The Rim Pattern of Meningioma on 3D FLAIR Imaging: Correlation with Tumor-brain Adhesion and Histological Grading

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Purpose: We evaluated the rim patterns of intracranial meningiomas on nonenhanced (NE) and contrast-enhanced (CE) 3-dimensional fluid-attenuated inversion recovery (3D FLAIR) imaging on 3-tesla magnetic resonance (MR) imaging to clarify the associated imaging and pathological findings and the value of the rims in predicting tumor cleavability.

Methods: Thirty-two patients with meningioma underwent tumor excision. We classified the rim patterns on 3D FLAIR, subdivided into “rim-NE,” a rim with relatively low signal intensity on NE 3D FLAIR and “rim-CE,” a rim with relatively high signal intensity on CE 3D FLAIR, into 4 grades by their extent from 0 (no rim visible) to 3 (rim visible over most of the tumor-brain interface) and correlated them with tumor size, grade of peritumoral brain edema, presence/absence of pial supply, grade of tumor-brain adhesion, and histological findings.

Results: On NE 3D FLAIR, “rim-NE” was graded 0 in 5 patients, one in 5, 2 in 6, and 3 in 16. On CE 3D FLAIR, “rim-CE” was graded 0 in one patient, one in 13, 2 in 4, and 3 in 14. The grade of “rim-NE” correlated negatively with the grade of brain edema ($P = 0.023$) and positively with surgical tumor-brain cleavability ($P < 0.001$). It also correlated with the amount of connective tissue at the tumor-brain interface histologically ($P = 0.041$). Furthermore, a lower grade of “rim-NE” was more often seen in atypical than benign meningioma ($P = 0.003$). Although “rim-CE” was more prominent in tumors with pial supply on digital subtraction angiography (DSA) ($P = 0.002$), it was not useful in predicting tumor-brain adhesion or histological tumor grading.

Conclusion: The rim pattern of meningioma on NE 3D FLAIR can predict surgical cleavability and histological tumor grading. A higher grade of rim pattern on CE 3D FLAIR suggests prominent pial supply to the tumor but has no added value in predicting tumor-brain adhesion and histological tumor grading.

Keywords: DSA, meningioma, MRI, tumor-brain adhesion, 3D FLAIR

Introduction

Fluid-attenuated inversion recovery (FLAIR) is a $T_2$-weighted imaging ($T_2$WI) method in which signals of cerebrospinal fluid (CSF) are suppressed. A recently developed 3-dimensional (3D) FLAIR technique reduces pulsation and blood flow artifacts and improves signal-to-noise ratio (SNR) when compared with 2-dimensional (2D) FLAIR imaging. Furthermore, because 3D FLAIR imaging yields 3D volume data with isotropic information, images of thinner slices can be acquired in any plane, reducing the partial volume effect between small lesions and
surrounding tissue.\textsuperscript{1–3} Several studies evaluating rim patterns at the meningioma-brain interface on 2D FLAIR images as well as $T_1$-WI and $T_2$-weighted images\textsuperscript{4–7} have speculated that the rim patterns represent fibrous connective tissue, CSF, or vascular structures according to the pattern of signal intensity. Rim patterns can be used to distinguish extra-axial lesions from intra-axial lesions, such as meningiomas from gliomas, but factors that contribute to the extent of rim pattern have not been fully elucidated.

We evaluated rim of meningiomas on 3D FLAIR images to clarify the grades of the rim patterns in meningiomas, factors associated with them, and the predictability of tumor cleavability (possibility of dissection through the extra-pial plane) based on rim patterns.

Materials and Methods

Patients

We retrospectively evaluated 32 consecutive cases of surgically confirmed meningiomas (24 women, 8 men; aged 32 to 77 years) identified at our institution March 1, 2013 through June 30, 2013. All patients underwent pre- and post-contrast 3D FLAIR magnetic resonance (MR) imaging at 3-tesla prior to surgery. Preoperative digital subtraction angiography (DSA) was available for 19 of the 32 meningiomas.

Our institutional review board approved this retrospective study and waived the requirement for informed consent.

MR sequences

All MR imaging studies were performed with a 3T MR system (Signa HDx 3T; GE Healthcare, Milwaukee, WI, USA) using an 8-channel head coil. Gadopentetate dimeglumine (Magnevist\textsuperscript{®}; Bayer Schering Pharma, Germany) was intravenously administered at a dose of 0.1 mmol/kg body weight. Images of 3D FLAIR were obtained with fast spin-echo pulse sequence with parallel imaging and extended echo train acquisition (Cube\textsuperscript{™}) with parameters: acquisition plane, sagittal; acceleration factor, 2.82; repetition time (TR)/echo time (TE), 6000 ms/112.68 ms; inversion time (TI), 1892 ms; echo train length, 160; matrix size, 256 \times 256; matrix zero-filling interpolation (zip), 512; field of view (FOV), 240 mm \times 240 mm; slice thickness, 1.2 mm; number of acquisition slices, 128; number of excitations, one; and acquisition time, 5 min 39 s.

Evaluation of MR imaging findings

Two neuroradiologists (M. E. and M. M.) retrospectively evaluated MR imaging findings by consensus.

First, on 3D FLAIR with/without contrast enhancement, we defined the characteristics of the rims of the tumor-brain interface, one-layered thin structures with signals differing from those of the tumor and brain.\textsuperscript{4,5} We defined “rim-NE” as a rim with relatively low signal intensity on NE 3D FLAIR and “rim-CE,” as a rim with relatively high signal intensity on CE 3D FLAIR (Fig. 1). We graded the rim patterns from 0 to 3 by their extent as: 0, no rim visible; one, rim visible in part (less than a semicircle); 2, rim visible across roughly half; and 3, rim visible over most of the tumor-brain interface.

We measured maximum tumor diameter in all patients.

We graded peritumoral brain edema from 0 to 2: 0, no edema; one, edema <2 cm in width; and 2,
Evaluation of DSA findings

We examined the preoperative DSA findings of 19 of the 32 meningiomas. Selective DSA and, if necessary, 3D rotational angiography (3D-RA) of the internal/external carotid artery and vertebral artery were performed. Two neuroradiologists (M. E. and M. M.) retrospectively evaluated DSA findings and classified the tumors into 2 groups based on the presence or absence of pial supply to the tumors.

Evaluation of surgical findings

A neurosurgeon (T. M.) who had performed the surgery retrospectively graded tumor-brain (pial) adhesion from 0 to 3: 0, no adhesion to the intercalated arachnoid; one, weak adhesion where the arachnoid in contact with the tumor was conserved after tumor excision; 2, strong adhesion where the arachnoid in contact with the tumor was stripped off in parts with exposure of the brain surface; and 3, markedly strong adhesion where the tumor could not be separated without excision of the brain.

Evaluation of histological findings

A pathologist (T. H.) evaluated pathological findings, focusing on the tumor-brain interface and histological tumor grading.

Histologically, meningioma often shows proliferation of connective tissue composed of tumor stroma, arachnoid membrane, and arachnoid trabecules at the tumor-brain interface. The thickness of this connective tissue was graded as 0, none (no tissue); one, thin (less than triple the thickness of normal tissue); or 2, thick.

Histological vascularity at the tumor-brain interface was graded as 0, scarce; one, modest; or 2, abundant.

Histological tumor grading was classified as either benign or atypical/malignant.

Statistical analysis

We used Spearman’s correlation coefficient with rank test to correlate the grade of rim patterns with size of the tumor, extent of brain edema on 3D FLAIR, grade of tumor adhesion at surgery, and histological findings (except histological tumor grading). We used Cochran-Armitage Trend Test to correlate the grade of rim patterns with the presence of pial supply to the tumors on DSA and histological tumor grading. \( P < 0.05 \) was regarded as significant.

Results

Table summarizes data of the 32 patients with meningioma. “Rim-NE” was graded 0 in 5 patients, one in 5 patients, 2 in 6 patients, and 3 in 16. “Rim-CE” was graded 0 in one patient, one in 13 patients, 2 in 4 patients, and 3 in 14 (Figs. 2, 3).

Tumor diameters ranged from 1.3 to 12 cm (median, 3.1 cm). No significant correlation was found between tumor diameter and “rim-NE” or “rim-CE” \(( P = 0.182, 0.479 \)).

Peritumoral brain edema was graded 0 in 13 patients, one in 4 patients, and 2 in 8 patients. Negative correlation was found between the grade of “rim-NE” and the grade of brain edema \( (P = 0.023, \text{Fig. 4}) \). No significant correlation was found, but the grade of “rim-CE” tended to correlate positively with the grade of brain edema with marginal significance \( (P = 0.057, \text{Fig. 4}) \).

Of 19 patients who underwent DSA, we observed pial-cortical supply in 13 patients and no pial supply in six. “Rim-CE” was more prominent in cases with pial supply \( (P = 0.002, \text{Figs. 3, 5}) \). No significant correlation was found, but the grade of “rim-CE” was more prominent \((P < 0.001, \text{Fig. 6}) \). In contrast, “rim-CE” showed no such correlation \( (P = 0.223, \text{Fig. 6}) \).

The amount of connective tissue observed at the tumor-brain interface was graded 0 in 8 patients, one in 6, and 2 in 7 and was undetermined in 11 patients. Positive correlation was found between the grade of “rim-NE” and the amount of connective tissue \( (P = 0.041, \text{Fig. 7}) \), but no significant correlation was found between the grade of “rim-CE” and the amount of connective tissue \( (P = 0.997, \text{Fig. 7}) \).

Histological vascularity at the tumor-brain interface was graded 0 in 7 patients, one in 6, and 2 in 9. Neither “rim-NE” nor “rim-CE” showed significant correlation with vascularity at the tumor-brain interface \( (P = 0.884 [\text{NE}], 0.598 [\text{CE})] \).

Histological tumor grading was classified as benign in 24 patients and atypical in 8 patients. Low grade “rim-NE” was more frequently seen in atypical than benign tumors \( (P = 0.003, \text{Fig. 8}) \), but “rim-CE” showed no such correlation \( (P = 0.759, \text{Fig. 8}) \).
Table. Summary of 32 patients with meningioma (N/A = not available)

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Fig. 2. Right parieto-occipital convexity meningioma (Case 3). (a) Nonenhanced 3-dimensional fluid-attenuated inversion recovery (NE 3D FLAIR) shows extra-axial mass with no brain edema and rim-NE all around the tumor-brain interface (Grade 3 of “rim-NE”), excluding skull involvement. (b) Contrast-enhanced (CE) 3D FLAIR shows no “rim-CE” (Grade 0 of “rim-CE”). (c) Arteriogram of the right internal carotid artery (ICA) shows no pial supply. (d) Histological specimen (hematoxylin and eosin stain) shows thick connective tissue and modest vascularity at the tumor-brain interface without tumor-brain invasion. (At surgery, no tumor-brain adhesion is observed.)

Fig. 3. Left frontal convexity meningioma (Case 7). (a) Nonenhanced 3-dimensional fluid-attenuated inversion recovery (NE 3D FLAIR) shows extra-axial mass with extensive edema and no “rim-NE” at the tumor-brain interface (Grade 0 of “rim-NE”). (b) Contrast-enhanced (CE) 3D FLAIR shows “rim-CE” all around the tumor (Grade 3 of “rim-CE”). (c) Arteriogram of the left internal carotid artery (ICA) shows pial supply to the tumor. (d) Histological specimen (hematoxylin and eosin stain) confirms no connective tissue and direct tumor-brain invasion and abundant vascularity at the tumor-brain interface. (At surgery, markedly strong tumor-brain adhesion is observed.)
FLAIR imaging is widely used to evaluate various intracranial diseases, such as subarachnoid hemorrhage, meningitis, and acute infarction. The recently developed 3D FLAIR sequence has an advantage over the conventional 2D technique in reducing artifacts of high signal intensity from the inflow of non-inverted CSF and from pulsatile motion. Furthermore, the 3D FLAIR technique improves SNR and reduces partial volume effects by obtaining thinner sections with isotropic resolution.

Several studies have investigated the significance of a “rim sign” observed at the meningioma-brain interface on conventional T1- and T2-weighted images. Spagnoli and associates reported 3 types of structures at the meningioma-brain interface using a 1.5T MR imaging unit: first, a CSF cleft showing fluid-like signal intensity; second, a vascular structure, seen as a signal void; and third, the dura, showing low signal intensity on both T1- and T2-weighted images. Nakasu and colleagues classified the patterns of the meningioma-brain interface into 4 types using 0.5- and 0.2T MR imaging units: Type I, rim of low signal intensity on both T1- and T2-weighted images representing thick collagenous tissue; Type II, rim of low signal intensity on T1-weighted images and high signal intensity on T2-weighted images representing CSF; Type III, no distinct rim; and Type IV, mixed type. They found MR imaging useful in delineating the tumor-brain interface in most cases, but their study is limited by the poor spatial resolution of the low-tesla unit. Takeguchi’s group evaluated the meningioma-brain interface on NE 2D FLAIR and CE T1-weighted images in addition to conventional T1- and T2-weighted images and found low signal intensity of the rim on T1WI and high intensity on T2WI in 70% of cases. The rim exhibited iso- to high signal intensity on FLAIR and showed enhancement effect on CE T1WI. Although they performed no histological correlation, they considered that the rim might reflect the capsule structure of meningiomas.
To our knowledge, no studies have evaluated the meningioma-brain interface using 3D FLAIR sequences on a 3T MR imaging system. It must be noted that the characteristics of “rim-NE” and “rim-CE” differ on 3D FLAIR. The grade of “rim-NE” correlated positively with the amount of connective tissue observed at the meningioma-brain interface histologically and negatively with tumor-brain adhesion. These results indicate that “rim-NE” represents connective tissue that separates the tumor from the brain like a capsule, as previous studies have suggested. Therefore, a lower grade of “rim-NE” may suggest tumor infiltration beyond the connective tissue at the tumor-brain interface. It also helps to explain the correlation between the grade of histological malignancy and the grade of “rim-NE” because atypical meningiomas tend to show tumor infiltration beyond the connective tissue at the tumor-brain interface.

In contrast to “rim-NE,” “rim-CE” showed no such correlation to predict tumor-brain adhesion and histological tumor grading. However, in this study, “rim-CE” correlated significantly with the presence of a dual (dural and pial) vascular supply revealed by DSA. The frequent observation of peripheral enhancement of meningioma on 2D FLAIR has been reported in tumors exceeding 2 cm in diameter, and this has been attributed to a dual vascular supply, which is common in larger meningiomas. Because FLAIR imaging is more sensitive than T1WI to lower concentrations of gadopentetate dimeglumine, a rim of high signal intensity in meningioma would represent the area supplied by pial arteries, which have lower concentrations of gadolinium than the highly vascularized central part supplied by meningeal arteries. Our study evaluated the correlation between 3D FLAIR and DSA but also showed the dual vascular supply in cases with “rim-CE,” which supports the hypotheses of previous studies with 2D FLAIR. Although we could not identify the structure “rim-CE” represents, we speculate it is the interstitial gap at the tumor-brain interface where gadolinium...
Peritumoral brain edema is frequently seen in meningioma and reported to be correlated with tumor size, mechanical factors such as tumoral compression of the adjacent parenchyma, histological type, blood supply to the tumor, and level of vascular endothelial growth factor (VEGF). Based on surgical and histological findings in previous studies, changes in the tumor-brain interface may play a fundamental role in producing edema in meningioma. Tumor infiltration into adjacent brain parenchyma and a pial-cortical blood supply are considered critical factors for the development of peritumoral brain edema in meningioma. Our study showed the correlation of a lower grade of “rim-NE” on 3D FLAIR with peritumoral brain edema, possibly indicating tumor infiltration into the surrounding brain tissue at the tumor-brain interface. In addition, a higher grade of “rim-CE,” possibly suggesting pial-cortical blood supply, was correlated with a higher grade of peritumoral brain edema with marginal significance. These findings agree with those of previous studies. However, multiple other factors can be associated with the production of peritumoral brain edema. Histological subtype is associated with brain edema; some reports indicate the prominence of peritumoral edema in uncommon WHO Grade I meningiomas, including angiomatic, microcystic, secretory, and lymphoplasmacyte-rich meningiomas. In our results, the number of special histological subtypes of meningioma is too small (2 secretory meningiomas) to investigate an association with peritumoral brain edema. Further examination is required to understand the exact pathogenesis of this association.

Our study is limited because we could not precisely compare rim patterns with surgical results using an image-guided neurosurgery navigation system. So, the site in which “rim-NE” is absent may not necessarily be the site of tumor adhesion. We also did not correlate 3D FLAIR images with conventional T1WI and T2WI, and we could not compare them with conventional 2D images because the rim on 3D FLAIR images is often too thin to be delineated on 2D images. Moreover, peritumoral brain edema could not be well differentiated from the rim on conventional 2D images alone.

Conclusion

“Rim NE” on NE 3D FLAIR is useful for predicting surgical cleavability between the meningioma-brain interface and for histological grading of meningioma. A higher grade of “rim-CE” in meningioma on CE 3D FLAIR suggests pial supply to the tumor but is not useful for predicting tumor-brain adhesion and histological tumor grading.

References


Fig. 8. Bar graph showing the relationship between histological tumor grading and rim patterns. Low grade “rim-NE,” a rim with relatively low signal intensity on nonenhanced 3-dimensional fluid-attenuated inversion recovery (NE 3D FLAIR), was more often seen in atypical tumors than in benign tumors (P = 0.003). “Rim-CE,” a rim with relatively high signal intensity on contrast-enhanced (CE) 3D FLAIR, showed no such correlation (P = 0.759).
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