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Original Article

Susceptibility-Weighted Imaging Features of Meningiomas with Histopathologic Correlation

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Abstract

Objective: The aim of the study was to investigate the characteristics of meningiomas, which are quite common tumors, in susceptibility-weighted imaging sequence which is increasingly used in magnetic resonance imaging in daily practice.

Methods: This study included 40 patients with intracranial meningioma between 2011 and 2017. The patients comprised 22 females and 18 males with a mean age of 47.7 years (range, 28-81 years). Magnetic resonance imaging with susceptibility-weighted imaging sequence and computed tomography were performed on all patients. The susceptibility score was calculated for each patient via susceptibility-weighted imaging sequence. Accordingly, less than 1/4 of the mass signal loss 1, 1/4-2/4 signal loss 2, 2/4-3/4 signal loss 3, and 3/4-4/4 signal loss were evaluated as 4 points.

Results: According to the pathologic World Health Organization classification, 21 of the patients (52.5%) had grade 1 (15 transitional, 3 meningothelial, 1 angiomatous, 1 microcystic, 1 psammomatous), 14 (35%) had grade 2 (all atypical), and 5 (12.5%) had grade 3 (all anaplastic) meningioma. Ten patients (25%) had calcificationn within the tumor in computed tomography. The median susceptibility score of the patients was 1. When age, tumor size, susceptibility score, and peripheral edema were compared with pathological grades, age (<0.001) and peripheral edema (0.009) were found to be statistically different.

Conclusions: Although meningiomas have different susceptibility-weighted imaging characteristics, this sequence has the potential to be used routinely in meningioma evaluation in the near future.

Keywords: A08–nervous system, computed tomography, magnetic resonance imaging, meningioma, susceptibility weighted imaging

INTRODUCTION

Meningiomas are accounting for 16%-20% of all intracranial tumors.[1] The incidence increases with age.[2] It is about 2 times more common in women.[3] Most of the patients who do not have symptoms and are diagnosed incidentally have a stable course.[4] As the tumor grade increases, the probability of tumor invasion and malignancy increases.[5] Although magnetic resonance imaging (MRI) is the useful imaging modality for the evaluation of meningioma, computed tomography (CT) is also widely used in the initial evaluation.[6] However, in the diagnosis and follow-up of meningioma, MRI is the examination that should be used in order to evaluate a tumor invasion and to make a differential diagnosis. The diagnosis and follow-up of meningiomas are performed with high accuracy thanks to advanced MRI techniques that have become more common in recent years.[7]

One of the advanced MRI applications is the susceptibility weighted imaging (SWI) examination.[8] Although the major indications of the SWI sequence were neurovascular and neurodegenerative diseases, they are used successfully in many different diseases.[9] The aim of current study was to evaluate the characteristic findings of meningiomas, which are quite common tumors, in SWI sequence which is increasingly used in daily MRI practice. We also evaluated the association between histopathologic subtype and susceptibility score.

METHODS

Magnetic resonance images of 40 patients with intracranial meningioma diagnosed between 2011 and 2017 were reviewed retrospectively. Spinal meningiomas were excluded from this study. Of our patients, 18 (45%) were male and 22 (55%) were female. The mean age of the patients was 47.7 years (range, 28-81 years).

Approval for the study was granted by the local ethics committee (12.02.2019-38/16), and all procedures were applied in accordance with the Helsinki Declaration. Informed consent was waived because of the retrospective nature of the study.

All MRI examinations were performed on a 1.5-T Magnet (Symphony Tim, Siemens Medical Systems, Germany). Axial and sagittal T1-weighted, axial fluid-attenuated inversion recovery (FLAIR), and axial T2-weighted images were taken. Susceptibility-weighted imaging sequence was

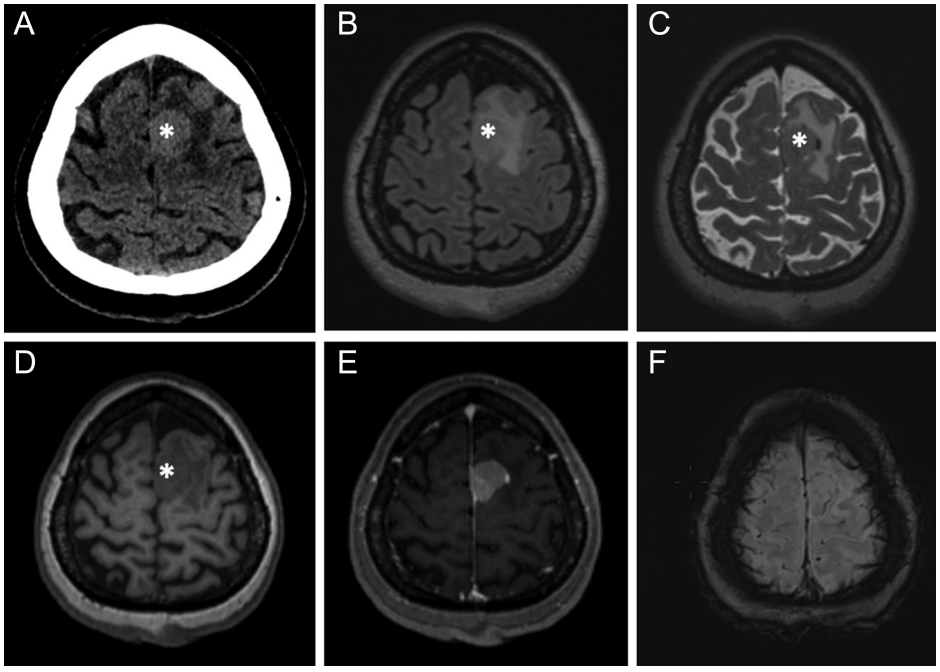

Figure 1. A 46-year-old woman was diagnosed with histopathologically WHO grade 3 anaplastic meningioma. Non-contrast axial CT scan (A) shows a parasagittal falx in meningioma (asterisk) in the left frontal. Axial FLAIR (B), T2 (C), and T1 (D) weighted MRI sequences show left frontal meningioma (asterisk) and its peripheral vasogenic edema. Post-contrast T1 (E) weighted MRI shows intense enhancement. In SWI sequence (F), the susceptibility score of the lesion is compatible with 0.
CT, computed tomography; FLAIR, fluid-attenuated inversion recovery; MRI, magnetic resonance imaging; SWI, susceptibility-weighted imaging; WHO, World Health Organization.

obtained in all the patients. The susceptibility score was calculated for each patient from the SWI sequence. Accordingly, less than 1/4 of the mass signal loss 1, 1/4-2/4 signal loss 2, 2/4-3/4 signal loss 3, and 3/4-4/4 signal loss were evaluated as 4 points. All of the patients were examined by CT (Emotion 16, Siemens Medical Systems, Germany) and the presence of calcification on CT images was evaluated. The images were retrospectively reviewed by two experienced radiologists. There was an agreement between them for each case. Pathological records were evaluated retrospectively to determine pathologic grade and tumor subtype.

For statistical analysis, MedCalc (Medcalc ver.12, Ostend, Belgium) was used. The chi-square test was performed for the comparison of categorical variables. The independent samples *t*-test was made for the comparison of continuous variables with normal distribution in the Kolmogorov–Smirnov and Shapiro–Wilk tests. Mann–Whitney *U* and Kruskal–Wallis tests were used to compare the data that did not conform to normal distribution according to the normality evaluation with the Kolmogorov–Smirnov and Shaphiro–Wilk tests. A value of $P < .05$ was accepted as statistically significant.

MAIN POINTS

- Susceptibility-weighted imaging sequence can be used successfully in detecting calcifications in meningiomas.
- Susceptibility-weighted imaging of the advanced magnetic resonance imaging (MRI) applications has the potential to be used routinely in meningioma evaluation in the near future.
- On susceptibility-weighted imaging, meningiomas have different imaging characteristics.

RESULTS

According to the pathologic World Health Organization (WHO) classification, 21 of the patients (52.5%) had grade 1 (15 transitional, 3 meningothelial, 1 angiomatous, 1 microcystic, and 1 psammomatous), 14 (35%) had grade 2 (all atypical), and 5 (12.5%) had grade 3 (all anaplastic) meningioma. Ten patients (25%) had calcification within the tumor in CT. Five patients had punctate, 4 had millimetric, and 1 had intense calcifications. The size of the lesions was 42 ± 20 mm. In 15 patients (37.5%), the tumor was frontal, in 6 patients (15%) it was parietal, in 5 patients (12.5%), it was temporal, in 4 patients (10%), it was occipital, in 3 patients (7.5%), it was sphenoid wings, in 3 patients (7.5%), it was sphenoid wings, 2 patients (5%) had medullopontine angle, 1 patient (2.5%) had olfactory sulcus, and 1 patient (2.5%) had ethmoid roof tumor. Twenty-four patients (60%) had peripheral edema accompanying the tumor.

The susceptibility score was found to be 0 in 9 (22.5%) patients (Figure 1A-F), 1 in 17 patients (42.5%) (Figure 2A-D), 2 in 10 patients (25%) (Figure 3A-H), 3 in 3 patients (7.5%) (Figure 4A-F), and 4 in 1 patient (2.5%). When age, tumor size, susceptibility score, and peripheral edema were compared with pathological grades, age (Figure 5) and peripheral edema (Figure 6) were found to be statistically significant, respectively, with $P < .001$ and $P = .009$ (Table 1). When histological subtypes of grade 1 meningiomas were examined, no significant difference was found between the transitional subtype and other subtypes in terms of susceptibility score ($P = .262$). There was no statistically significant difference in the susceptibility scores between the lesions with calcification on the CT and the lesions without calcification ($P = .463$).

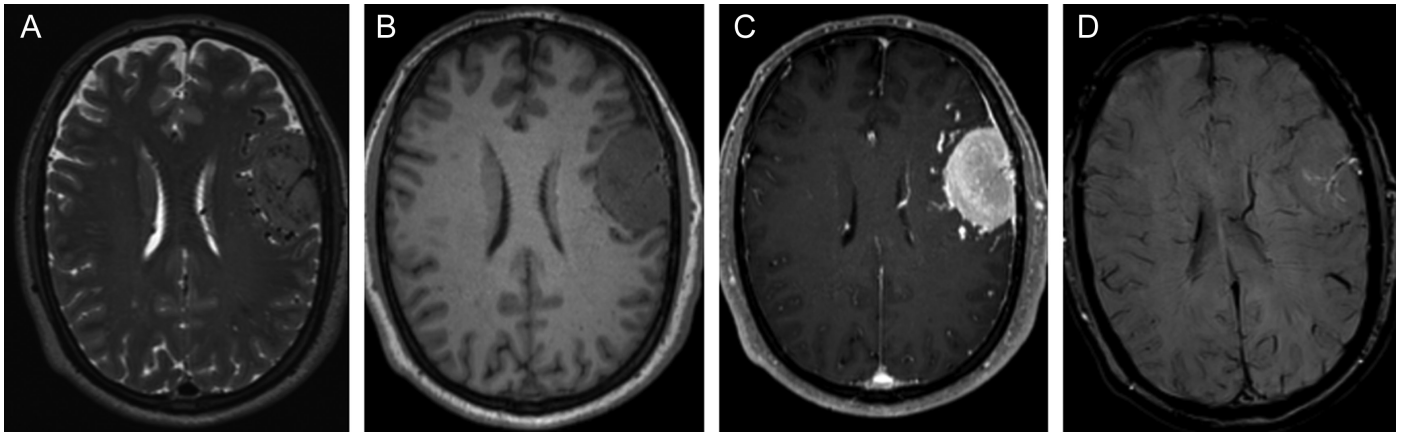

Figure 2. A 54-year-old man was diagnosed with histopathologically WHO grade 1 transitional meningioma. T2 (A) and T1 (B) weighted axial MRI show left frontal meningioma. Post-contrast T1 (C) weighted MRI shows intense enhancement. In SWI sequence (D), the susceptibility score of the lesion is compatible with 1. MRI, magnetic resonance imaging; SWI, susceptibility-weighted imaging; WHO, World Health Organization.

DISCUSSION

Two previous studies have shown SWI sequence to be a reliable diagnostic tool in detecting magnetic susceptibility in meningiomas compared with routine MRI pulse sequences.[10,11] However, in these studies all patients had no correlation of SWI sequence with histopathologic findings. In a study by Schwyzer et al.[10] which included 36 patients, the susceptibility and diffusion characteristics of meningiomas were compared. In this study, 36% of meningiomas were evaluated as SWI positive and ADC values were higher in SWI positive group. In our study, the median susceptibility score was 1 in the grade 1 group and 2 in the grade 2 and 3 groups. In the study by Adams et al.[11] CT and SWI were compared in the detection of calcifications in meningioma. In this study,

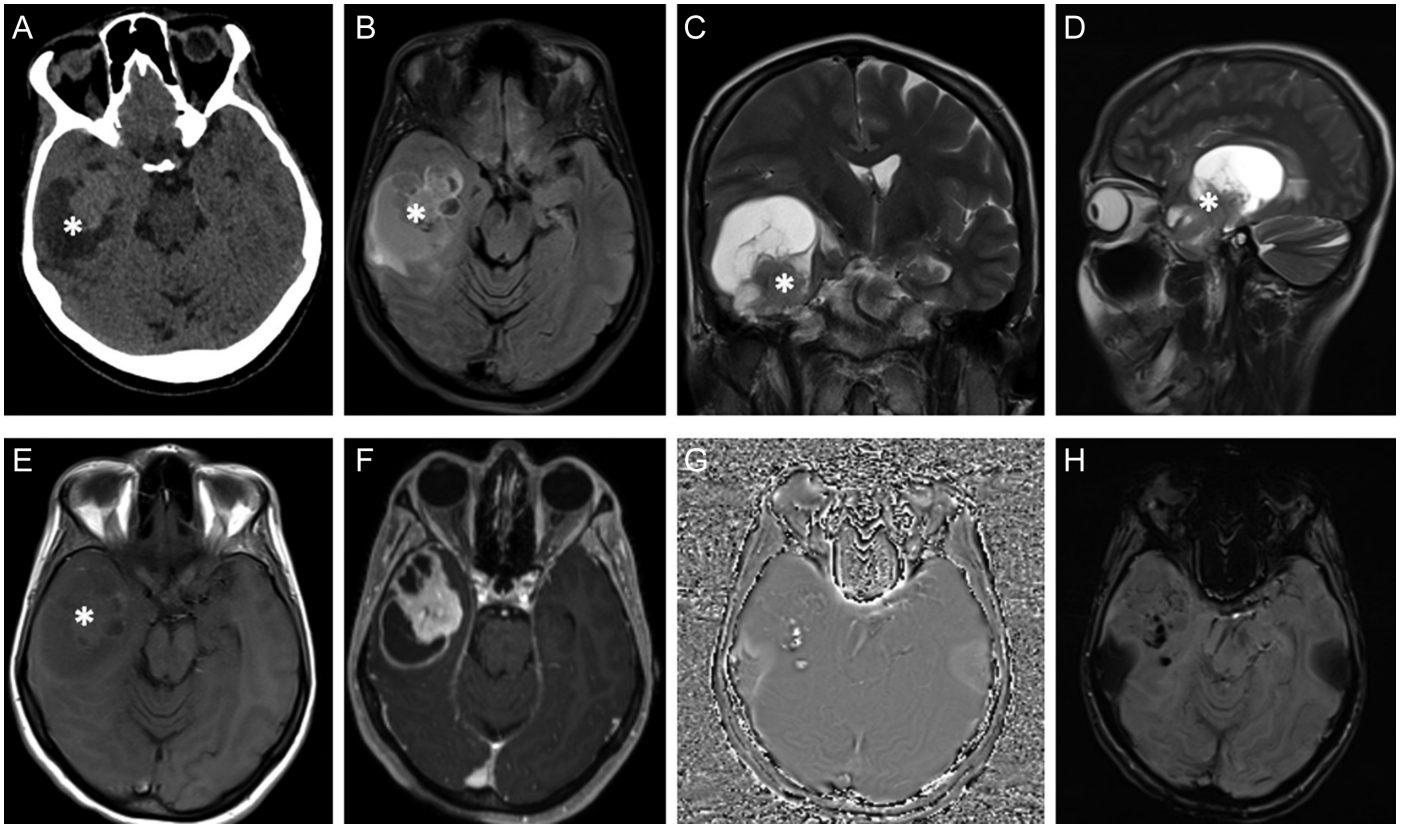

Figure 3. A 39-year-old woman was diagnosed with histopathologically WHO grade 3 anaplastic meningioma. Non-contrast axial CT scan (A) shows an extra-axial hypodense mass (asterisk) in the right temporal. Axial FLAIR (B), coronal T2 (C), sagittalT2 (D), and axial T1 (E) weighted MRI sequences show right middle cranial fossa meningioma (asterisk) and its peripheral vasogenic edema. Post-contrast T1 (F) weighted MRI shows intense enhancement in the solid component of the semisolid lesion. In phase image (G) and SWI (H) sequences, the susceptibility score of the lesion is compatible with 2.
CT, computed tomography; FLAIR, fluid-attenuated inversion recovery; MRI, magnetic resonance imaging; SWI, susceptibility-weighted imaging; WHO, World Health Organization.

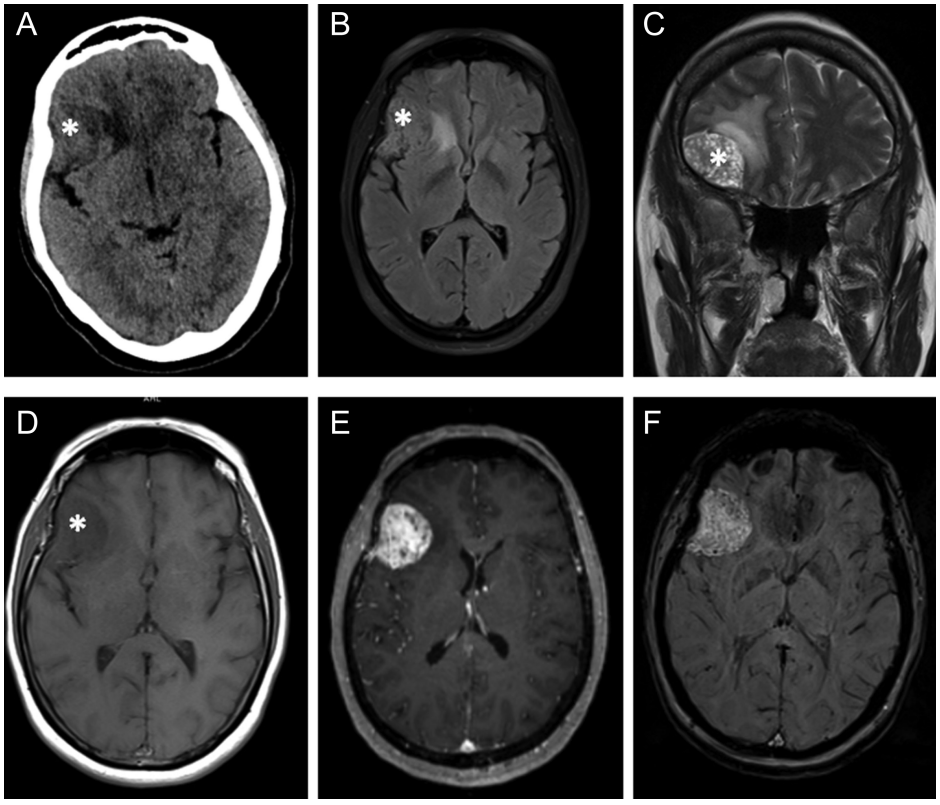

Figure 4. A 63-year-old woman was diagnosed with histopathologically WHO grade 1 meningothelial meningioma. Non-contrast axial CT scan (A) shows an extra-axial mass (asterisk) in right orbitofrontal. Axial FLAIR(B), coronal T2 (C), and axial T1 (D) weighted MRI sequences show right anterior cranial fossa meningioma (asterisk) and its peripheral vasogenic edema. Post-contrast T1 (E) weighted MRI shows intense enhancement of the lesion. In SWI sequence (F), the susceptibility score of the lesion is compatible with 3.
CT, computed tomography; FLAIR, fluid-attenuated inversion recovery; MRI, magnetic resonance imaging; SWI, susceptibility weighted imaging; WHO, World Health Organization.

SWI has been shown to be as successful as CT in detecting calcifications in meningiomas. In our study, 25% of the patients had calcification on the CT and all of these patients had calcification on the SWI examination.

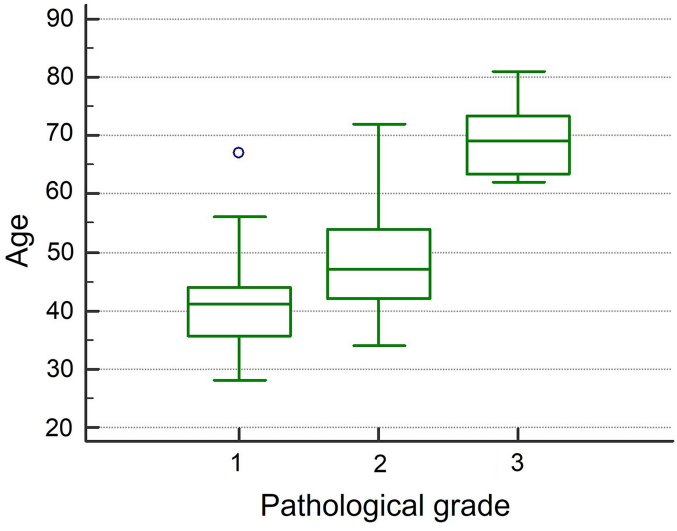

Figure 5. The graphic shows the correlation between age and pathological grade.

Meningiomas occur in the regions where the arachnoidal cells are intensively located. Many endogenous and exogenous factors may predispose to meningiomas. The most common exogenous factor is the ionizing radiation applied to the scalp region. Meningiomas are thought to have a role in the etiology of sex hormones because they are seen more frequently in women, they accelerate their growth during the luteal phase of pregnancy and menstrual cycle, and contain hormone receptors.[12] In the current study, the number of our patients of

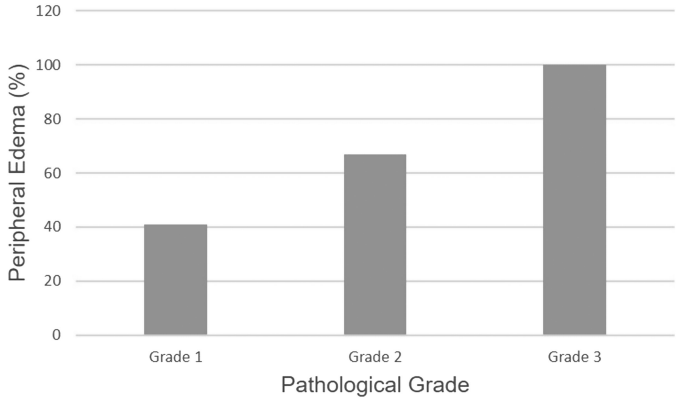

Figure 6. The graphic shows the correlation between peripheral edema and pathological grade.

Table 1. Comparison of Age, Tumor Size, Susceptibility Score, and Peripheral Edema According to Pathological Grade

	Grade 1	Grade 2	Grade 3	*P*
Age (mean)	41.6	49	69.4	<.001
Tumor size (mm, mean)	37.3	44.6	54.6	.410
Susceptibility score (median)	1	2	2	.285
Peripheral edema (percentage)	41%	67%	100%	.009

the female gender was higher. Meningiomas are usually dura-related, slow-growing benign tumors. They usually form masses of extra-axial growth, which are more repellent than neural parenchymal infiltration. Most meningiomas are located in intracranial, orbital, and intravertebral cavities. Meningioma development has been reported in almost all other organs, albeit quite rare. The most common location in the intracranial cavity is cerebral convexities, falx, and parasagittal area.[13] In our study, tumors were mostly located in the frontal, parietal, and temporal regions. Nine types of grade 1 (fibroblastic, meningothelial, transitional, angiomatous, psammomatous, secretory, microcystic, metaplastic, and lymphoplasma-rich), three grade 2 (clear-cell, chordoid, and atypical) and three grade 3 (rhabdoid, papillary, and anaplastic) meningioma subtypes have been defined in 2016 WHO classification of meningiomas of histopathological appearance. The recurrence rate was 7%-20% in grade 1 meningiomas, 30%-40% in grade 2 meningiomas, and 50%-80% in grade 3 meningiomas.[5] In our study, 21 of the patients (52.5%) had grade 1 (15 transitional, 3 meningothelial, 1 angiomatous, 1 microcystic, and 1 psammomatous), 14 (35%) had grade 2 (all atypical), and 5 (12.5%) had grade 3 (all anaplastic) meningioma.

Meningiomas appear to be iso (~40%) or hyperdense (~60%) extra-axial masses in CT without contrast. Calcifications can be found in the tumor (~25%). Contrast-enhanced CT shows intense and homogenous enhancement. The formation of hyperostosis in neighboring bone (~20%) is an important feature.[7] Magnetic resonance imaging shows the whole extension of meningioma, vascular invasion, tumor vascularity, parenchymal edema, and intraosseous invasion, much better and more detailed than CT. In T1-weighted images, meningioma is mild hypointense similar to cerebral cortex, and T2-weighted images are mild hyperintense compared to gray matter. It shows intense enhancement after contrast agent.[14,15] The cleft sign defined for differentiation of extra-axial intradural lesions such as meningioma can be said between the lesion and brain tissue in the presence of cerebro spinal fluid (CSF), vascular, or hypointense dura. Dural tail is the name given to dural thickening extending from the sides of the lesion to the periphery and it is seen in 72% of meningiomas.[16]

Brain edema is not uncommon in meningiomas despite extra-axial localization.[17] Brain edema was found to be vasogenic in electron microscopy and diffusion-weighted images.[18] This finding suggests that the source of edema is caused by meningioma tissue rather than brain tissue. Vascular endothelial growth factor is thought to play an important role in edema formation. Vascular endothelial growth factor-induced pial vascularity and tumor vascularity are thought to be associated with peritumoral brain edema.[19] As a result of proliferation and prolongation of the meningioma through the arachnoid membrane, the brain barrier is impaired.[20] In the current study, the possibility of peripheral edema increased as the grade increased ($P=.009$), although there was no statistically significant relationship between peripheral edema and tumor size ($P=.258$). There are many publications in the literature showing that there is a relationship between grade and peripheral edema.[21–23] The relationship between tumor size and edema is controversial. In some studies, no significant relationship was found between the size of the tumor and the amount of peritumoral edema.[21,24] However, there are also studies suggesting that large-sized tumors can lead to greater brain compressions, resulting in a reduction in venous return and associated ischemia and secondary peritumoral payment.[25,26]

There were several limitations of this study. First, the nature of the study was retrospective. Second, because of the retrospective nature of the study, sequence parameters could not be optimized. Finally, this study had a relatively small sample size.

In conclusion, although meningiomas have different SWI characteristics, this sequence has the potential to be used routinely in meningioma evaluation in the near future.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Sakarya University (Date: February 12, 2019, Decision No: 38/16).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – H.O.; Design – O.T.; Supervision – H.O.; Resources – H.O.; Materials – H.O.; Data Collection and/or Processing – H.O., O.T.; Analysis and/or Interpretation – H.O.; Literature Search – H.O., A.K.; Writing Manuscript – H.O., O.T.; Critical Review – H.O.; Other – A.K.

Declaration of Interests: The authors have no conflicts of interest to declare.

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