTI is considered to be able to detect white matter infiltration around the tumor that is not visible on conventional MRI. (7)

This study aims to find the characteristics of FA and MD values in DTI and their association with intracranial meningioma subtypes.

2. Materials and Methods

Researchers examined the medical records of surgically treated intracranial meningioma patients at Dr. Soetomo Hospital, dated January 2020 to December 2022, who underwent presurgical head MRI at Dr. Soetomo Hospital. The medical record should specify the grade and subtype of meningioma, and the presurgical head MRI performed should include a DTI sequence with standard protocol. Eighteen subjects were eligible for the study, three of whom were male and 15 of whom were female. The mean age of all subjects was 48.3 ± 10.0 years old (30-72 years old). Subjects with incomplete medical records, incomplete MRI sequence, history of prior surgery, radiotherapy, chemotherapy, and embolization were excluded. The data obtained were then processed using the SPSS version 26 software and then presented in table form with percentages (%) and tables.

Of the 18 subjects, 15 subjects were found with WHO grade 1 meningioma, two with WHO grade 2 meningioma, and one with WHO grade 3 meningioma. Among the 15 grade 1 meningiomas, transitional subtypes were found in eight subjects, fibroblastic in four subjects, and meningothelial, microcystic, and metaplastic in one subject each.

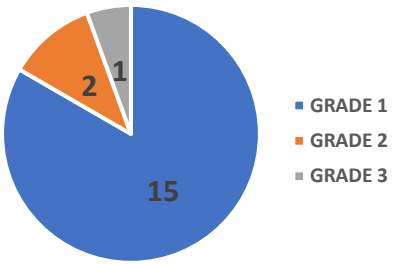

Figure 1. Findings of meningioma grades in research subjects

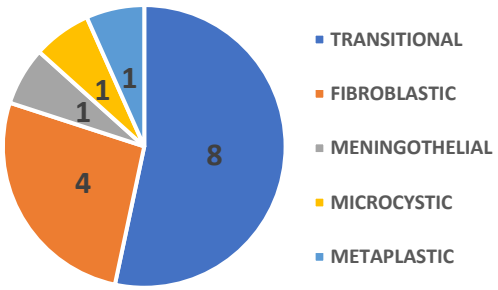

Figure 2. Findings of meningioma subtypes in all research subjects with meningioma grade 1

One radiologist, blinded to the histopathological results of the subjects, placed circular ROIs with an area of approximately 0.5 cm2 on a solid area at the center of the tumor and peritumoral area to obtain FA and MD values. Moreover, solid areas of the tumor are identified by intratumoral enhancing areas on T1WI after gadolinium-based contrast administration. For the peritumoral area, ROIs were placed on the brain parenchyma next to the indistinct part of the tumor border.

3. Result

Subjects were divided into four groups based on histopathological reports of meningioma subtypes. Meningothelial, microcystic, and metaplastic subtypes were combined into the “OTM” group. WHO grade 2 and 3 meningiomas were also combined into the “HGM” group.

Intratumoral and peritumoral FA and MD of all subjects were obtained. Measured all subjects’ mean intratumoral and peritumoral FA were 0.215 ± 0.096 (0.117-0.440) and 0.212 ± 0.069 (0.086-0.397), respectively. For MD, the measured mean intratumoral and peritumoral MD were 0.966 ± 0.175 (0.741-1.533) and 1.390 ± 0.332 (0.801-2.119), respectively.

Table 1. Findings of mean FA and MD values in research subjects

	Mean FA Value	Mean MD Value
Intratumoral	0.215 ± 0.096 (0.117-0.440)	0.966 ± 0.175 (0.741-1.533)
Peritumoral	0.212 ± 0.069 (0.086-0.397)	1.390 ± 0.332 (0.801-2.119)

Among grade 1 meningiomas, the mean intratumoral FA value in the transitional subtype was 0.159 +/- 0.022, in the fibroblastic subtype 0.370 +/- 0.075, and in the OTM group 0.127 +/- 0.011. The mean intratumoral FA value in the HGM group was 0.232 +/- 0.014. The mean peritumoral FA value in the transitional subtype was 0.185 +/- 0.064, in the fibroblastic subtype 0.243 +/- 0.037, and in the OTM group 0.214 +/- 0.025. The average peritumoral FA value in the HGM group was 0.240 +/- 0.140.

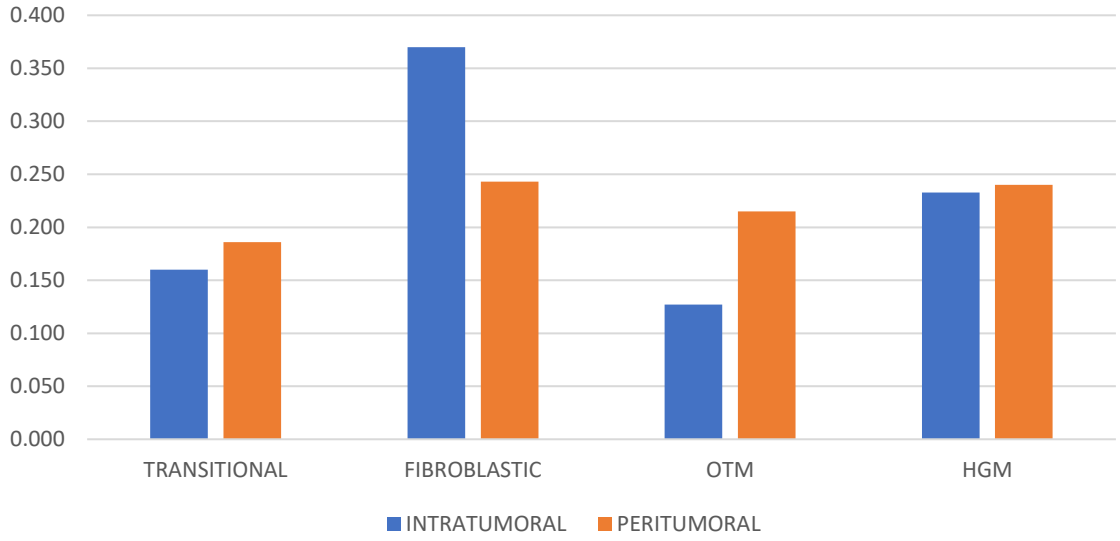

Figure 3. Findings of mean intratumoral and peritumoral FA values with meningioma subtypes in research subjects. The highest intratumoral FA mean values were found in the fibroblastic subtype, followed by HGM group, followed by transitional, and the lowest in OTM group.

Among grade 1 meningiomas, the mean intratumoral MD value in the transitional subtype was 0.994 +/- 0.126, in the fibroblastic subtype 1.038 +/- 0.334, and in the OTM group 0.920 +/- 0.083. The average intratumoral MD value in the HGM group was 0.841 +/- 0.086. The mean peritumoral MD value in the transitional subtype was 1.398 +/- 0.430, in the fibroblastic subtype 1.407 +/- 0.283, and in the OTM group 1.377 +/- 0.143. The average peritumoral MD value in the HGM group was 1.294 +/- 0.431.

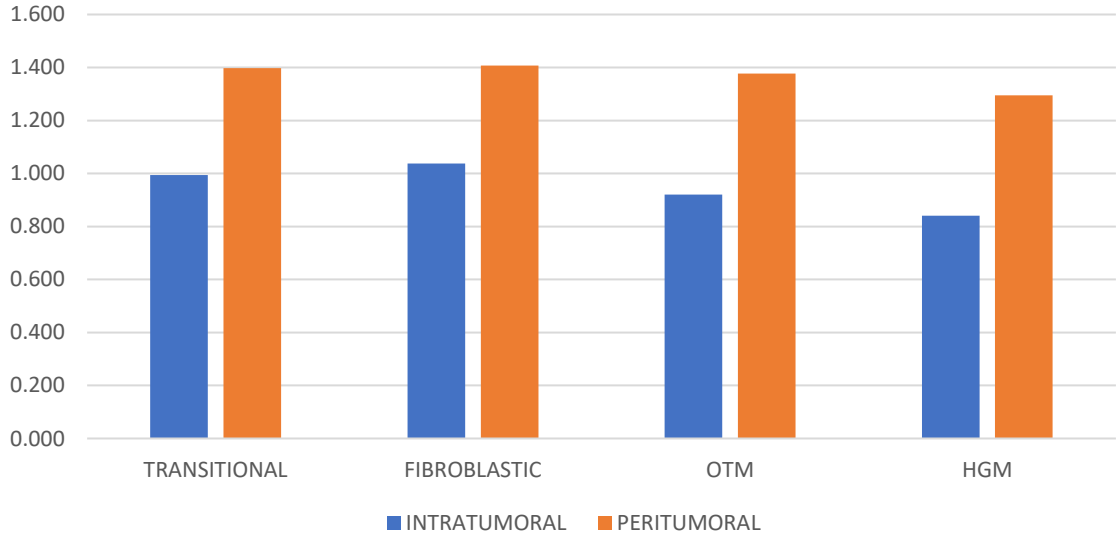

Figure 4. Findings of mean intratumoral and peritumoral MD values with meningioma subtypes in research subjects.

Statistical analysis using the Mann-Whitney test found that the fibroblastic subtype had a significantly higher mean intratumoral FA value compared to the transitional subtype and OTM group ($p < 0.05$). A similar result was found in the HGM group, which also had a significantly higher mean intratumoral FA value than the

transitional subtype and OTM group ($p < 0.05$). Nevertheless, there was no statistically significant difference when the fibroblastic subtype was compared with the HGM group. Moreover, no significant differences were found between the transitional subtype and the OTM group.

Other statistical studies yielded no significant differences in peritumoral FA, intratumoral MD, and peritumoral MD among all groups.

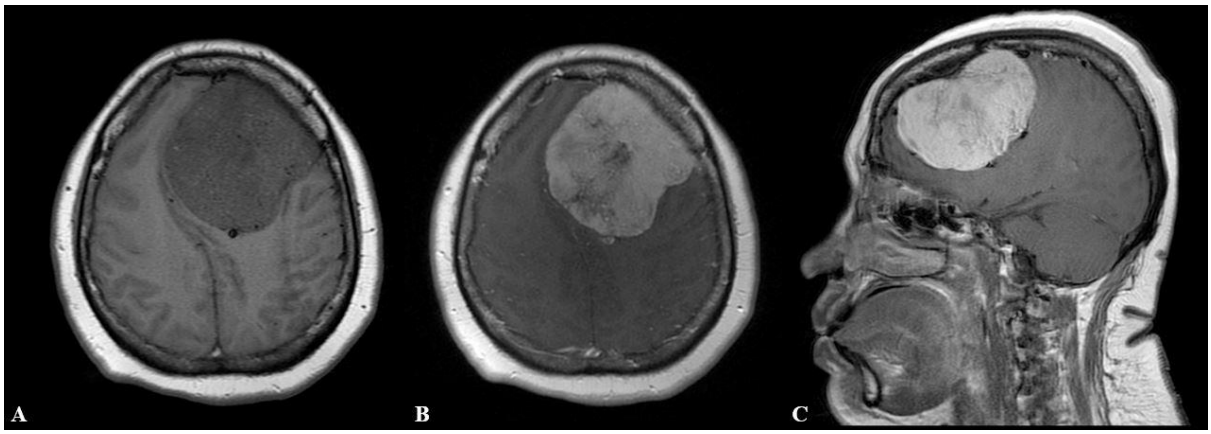

Figure 5. Head MRI of 44 y.o. female with fibroblastic meningioma, axial T1WI (A), axial T1 post-contrast (B), and sagital T1 post-contrast (C). An extraaxial solid mass was present on left frontal convexity, causing visible midline deviation to the right. The mass demonstrated strong contrast enhancement on contrast administration. Slight hiperostosis was also noted from sagital plane.

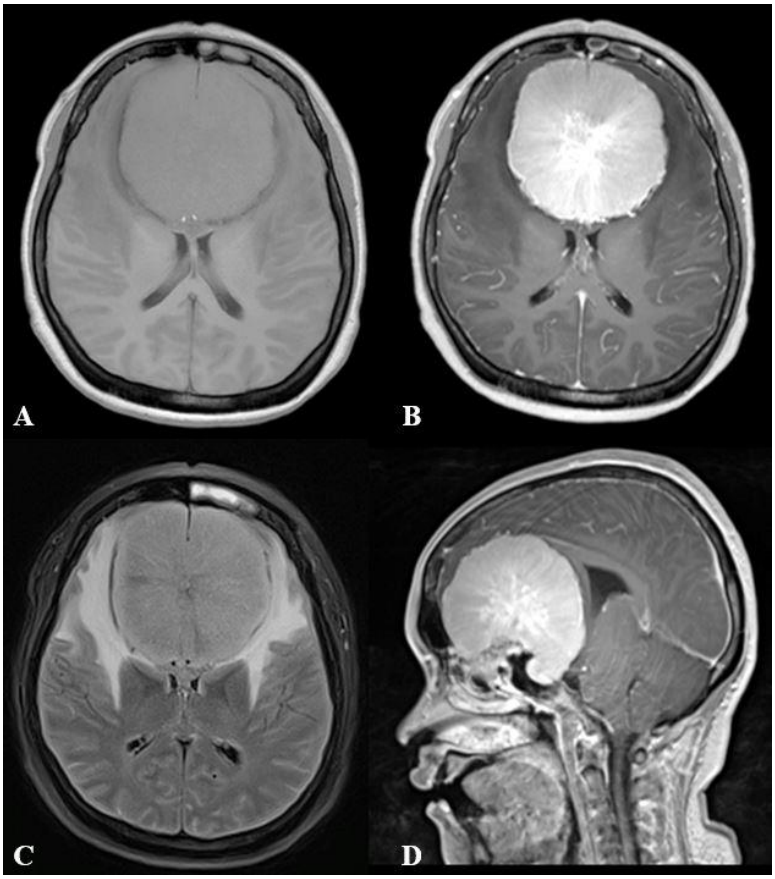

Figure 6. Head MRI of 36 y.o. female with meningothelial meningioma, axial T1WI (A), T1 post-contrast (B), T2-FLAIR (C), and sagital T1 post-contrast (D). A sizable extraaxial mass with perifocal oedema and strong homogenous contrast enhancement was noted on olfactory groove, pushing adjecent brain parenchyme and ventricular system. Also note abnormal signal intensity on left frontal sinus.

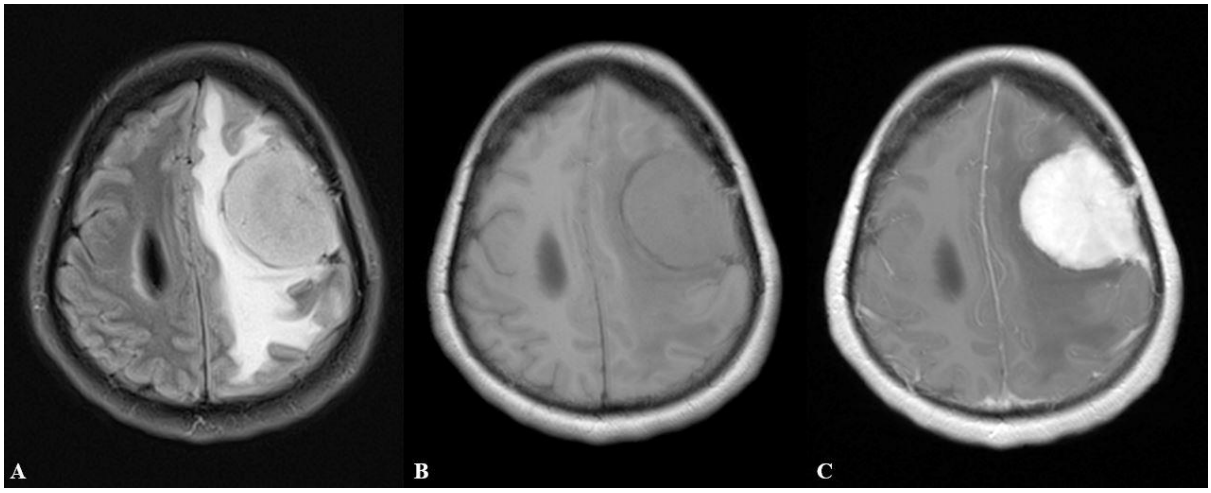

Figure 7. Head MRI of 42 y.o. female with atypical meningioma, axial T2-FLAIR (A), T1WI (B), and T1 post-contrast (C). There was a solid mass on left frontal convexity with significant peritumoral oedema causing slight midline shift to the right. CSF cleft sign was clearly seen on T2-FLAIR and T1WI. On T1 post contrast the mass demonstrated strong homogenous contrast enhancement and dural tail.

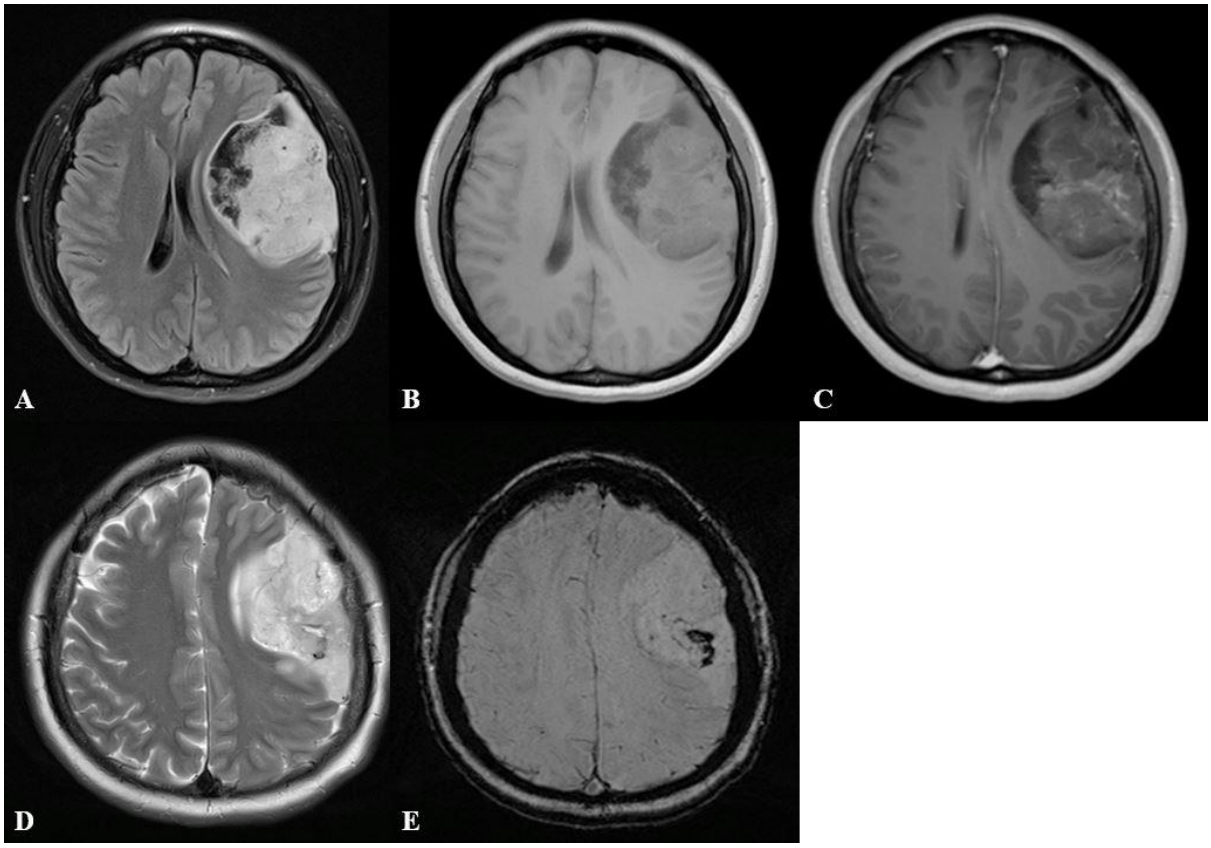

Figure 8. Head MRI of 43 y.o. female with anaplastic meningioma, axial T2-FLAIR (A), T1WI (B), T1 post-contrast (C), axial T2WI (D), and SWI (E). A heterogenous extraaxial mass was present on left frontoparietal lobe with solid and necrotic components. After contrast administration, the mass demonstrated small area of contrast enhancement. There were foci of signal loss and blooming artefact seen on T2WI and SWI, suggesting blood product.

4. Discussion

Peritumoral edema occurred in 13 of our 18 study subjects. Although peritumoral brain edema in meningiomas is common (38–67% of intracranial meningiomas), its pathogenesis is still debated (8). Things that are believed to be associated with the occurrence of edema include tumor size, histological subtype, vascularization, secretory activity, tumor-related venous obstruction, and expression of sex hormones and

receptors (9). A study by Nakano et al. found that tumors that appeared hyperintense on T2 MRI sequences had brain edema more frequently and tended to be much more severe than hypointense tumors (10). This stipulation is thought to be due to the high water content of hyperintense tumors that allows more water diffusion to the surrounding brain, in accordance with the pressure gradient theory. This theory states that the pressure difference between the tumor extracellular space and the brain interstitium results in osmotic dispersion (2). One thing worth noting regarding edema is that edema is believed to be a secondary sign of invasion of the brain parenchyma, and the presence of brain invasion is sufficient to categorize a meningioma into grade 2 (11).

Our study showed that in peritumoral FA and MD, there were no significant differences between each meningioma group. Similar results were obtained by Toh et al., who found no significant difference in the DTI finding of peritumoral edema between typical and atypical meningioma, although brain infiltration occurred in both typical and atypical meningioma (43% and 57%, respectively) of their subjects (9). The study by Panigrahi et al also found no significant difference in perilesional edema between typical and atypical meningioma (12). This finding suggests that brain edema associated with meningiomas is likely to be of vasogenic origin and not due to tumor infiltration.

Significant differences in intratumoral FA were found in the fibroblastic meningioma subtype compared to the transitional and OTM groups. Several studies have been conducted previously to discriminate the grades of meningioma based on FA findings with varying results. Toh et al reported significantly higher FA values in HGM compared to low-grade meningioma (9). As opposed to their findings, Zikou et al (13). and Wang et al (7) reported lower FA value in HGM. We assume these discrepancy may be due to the different sample sizes of the fibroblastic subtype in the aforementioned studies. A study by Toh et al., which included only two cases of fibroblastic meningioma out of a total of 24 samples, was able to differentiate between atypical and typical meningiomas (9). Moreover, their report did not include a separate comparison between fibroblastic and atypical meningioma.

The increased anisotropy in HGM and fibroblastic meningioma can be attributed to the more orderly cell arrangement, allowing water molecules to move more in one direction (14). Some literatures also mentioned that HGM is characterized by histologically continuous or sheet-like growth, reflecting a more organized cellular microstructure of the tumor (15). On the other hand, several literatures reported structures such as whorls, fascicles, cords, or nodules present in typical meningioma. In particular meningioma subtypes, such as transitional and meningothelial, the cells are arranged in a random manner. The less organized cellular structures commonly found in typical meningioma inhibit water molecules from moving linearly, and thus, more isotropic diffusion (9).

Another finding of this study was that there were no significant differences between fibroblastic subtype meningioma compared to HGM. This finding aligns with the study conducted by Jolapara et al. They found higher FA value in both atypical and fibroblastic meningioma, with no significant difference between both (14). From this finding, it is safe to assume that both HGM and fibroblastic meningioma experience increased anisotropy. If the subtype of fibroblastic meningioma is compared with others in grade 1, another study by Kashimura et al. found that the FA value of fibroblastic meningioma was significantly higher than that of meningothelial meningioma (16).

The mean value of intratumoral MD in atypical and anaplastic meningiomas was the lowest compared with other meningioma groups. However, statistically, there was no significant difference.

Inconsistent results were obtained from previous studies analyzing whether MD (often referred to as ADC in many other studies) can differentiate classic from atypical meningioma. Several studies show that HGM has a lower MD value, as found in a study conducted by Toh et al (9). Low MD values in HGM are believed to reflect greater cellularity and a higher nucleus/cytoplasm ratio (9). However, studies conducted by Santelli et al (17). and Sanverdi et al (18) reported unreliability of MD values in differentiating typical meningioma and HGM. MD values indicate that limited diffusion occurs in all meningiomas, and this is due to the dense cell arrangement found in meningiomas (14). In addition, the tumor component can also affect the MD value, especially if the tumor has high fluid, cystic, and necrotic components, making evaluation of diffusion to differentiate these two types of tumors more challenging (19).

One of the anaplastic meningioma subjects we had had necrotic and hemorrhagic components. Tissues with significant necrotic components may have loose cell arrangement and bodies, which may lower intratumoral FA value (13). Also, we believe this phenomenon increases the water content in the tumor. A decrease in FA value and an increase in MD value were found under conditions of tissue edema, and we speculate that this is the case

in our subject, which causes statistical analysis to be unable to find significant differences. One reason for this finding not being reported in some previous studies is arguably because of the exclusion of tumors with a bleeding component in some studies (9, 15).

5. Conclusion

Intratumoral FA values were able to differentiate fibroblastic subtype meningioma and high-grade meningioma from other typical meningioma, in which fibroblastic and high-grade meningioma had significantly higher FA values.

6. Source of funding

This study did not receive any funding from any source.

7. Conflict of Interest

Null.

8. Abbreviation

ADC : apparent diffusion coefficient ; DTI : diffusion tensor imaging ; FA : fractional anisotropy ; FLAIR : fluid attenuated inversion recovery ; HGM : high grade meningioma ; MD : mean diffusivity ; MRI : magnetic resonance imaging ; OTM : other typical meningioma ; ROI : region of interest ; SPSS : Statistical Program for Social Sciences ; SWI : susceptibility weighted imaging ; T1WI : T1 weighted image ; T2WI : T2 weighted image ; WHO : World Health Organization

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