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Clinical commentary

Differentiating meningioma grade by imaging features on magnetic resonance imaging

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ABSTRACT

Atypical meningioma has an aggressive clinical course. Distinguishing atypical from benign meningioma preoperatively could affect surgical planning and improve treatment outcomes. In this study, we examined whether pre-operative magnetic resonance imaging (MRI) features could distinguish between benign and atypical meningioma. Imaging factors analyzed included peritumoral edema, the presence of a draining vein, tumor necrosis, tumor location and tumor volume. Using univariate analysis, the most striking predictor of grade was tumor volume ($p < .001$). When adjusting for the degree of peritumoral edema, volume remained a positive predictor of higher histological grade meningioma ($p = .042$) and was the strongest single predictor of higher-grade meningioma in this study. Additional imaging features associated with increased risk for atypical pathology in univariate analysis included the presence of tumor necrosis ($p = .012$), peritumoral edema ($p = .022$) and location along the falx and convexity ($p = .026$). Despite statistically significant associations using univariate analysis, in multivariate analysis, we found that only presence of peritumoral edema was predictive of a higher-grade meningioma. Further multivariate analyses suggests that edema, draining vein and necrosis are all positive predictors of tumor volume ($p < .0001$). Overall, these data suggest that radiographic features including presence of tumor necrosis, and tumor location along the falx or convexity may be predictive of higher-grade meningioma when considered alone. However, most strikingly, our data point to tumor volume as the most robust pre-operative indicator of higher-grade meningioma.

1. Introduction

The World Health Organization (WHO) classifies meningioma into WHO I, which are typical or benign (88–94%), WHO II, which are atypical (5–7%) and WHO III, which are anaplastic or malignant (1–2%). WHO II/III tumors are far more likely to recur than benign meningioma, even when resected completely, and often require adjuvant radiation [1]. Previous studies have not found a single specific criterion predictive of atypical meningioma, despite an impressive battery of studies examining clinical presentation, imaging results, and immunohistochemical studies. The power of many of these studies has been limited by both a small sample size and the significant overlap in presenting features of benign and atypical meningioma [2]. Classic magnetic resonance imaging (MRI) features of meningioma, such as enhancement, low signal on T1, high signal on T2, and a dural tail, are seen in the majority of meningiomas, and have not been shown to be predictive of higher histological grade [3–6].

The ability to differentiate between WHO I and WHO II/III meningiomas prior to treatment has potentially profound clinical utility. Typically, patients with radiographically detected meningioma are either observed or undergo surgical resection. Surgical treatment is usually recommended for patients with neurologic symptoms, large tumors, and/or associated cerebral edema. However, patients with more aggressive WHO II/III meningiomas could benefit from early resection even in the absence of these clinical and radiographic features. In addition, information regarding potential tumor grade could be useful intraoperatively as surgeons frequently face decisions regarding the risks and benefits of more aggressive surgical resection of tumor-adjacent tissue potentially involved with microscopic tumor. It is our hope that these data will

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provide insight into expectant clinical management of patients with suspected meningioma.

Herein, we performed a series of analyses on a panel of imaging characteristics thought to play a role in tumor grade. In addition, we developed a multivariate approach for separating benign from atypical meningioma utilizing standard MRI findings and clinical demographics using a relatively large cohort of patients with surgically resected meningioma. We hypothesize that these multivariate models, which combine clinical features with imaging features of tumor necrosis, peritumoral brain edema, an identifiable draining vein, and tumor volume will provide cogent information to the practicing neurosurgeon necessary to better predict tumor histology preoperatively.

2. Methods

2.1. Patient cohort

The authors performed a retrospective review of 173 patients with histologically confirmed WHO grade I and II meningioma, who were imaged with MRI at our institution from 1998 to 2010. The patients were identified via a screen of the electronic medical record using a search for CPT codes used to define craniotomies for resection of meningioma. These patients were derived from a retrospective research database, and patients without adequate preoperative imaging were excluded. Predictive factors related to atypical meningioma, including patient age and sex, tumor pathology, and imaging features were collected from the electronic medical record and analyzed. All meningiomas were histologically graded after surgical resection by a board-certified neuropathologist according to WHO guidelines. Exclusion criteria included artifacts on MRI making images not interpretable, single-plane post contrast images only, and intraventricular tumor location. Only patients with WHO grade I and II tumors were included; one WHO grade III patient was excluded. 45 patients in total were excluded due to the aforementioned criteria, leaving 128 patients in total.

2.2. Imaging classification

Pre-operative MRI, performed with similar protocols, confirmed tumor location. A 1.5 Tessla MRI (Philips Achieva Dual Nova with R2.6-3.6 software level. Best, the Netherlands) was used to scan 102 patients. A 3-Tessla (T) MRI (Philips Achieva Dual Quasar with R2.6-3.6 software level) was used to scan 26 patients. All patients received intravenous gadolinium contrast (gadopentetate dimeglumine, Wayne, New Jersey, USA) administered at 0.1 mmol per kilogram. Two board-certified neuroradiologists, who were blinded to clinical history or pathologic grade, reviewed the pre-operative T2-weighted and post-contrast, T1-weighted sequences. MRI images were evaluated for tumor location, the presence and extent of edema surrounding the tumor, the presence of draining veins, and whether the tumor had central necrosis. Peritumoral edema was graded using the following scale: (0) No edema: absence of increased T2 signal surrounding the meningioma. (1) Mild edema: rim or crescent of increased T2 signal surrounding the meningioma without mass effect. (2) Moderate edema: more extensive increased T2 signal surrounding the meningioma without mass effect. (3) Severe edema: mass effect from edema and/or tongues of advancing edema. Tumor location was grouped in the following categories: (1) Convexity (including frontal, parietal, temporal, lateral sphenoid wing, and petrous) (2) Skull base (including sellar/-suprasellar/anterior clinoid, cavernous/medial sphenoid wing, and fovea ethmoidalis) (3) Falx (4) Posterior fossa (including tentorium, cerebellum, and cerebellar pontine angle). Tumor volume was calculated using manual tracing of multiple planes in the IMPAX imaging viewer, depending on anatomical location of the tumor, using predetermined standards in the IMPAX software.

2.3. Statistics

Univariate and multivariate statistical analysis was performed to determine imaging risk factors associated with atypical (WHO grade II) meningioma. In order to determine the association between risk factors and grade, we used a binary logistic regression model with grade as the outcome variable and edema, draining vein, and necrosis as the independent variables. We fit a separate logistic model to determine the association between location and grade. We also used another multivariate model to investigate the association between tumor volume and edema, draining vein and necrosis.

3. Results

The final study cohort included 128 patients (Table 1). Mean age at the time of meningioma diagnosis was 55 years (range 18–87 years). On histological grading at surgical resection, 94 patients had WHO grade I tumors and 34 patients had WHO grade II tumors (Table 1). Gender ($p = .072$), race ($p = .47$), age at diagnosis ($p = .76$) and presence of a draining vein ($p = .079$) were not significantly different between patients with benign and atypical meningioma (Table 1).

Presence of tumor necrosis observed on MRI was associated with an increased risk for atypical meningioma ($p = .012$) (Table 1). Seven (7%) patients with WHO grade I tumors and eight (24%) patients with WHO grade II tumors had necrosis. Peritumoral edema was also predictive of atypical meningioma in our cohort ($p = .022$). Twenty-one (64%) of patients with atypical meningioma had severe peritumoral edema If peritumoral edema was present, the degree of edema was positively correlated with higher grade. Strikingly, by univariate analysis, overall tumor volume was the strongest predictor of atypical meningioma ($p < .001$) (Table 1). Examples of tumors displaying varying degrees of edema, draining vein, necrosis and grade can be seen in Fig. 1.

Tumors along the falx and convexity were more often atypical than skull base or posterior fossa tumors ($p = .026$) (Table 1). Tumors along the falx were also more likely to display peritumoral edema. Of the 58 convexity tumors, 19 (32.8%) were WHO Grade II. Of the 24 skull base meningioma, six (25%) were WHO Grade II. Of the 26 falcine meningioma, 9 (34.6%) were WHO Grade II. None of the 20 posterior fossa tumors were WHO Grade II. These data are listed in Table 1. Degree of peritumoral edema and presence of necrosis by tumor location are listed in Table 2. Overall, these data suggest that meningioma in the posterior fossa are more likely to be benign, while tumors originating in the falx/convexity were more likely to be atypical ($p = .026$).

Next, we utilized multivariate analyses to ascertain the strength of association between pre-operative imaging features and atypical pathology. In the first multivariate model, edema was the only positive predictor of grade when controlled by presence of draining vein and tumor necrosis (Table 3). Thus, despite univariate models predicting presence of necrosis to be a predictor of tumor grade, when other pre-operative imaging features are controlled for, edema emerges as the only statistically significant predictor of grade ($p = .037$, Table 3). Further, univariate analysis revealed that tumor volume was the strongest predictor of atypical meningioma ($p < .001$, Table 1). We noted that peritumoral edema, draining vein and necrosis were predictors of higher volume tumors ($p < .001$, Table 4).

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