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ABSTRACT

BACKGROUND AND PURPOSE: Meningiomas are very commonly diagnosed intracranial primary neoplasms, of which the chordoid subtype is seldom encountered. Our aim was to retrospectively review preoperative MR imaging of intracranial chordoid meningiomas, a rare WHO grade II variant, in an effort to determine if there exist distinguishing MR imaging characteristics that can aid in differentiating this atypical variety from other meningioma subtypes.

MATERIALS AND METHODS: Ten cases of WHO grade II chordoid meningioma were diagnosed at our institution over an 11-year span, 8 of which had preoperative MR imaging available for review and were included in our analysis. Chordoid meningioma MR imaging characteristics, including ADC values and normalized ADC ratios, were compared with those of 80 consecutive cases of WHO grade I meningioma, 21 consecutive cases of nonchordoid WHO grade II meningioma, and 1 case of WHO grade III meningioma.

RESULTS: Preoperative MR imaging revealed no significant differences in size, location, signal characteristics, or contrast enhancement between chordoid meningiomas and other meningiomas. There were, however, clear differences in the ADC values and normalized ADC ratios, with a mean absolute ADC value of $1.62 \pm 0.33 \times 10^{-3}$ mm^2/s and a mean normalized ADC ratio of $2.22 \pm 0.47 \times 10^{-3}$ mm^2/s in chordoid meningiomas compared with mean ADC and normalized ADC values, respectively, of $0.88 \pm 0.13 \times 10^{-3}$ mm^2/s and $1.17 \pm 0.16 \times 10^{-3}$ mm^2/s in benign WHO grade I meningiomas, $0.84 \pm 0.11 \times 10^{-3}$ mm^2/s and $1.11 \pm 0.15 \times 10^{-3}$ mm^2/s in nonchordoid WHO grade II meningiomas, and 0.57×10^{-3} mm^2/s and 0.75×10^{-3} mm^2/s in the 1 WHO grade III meningioma.

CONCLUSIONS: Chordoid meningiomas have statistically significant elevations of ADC and normalized ADC values when compared with all other WHO grade I, II, and III subtypes, which enables reliable preoperative prediction of this atypical histopathologic diagnosis.

ABBREVIATIONS: NADC = normalized ADC; WHO = World Health Organization

Meningiomas are the second most common primary intracranial neoplasm, constituting approximately 13%–25% of such tumors.[1] There are 15 variants of meningioma according the 2007 World Health Organization (WHO) classification of tumors of the central nervous system.[2] Although 80%–90% of meningiomas are classified as benign WHO grade I tumors, WHO grade II and III varieties demonstrate a more aggressive clinical course and have a greater propensity for recurrence, and the grade and extent of original resection accounts for these differences.[3] Ideally, preoperative imaging to identify the potentially more aggressive grade II and III varieties would be helpful for presurgical planning and subsequent imaging follow-up. One such rare variant is the WHO grade II chordoid meningioma. A little more than 100 cases of chordoid meningioma have been described in the English-language literature, the majority of which are in the pathology and neurosurgery literature.[4-9]

Attempts to distinguish benign from atypical and malignant meningiomas have been undertaken with variable results, and DWI and ADC values have provided the most reliable means of differentiation,[10,11] though no data analysis specifically examining the chordoid morphologic variant has been performed. To the best of our knowledge, only 3 case reports in which the MR imaging characteristics of chordoid meningiomas were described have been published in the radiology literature.[12-14]

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We compared 8 cases of intracranial chordoid meningioma to 80 consecutive cases of WHO grade I meningioma, 21 consecutive cases of nonchordoid WHO grade II meningioma, and 1 WHO grade III meningioma in an effort to determine if there exist distinguishing MR imaging characteristics that can aid in differentiating this particular subtype.

MATERIALS AND METHODS

This was a retrospective institutional review board–approved study.

Case Selection

Ten cases of histologically proven WHO grade II chordoid meningioma were diagnosed at our institution from August 2002 through December 2012. We performed a retrospective review of the preoperative MR imaging of 8 patients. Two patients were excluded from our analysis, 1 because of intraspinal tumor location and 1 because of a lack of available preoperative imaging. All the patients maintained routine neurosurgical clinic and imaging follow-ups at our institution.

Using an institutional neuropathologic database, we compared these chordoid meningiomas to 80 consecutive cases of WHO grade I meningioma, 21 consecutive cases of WHO grade II (nonchordoid) meningioma, and a single case of WHO grade III meningioma for which preoperative MR imaging was performed at our institution with the appropriate imaging sequences available for comparison. Subtypes of WHO grade I meningioma included 38 meningothelial, 15 transitional, 12 fibroblastic, 5 microcystic, 4 angiomatous, 3 secretory, 2 metaplastic, and 1 lymphoplasmacyte-rich meningioma. Nonchordoid WHO grade II meningioma subtypes included 20 atypical and 1 clear-cell meningioma. The single case of WHO grade III meningioma was of the anaplastic subtype.

MR Imaging Protocol

Five MR examinations were performed at our institution, and 3 patients received preoperative imaging at outside institutions. MR imaging at our institution was performed by using our institutional standard tumor protocol with conventional acquisition of fast spin-echo T1-weighted imaging, fast spin-echo T2-weighted imaging, T2-weighted FLAIR imaging, contrast-enhanced T1-weighted imaging after administration of an intravenous Gd-DTPA contrast agent (0.1 mmol/kg), and DWI. DWI scans at our institution were acquired before contrast by using single-shot multisection spin-echo echo-planar imaging with fat saturation, b values of 0 and 1000 s/mm^2, 4- to 5-mm-thick sections with 0.5- to 1.0-mm gaps, a field of view of 220–230 mm, a minimum matrix size of 128 × 128, and minimal TE. Processing of the ADC maps was performed automatically on the MR scanners by using the diffusion-weighted (b=0 and b=1000) images. Outside studies were uploaded to our PACS for review and consisted of at least fast spin-echo T1-weighted, T2-weighted, T2-weighted FLAIR, and post–contrast-enhanced T1-weighted images. DWI was obtained from 1 of the 3 outside studies.

Data Analysis

The patient age at diagnosis, sex, and clinical follow-up data were obtained via the institution's electronic medical record. Three investigators (J.B.P., T.G.M., and D.B.M.) evaluated the MR imaging by consensus reading. Images were analyzed for tumor location, size (maximal axial dimension), T1 and T2/FLAIR signal characteristics, peritumoral edema, enhancement characteristics, cystic necrosis, bone changes, restricted diffusion, ADC values, and normalized ADC (NADC) ratios. Signal characteristics were classified as hypointense, isointense, or hyperintense compared with normal gray matter. Enhancement characteristics were classified as homogeneous or inhomogeneous. Tumoral ADC values were measured by 2 investigators (J.B.P. and T.G.M.) directly from the PACS workstation in units of × 10^{-3} mm^2/s by using manual freehand regions of interest to include the entirety of the tumor in the axial section demonstrating the greatest tumor diameter, with exclusion of any calcification or cystic necrosis. NADC ratios were calculated by using the formula NADC = tumor ADC/control ADC. Control ADC values were obtained from contralateral normal white matter. ADC maps were available for 4 of the 8 chordoid meningiomas and for all of the included WHO I, II, and III tumors. Intraclass correlation coefficients were calculated to determine interrater reliability of the measured ADC values of the chordoid meningiomas. Generalized linear model and Tukey-Kramer method analyses were used to compare ADC values and NADC ratios across all the histologic subtypes. Follow-up MR imaging was performed on all 8 patients at various intervals as deemed appropriate by the neurosurgical providers and retrospectively reviewed for evidence of tumor recurrence by the 3 principal investigators.

RESULTS

The 8 patients with chordoid meningioma consisted of 6 women and 2 men. Age at diagnosis ranged from 34 to 66 years (mean age, 47 years). The presenting symptoms were variable and included headache, visual disturbance, seizure, altered mental status, and gait instability. A frontal/parietal convexity location was most prevalent, occurring in 4 patients. The remaining tumors were located along the sphenoid wing, tentorium cerebelli, parasagittal region, and at the foramen magnum. In 3 cases, preoperative MR imaging revealed the presence of multiple meningiomas. Of these cases, none proved on subsequent histopathologic analysis to be multifocal chordoid meningioma but rather a single chordoid meningioma in the presence of other WHO grade I meningiomas.

The preoperative MR imaging characteristics of chordoid meningiomas, WHO grade I meningiomas, nonchordoid WHO grade II meningiomas, and WHO grade III meningiomas are summarized in On-line Tables 1, 2, 3, and 4, respectively.

Evaluation of the signal characteristics of chordoid meningioma revealed mild hyperintensity to gray matter on T2 FLAIR imaging in all cases, 7 of the 8 tumors demonstrated T1 isointensity to gray matter, and 6 of the 8 tumors demonstrated avid homogeneous contrast enhancement (Fig 1). The 2 tumors that showed avid inhomogeneous enhancement did so as a result of cystic necrosis. Two patients had marked peritumoral edema on T2 FLAIR imaging, 1 patient had trace peritumoral edema, and the remaining patients had no appreciable edema. Involvement of the adjacent calvaria with extension into the orbit was seen in 1 patient.

Evaluations of DWI revealed variable signal intensities. No restricted diffusion was identified in any chordoid meningioma;

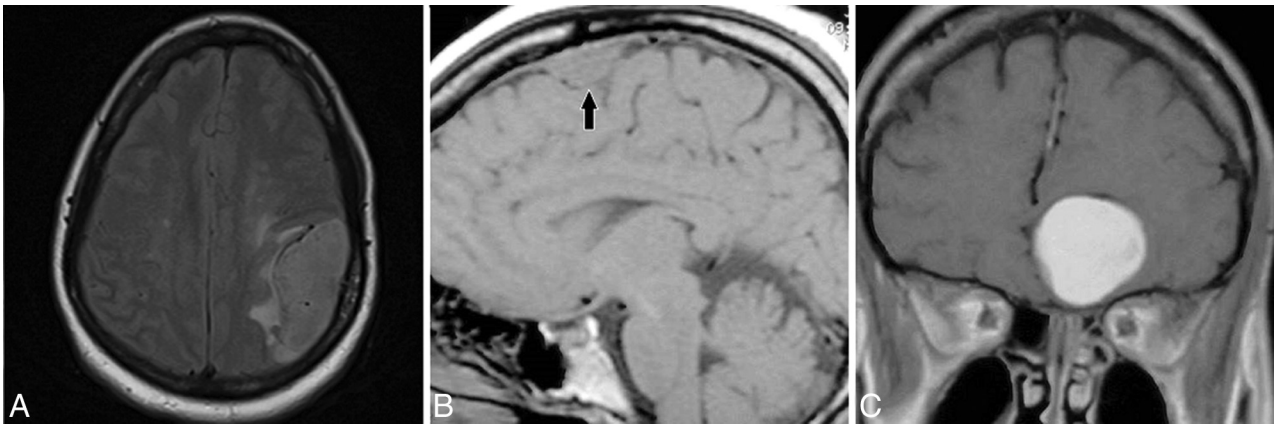

FIG 1. Three different cases of chordoid meningioma show the characteristic T1, T2 FLAIR, and postcontrast T1 appearances, which are similar to those of other meningioma subtypes. *A,* T2-weighted FLAIR image shows slight hyperintensity to gray matter with mild surrounding edema. *B,* T1-weighted image shows isointensity of the chordoid meningioma (*arrow*) to gray matter. *C,* Contrast-enhanced T1-weighted image shows avid homogeneous enhancement of the meningioma.

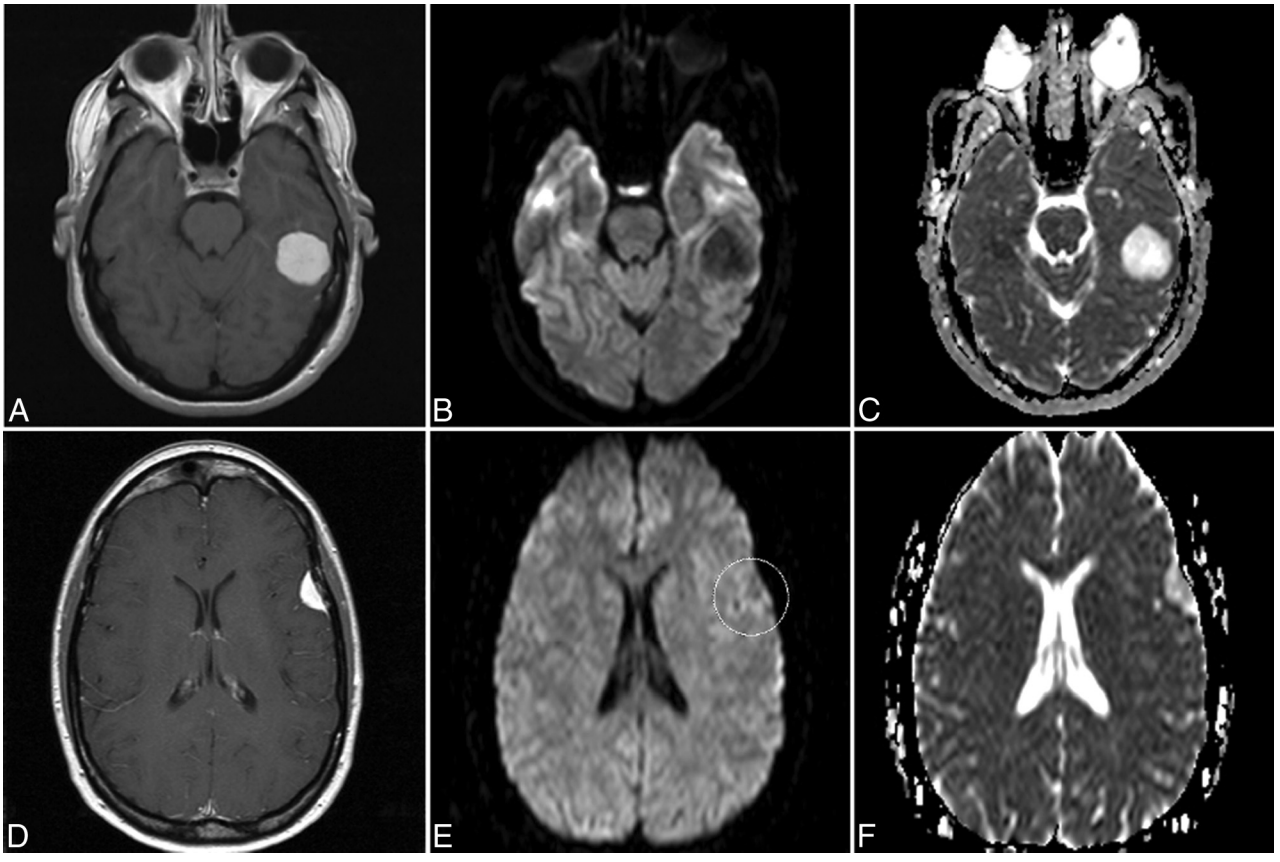

FIG 2. Chordoid meningioma shows facilitated diffusion. *A,* Postcontrast T1-weighted image showing avid homogeneous enhancement of a left temporal chordoid meningioma. *B,* DWI shows hypointensity of this chordoid meningioma. *C,* ADC map corresponding to the tumor shown in *B* depicting hyperintensity of the meningioma with an ADC value of 2.11 and an NADC ratio of 2.93, which represent increased diffusion. *D,* Postcontrast T1-weighted image of a different patient shows avid homogeneous enhancement of a left frontal convexity chordoid meningioma. *E,* DWI of this tumor shows isointensity to slight hypointensity of the tumor. *F,* ADC map corresponding to tumor shown in *E* shows increased signal of the meningioma with an ADC value of 1.47 and an NADC ratio of 1.99, which are consistent with facilitated diffusion.

rather, increased signal was present on the ADC map in each case, which is consistent with facilitated diffusion (Fig 2). The outside study from which absolute ADC values could not be obtained revealed relative hyperintensity within the tumor compared with the contralateral unaffected white matter, in keeping with facilitated diffusion.

Each patient underwent surgery in which total meningioma resection was achieved. Follow-up scans were performed in each case. One patient experienced recurrent disease at the site of surgical resection 3 years after resection; however, subsequent surgery and histopathologic evaluation of this lesion revealed a WHO grade I meningothelial meningioma. To date,

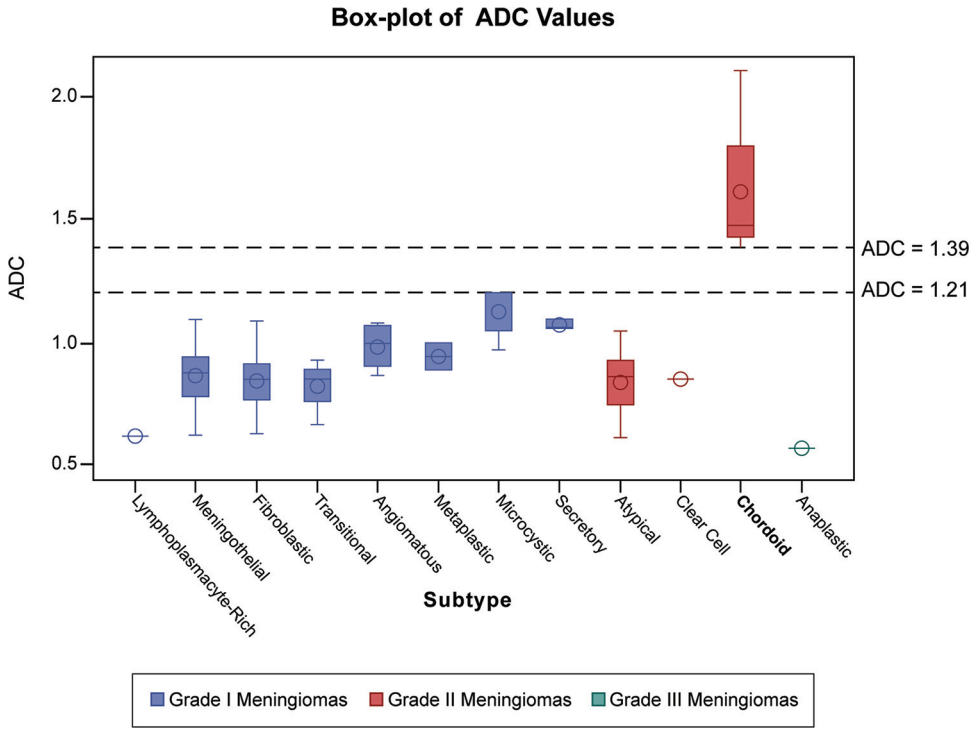

FIG 3. Boxplot of the ADC values of all WHO grade I, II, and III meningiomas shows that chordoid meningiomas have significantly higher ADC values than all other subtypes, and there is a clear gap between the lowest chordoid meningioma ADC and the highest ADC from all other subtypes.

no recurrent chordoid meningiomas have occurred in our patient cohort.

The MR imaging characteristics of chordoid meningioma compared with those of WHO grade I, II, and III meningiomas revealed no significant differences in size, location, signal characteristics, or contrast enhancement. In addition, the presence and degree of peritumoral edema and the involvement of the adjacent calvaria were variable, which did not allow for reliable differentiation between histologic subtypes. There were, however, clear differences in the ADC values (Fig 3) and NADC ratios (Fig 4), with a mean absolute ADC value of $1.62 \pm 0.33 \times 10^{-3}$ mm^2/s and a mean NADC ratio of $2.22 \pm 0.47 \times 10^{-3}$ mm^2/s in chordoid meningiomas compared with mean ADC and NADC values, respectively, of $0.88 \pm 0.13 \times 10^{-3}$ mm^2/s and $1.17 \pm 0.16 \times 10^{-3}$ mm^2/s in benign WHO grade I meningiomas, $0.84 \pm 0.11 \times 10^{-3}$ mm^2/s and $1.11 \pm 0.15 \times 10^{-3}$ mm^2/s in nonchordoid WHO grade II meningiomas, and 0.57×10^{-3} and 0.75×10^{-3} mm^2/s in the 1 case of WHO grade III meningioma. The intraclass correlation coefficient of measured ADC values between the raters was 0.996 (95% confidence interval, 0.938–0.999). Statistical analyses of the absolute ADC values and NADC ratios by using the generalized linear model and the Tukey-Kramer method revealed a statistically significant difference between chordoid meningiomas and all other WHO grade I, II, and III subtypes (all pair-wise *P* values, <.01). ADC and NADC cutoff values of 1.39 and 1.93, respectively, enable the distinction of the chordoid variant.

DISCUSSION

Our analysis demonstrates an MR imaging characteristic of the chordoid meningioma subtype that clearly differentiates it from all other subtypes, with statistically significant increases in the ADC value and NADC ratio of the chordoid meningioma. Greater diffusivity, as demonstrated by elevated ADC values, was seen consistently in all the chordoid meningiomas in our review, and there was a clear gap between the lowest chordoid meningioma value and the highest values of all other subtypes. No other MR imaging characteristic reliably enabled distinction among the subtypes.

The hypothesized basis for these results is the unique tumoral architecture and cytologic features of the chordoid subtype. Differences in extracellular matrix, cell density, and the nucleus-to-cytoplasm ratio have been shown to contribute to the diffusivity of water as detected on diffusion-weighted imaging.[15-17] Microscopic evaluation of the chordoid meningioma subtype reveals epithelioid cells with some degree of cytoplasmic vacuolization, which form cords in a pale basophilic mucoid matrix rich in hyaluronic acid and chondroitin sulfate.[8] This mucoid extracellular matrix is unique to the chordoid subtype among the histopathologic meningioma variants. The presence of the mucoid stroma results in relatively free extracellular water motion, which is in keeping with multiple studies in which elevated ADC values were found in other tumors that are composed of myxoid stroma, such as chordomas, chondrosarcomas, and myxoid soft-tissue tumors.[18,19] In addition, a component of cell vacuolization resulting in a decreased nucleus-to-cytoplasm ratio likely contributes further to an increase in the diffusivity of water in these tumors.

Our findings differ from previously published data which reveal that atypical WHO grade II/III meningiomas show decreased ADC values consistent with a greater degree of restricted diffusion

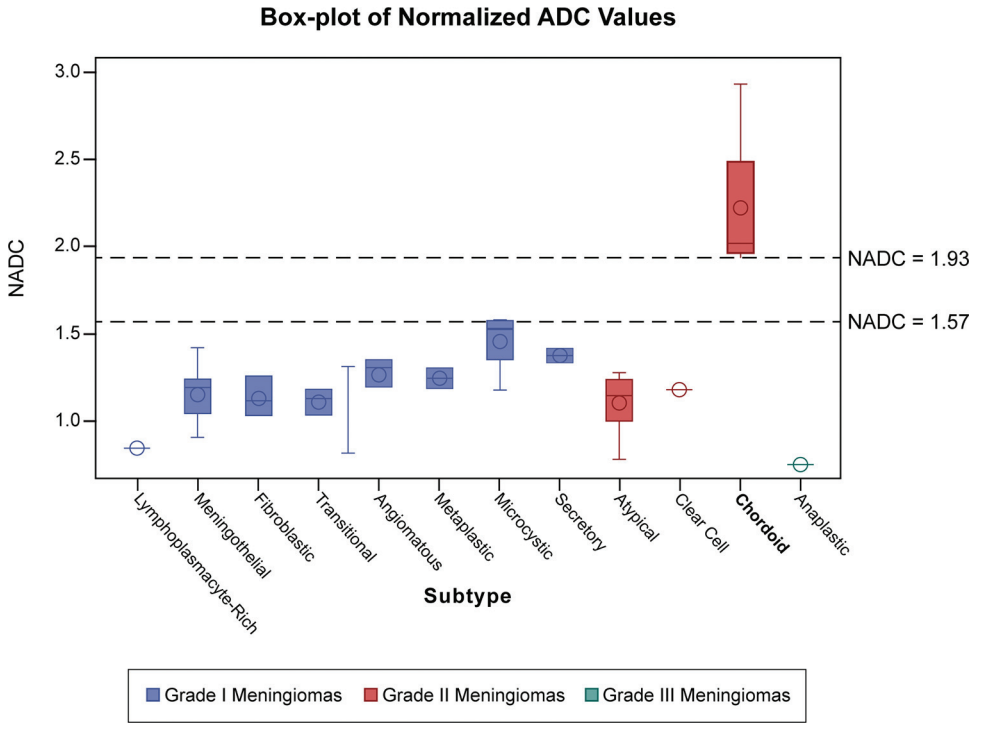

FIG 4. Boxplot of the NADC ratios of all WHO grade I, II, and III meningiomas shows that chordoid meningioma tumors have significantly higher NADC ratios than all other subtypes, and there is a clear gap between the lowest chordoid meningioma NADC ratio and the highest NADC ratio from all other types.

compared with that of typical WHO grade I meningioma subtypes.[10,11,20] It should be noted that these previous studies included fewer cases and that none included the chordoid variant. To our knowledge, ours is the largest case study to date and included 12 of the 15 meningioma variants, with the only subtype in our analysis demonstrating statistically significant differences in ADC values being the chordoid meningioma; these ADC values were elevated, not decreased, compared with those of typical WHO grade I meningiomas and all other subtypes. Potential explanations for these apparently contradictory results include the exclusion of the chordoid variant among these other studies and the lack of significant numbers of WHO grade III subtypes in our study. Our single WHO grade III anaplastic tumor demonstrated restriction with a markedly reduced ADC value, and it might be hypothesized that if a greater number of WHO grade III tumors had been included, statistically significantly decreased ADC values among these tumors could have been identified.

The primary limitation of this study is the small sample size of chordoid meningiomas. Given its rarity, only 10 cases of chordoid meningioma were diagnosed at our institution over an 11-year span, and only 4 had ADC maps available for review. However, to our knowledge, our case series includes the largest cohort of patients with chordoid meningioma in the radiology literature and demonstrates a statistically significant difference between ADC values and NADC ratios of the chordoid meningiomas and those of all other variants. An additional potential limitation is the inherent difficulty of measuring ADC values with small tumors and those near air-bone interfaces; however, this does not seem to be a limiting factor in our analysis, because we demonstrated very high interobserver reliability.

The clinical implications of our findings are significant in that surgical planning may be altered if the chordoid meningioma subtype can be reliably identified on preoperative MR imaging. The extent of resection is largely predictive of recurrence rates, especially with atypical meningiomas. This seems to hold especially true in the case of the chordoid variant. In the Couce et al[8] study of 42 chordoid meningiomas, all 13 meningiomas that underwent subtotal resection recurred, whereas only 1 of the 29 meningiomas that underwent total resection recurred. In our review, all 8 chordoid meningiomas were totally resected with no evidence of recurrence, further demonstrating the importance of total resection of this variant. If the extent of disease precludes total resection, knowledge of this subtype's propensity to recur should initiate a more rigorous imaging and clinical follow-up regimen.

CONCLUSIONS

Preoperative identification of atypical meningioma variants, such as chordoid meningioma, would be beneficial for treatment planning and follow-up surveillance. Our review revealed statistically significant elevations in ADC and NADC values of chordoid meningiomas when compared with those of all other WHO grade I, II, and III subtypes, with threshold values of 1.39 and 1.93, respectively, which enables reliable presurgical prediction of this atypical histopathologic diagnosis.

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