A New Method for Discriminating Cerebellar Tumors From Each Other: Algorithmic Approach

Serebellar Tümörleri Birbirinden Ayırt Etmek İçin Yeni Bir Yöntem: Algoritmik Yaklaşım

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Abstract

Objective	To evaluate the MR imaging findings of the cerebellar tumors (CT) in adults and to make an algorithm to discriminate these tumors from each other. **(Sakarya Med J 2019, 9(2):281-288)**
Materials and Methods	Adult patients with CT who were treated surgically were included. Brain MRs and patient records were evaluated for pathological diagnosis, imaging findings and Ki-67 labeling index. The apparent diffusion coefficient (ADC) values of the tumors and centrum semiovale (CS) and the ratio of each other were noted. Kruskal-Wallis test was used for comparison.
Results	100 adults (45 women, 55 men with a mean age of 46.6±15.6 years) with pathologically proven CT were included. Tumors were divided into five groups as: a. primitive neuro-ectodermal tumor (PNET) + medulloblastoma (MB), b. grade 3+4 gliomas, c. grade 1+2 gliomas, d. metastasis (MET) and e. lymphoma. The ratio of the mean ADC (x10-3 mm2/s) of the tumor to those of CS was 1.210.22, 1.38±0.93, 1.98±0.69, 1.48±0.45 and 1.25±0.11 for PNET&MBs, grade 3+4 gliomas, grade 1+2 gliomas, METs and lymphomas, respectively. Significant difference was detected between grade 1+2 gliomas and PNET&MB (P=0.018), MET (P=0.004) and lymphoma (P=0.002).
Conclusion	CT in adults might be differentiated from each other by using some MR imaging clues and patient characteristics.
Keywords	Apparent diffusion coefficient; cerebellum; cerebellar tumors; magnetic resonance

Öz

Amaç	*Erişkinlerde serebellar tümörlerin (ST) MR görüntüleme bulgularını inceleyip birbirlerinden ayrım için algoritmik yaklaşım oluşturabilmek.* ***(Sakarya Tıp Dergisi 2019, 9(2):281-288)****.*
Gereç ve Yöntemler	*Çalışmaya, cerrahi olarak tedavi edilmiş ST'li erişkin hastalar dahil edildi. Beyin MR'leri ve hasta kayıtları patolojik tanı, görüntüleme bulguları ve Ki-67 indeksi açısından tarandı. Tümöre ve sentrum semiovale (SS)'ye ait görünür difüzyon katsayıları (GDK) ile birbirlerine oranları hesaplandı. Karşılaştırma için Kruskal-Wallis testi kullanıldı.*
Bulgular	*Çalışmaya yaş ortalaması 46.6±15.6 yıl olan 100 (45 kadın, 55 erkek) ST'li hasta dahil edildi. Tümörler 5 gruba ayrıldı: a. primitif nöroektodermal tumor (PNET)+medulloblastom (MB) b. evre 3+4 gliomlar, c. evre 1+2 gliomlar, d. metastaz (MET) ve e. lenfoma. PNET&MB, evre 3+4 gliomlar, evre1+2 gliomlar, MET and lenfomalara ait ortalama ST/SS GDK (x10-3 mm2/s) değerleri sırasıyla1.21±0.22, 1.38±0.93, 1.98±0.69, 1.48±0.45 and 1.25±0.11. Evre 1+2 gliomlar ve PNET&MB'ler (P=0.018), MET (P=0.004) ve lenfomalar (P=0.002) arasında anlamlı fark vardı.*
Sonuç	*Erişkinde ST'ler bazı MR ipuçları ve hasta özellikleri ile birbirlerinden ayırt edilebilir.*
Anahtar Kelimeler	*Görünür difüzyon katsayısı; manyetik rezonans; serebellum; serebellar tümörler*

INTRODUCTION

Posterior fossa tumors are relatively rare in adults in contrast to pediatric age group and a posterior fossa tumor in an adult have a very diverse differential diagnosis list. Metastasis is by far the most common posterior fossa tumor in adults. Lung, breast, renal and colon cancers, melanoma are the most frequent primary tumors to metastasize to cerebellum like the cerebrum.[1] And the incidence of metastases is gradually increasing because of the rise in the survival of the cancer patients.[2,3] When metastases are excluded, primary cerebellar tumors (CT) in adults are rare central nervous system (CNS) neoplasias.

Although magnetic resonance (MR) imaging is a pivotal technique for diagnosing and following CTs like the other CNS tumors, in contrast to histological assessment, it gives restricted information with respect to tumor classification and grading.[4] Location, enhancement pattern, signal intensity and edema on MRI, give valuable information about the CTs. However, although a definite preoperative diagnosis is crucial, making a distinction between various CTs is difficult and imaging findings usually interfere with different tumor types. In the current study, we aimed to evaluate MR imaging findings and patient charactheristics of the CTs in adults and to make an algorithm to discriminate these tumours from each other.

MATERIALS and METHODS

The local Institutional Review Board (IRB) approved the current retropective study and informed consent was waived for this type of study. A retrospective assessment of our case records was performed to define adult patients with CTs who were treated between February 2004 and September 2014. A total of 100 adult patients with pathologically proven CTs were included in the study. There were 45 women and 55 men with a mean age of 46.1 years (range 18-77 years), harboring 3 pilocytic astrocytomas (PA), 11 hemangioblastomas (HB), 5 high grade gliomas (HGG), 13 medulloblastomas (MB), 4 epandimomas (EP), 4 low grade gliomas (LGG), 2 gliosarcomas (GS), 2 cavernomas (CA), 2 Lhermitte Duclos diseases (LDD), 4 primary brain lymphomas, 1 primitive neuro-ectodermal tumor (PNET) and 49 metastases (MET) (Table 1). All MR images were obtained by a 1.5 T system (Magnetom Vision, Siemens, Erlangen, Germany) with a standard head-coil.

Table 1. Histopathologically proven cerebellar tumors

Tumor type	Number of patients
Metastasis	49
Medulloblastoma	13
Hemangioblastoma	11
High grade glioma	5
Low grade glioma	4
Epandimoma	4
Primary brain lymphoma	4
Pilocytic astrocytoma	3
Gliosarcoma	2
Cavernoma	2
Lhermitte Duclos disease	2
Primitive neuroectodermal tumor	1

Age and gender distribution according to tumor types were given at Table 2.

Table 2. Characteristics of patients according to the tumor types.

Tumor type	< 45 years old Number of patients		> 45 years old Number of patients	
	Female	Male	Female	Male
PNET+MB	1	10	1	1
Glial 3+4	2	3	1	1
Glial 1+2	11	8	5	2
MET	8	3	10	28
Lymphoma	0	0	4	0

Extra-axial posterior fossa tumors, brain stem tumors and patients without pathological diagnosis were excluded. Imaging findings and patient records were retrospectively evaluated for pathological diagnosis, enhancement pattern (none, homogeneous, heterogeneous, tiny and mural), homogeneity on T2-weighted (T2W) images, location, morphology (cystic, solid and mixt), signal void vessels,

peri-tumoral edema, ascending or descending herniation, number of lesions and existence of supra-tentorial lesion. Ki-67 labeling index was analyzed in 33 patients and values greater and lower than 10% were accepted as high and low index, respectively.

The minimum, maximum and mean apparent diffusion coefficient (ADC) values of the tumors were noted in 62 patients and the mean ADC values of the centrum semiovale (CS) were also recorded as a control. Three region of interests (ROIs) were hand drawn on the center of the solid part of the tumor and on the normally-appearing ipsilateral CS. Final ROI was placed on the tumor covering the whole borders. The ratio of the mean ADC of the tumor to the mean ADC of the centrum semiovale was calculated. We divided patients into five groups in order to compare the ADC values and ratios as; group 1: PNET and MB, group 2: HGG and GS (World Health Organisation (WHO) grade 3 and 4 gliomas), group 3: LDD and PA (WHO grade 1 and grade 2 gliomas), group 4: MET and group 5: lymphoma.

Statistical Analysis

Mean ± standard deviation, minimum and maximum values were used to describe the quantitative variables. Also, frequency and percentages are given for the nominal data. Normality assumption was checked by Shapiro Wilk's test and it was found that data do not conform to normal distribution. Therefore, comparisons of quantitative variables among five-diagnostic groups were assessed with the non-parametric Kruskal Wallis test. Conover-Dunn multiple comparison test was used after a significant Kruskal Wallis test. Distribution of categorical variables was compared among groups with the Pearson Chi-square analysis, Fisher's exact test or Fisher-Freeman-Halton's test. Also, nonparametric classification and regression tree approach was used to identify variables discriminating diagnose groups. For all analyses the IBM-SPSS version 21.0 was used and the statistical significance was set at $P<0.05$.

RESULTS

5 cerebellar tumors (1 LGG, 2 LDDs and 2 CAs) were not enhancing on MR. The remained 3 LGGs were enhancing of which, 2 tumors had tiny and one tumor had heterogeneous enhancement. There were 5 tumors with homogeneous enhancement including 4 lung cancer metastases and one grade 2 EP. Heterogeneously enhanced tumors were 74 in number. All HGGs, all MBs and both GSs, 3 of the EPs, all lymphomas, one LGG, one PA, one PNET and 47 of the METs had heterogeneous enhancement. All HBs had mural enhancement as expected. 2 of the 3 PAs had mural enhancement and the other one heterogeneously enhanced.

74 heterogeneously enhanced tumors had all heterogeneous signal intensity on T2 weighted images. 15 tumors (6 METs, 3 lymphomas, 3 MBs, 2 HBs and 1 GS) had bilateral cerebellar involvement. Left cerebellar involvement was noted in 38 patients and in 43 patients right cerebellar hemisphere was involved. 4 patients had only vermian masses and involvement of both vermian and one of the cerebellar hemispheres was noted in 18 patients (7 METs, 6 MBs, 2 GSs 1 lymphoma, 1 EP and 1 LDD).

4 pure cystic lesions were all lung cancer metastasis (3 non-small cel carcinoma, 1 small cell carcinoma). Of the remaining 96 cerebellar tumors, 70 were solid masses and 26 were mixt tumors. 30 METs and 11 MBs were solid in nature. All PAs and HBs were mixt (solid-cystic) type tumors except one solid PA.

Signal voids on T2 weighted images, were not seen in 89 tumors. 4 out of 5 HGGs, 1 GS, 1 HB, 1 PNET, 1 MB, 2 LDDs and 1 MET had signal void vessels on T2 weighted images. However, on histo-pathological evaluation 23 tumors had vascularity (8 HBs, 4 HGGs, 4 MBs, 2 GSs, 2 PAs, 1 CA, 1 LGG and 1 PNET,).

15 tumors (3 PAs, 4 HBs, 3 EPs, 1 MB, 2 LDDs and 1 LGG) had no peri-tumoral edema. 6 out of 11 HBs had at least

minimal edema. All metastases and all MBs had peri-tumoral edema.

Descending tonsillar herniation was noted in 17 patients (7 METs, 4 HBs, 2 MBs, 1 LGG, 1 LDD, 1 lymphoma and 1 PNET). There were only 2 tumors causing ascending herniation, one of them was GS and the other one was LDD. 1 HB provoked both ascending and descending herniation.

17 tumors having multiple cerebellar masses of which 12 tumors were metastasis. The remaining 5 tumors which were also multiple in number, 3 masses were primary cerebellar lymphoma and 2 masses were HB. 27 patients had both infra- and supra-tentorial parenchymal lesion. 20 METs, 3 MBs, 1 GS, 1 EP, 1 HGG and 1 lymphoma comprised additional supra-tentorial lesion. 1 lymphoma and 2 METs had additional supra-tentorial meningeal involvement.

Analysis of Ki-67 labeling index revealed low index values for all LGGs, half of the HGGs/GSs and 42.9% of the PNET/MBs and high index values for all of the lymphomas, half of the HGGs/GSs and 35.7% of the PNET/MBs. The minimum, maximum and mean ADC values of the cerebellar tumors were summarized in Table 3. The ratio of the mean ADC (x10-3 mm2/s) of the tumor to the mean ADC of the centrum semiovale was 1.21 (±0.22), 1.38 (±0.93), 1.98 (±0.69), 1.48 (±0.45) and 1.25 (±0.11) for PNET&MBs, grade 3+4 gliomas, grade 1+2 gliomas, METs and lymphomas, respectively (Table 3).

The mean ADC ratio of the tumor to the centrum semiovale, was statistically significant for differentiating the grade 1+2 gliomas from PNET&MB (P=0.018), MET (P=0.004) and lymphoma (P=0.002) (Figure 1). However, the mean ADC ratio of the tumor to the centrum semiovale, was not statistically significant for differentiating grade 1+2 gliomas from grade 3+4 gliomas (P=1.00).

Table 3. The minimum, maximum and mean ADC values of the cerebellar tumors and centrum semiovale also the mean ADC ratios of both.

ADC value	PNET+MB	Glial 3+4	Glial 1+2	MET	Lymphoma
Minimum	248 (±214)	220 (±213)	565 (±429)	333 (±215)	324 (±189)
Maximum	872 (±833)	900 (±1010)	1423 (±896)	1238 (±902)	941 (±542)
Mean	474 (±414)	451 (±472)	982 (±631)	743 (±476)	661 (±376)
Centrum semiovale	421 (±371)	326 (±340)	525 (±321)	546 (±322)	542 (±310)
The mean ratio	1.20 (±0.22)	1.38 (±0.09)	1.98 (±0.69)	1.48 (±0.45)	1.25 (±0.11)

DISCUSSION

ADC in the brain tissue reflects tissue cellularity as quantified by intracellular volume fraction and extracellular volume fractions.5 The current study demonstrated that the highest cellularity was detected for PNET&MB, followed by lymphoma as indicated by the mean ADC ratios of the tumor to the centrum semiovale. In order to differentiate grade 1+2 cerebellar gliomas from PNET&MB, MET and lymphoma, mean ADC ratios may be useful. However, differentiation of PNET&MB, MET, lymphoma and grade 3+4 gliomas from each other was difficult and the difference of the mean ADC ratios was not statiscally significant. In order to make an algorithm (Figure 2) for discriminating cerebellar tumors by the findings of the current study; first of all, homogeneity was assessed and patients were divided into two groups as having heterogeneous (74 cases)

or homogeneous masses (26 cases) on T2W images. Then, patients with homogeneous tumors were further divided into two groups as solid and mixt type tumors or cystic tumors according to the tumor nature. The 4 cystic tumors which were also homogeneous masses were all metastasis. The remaining 22 cases included 21 glial 1+2 tumors and 1 MB. That MB case could be easily differentiated from others by means of the mean ADC ratios.

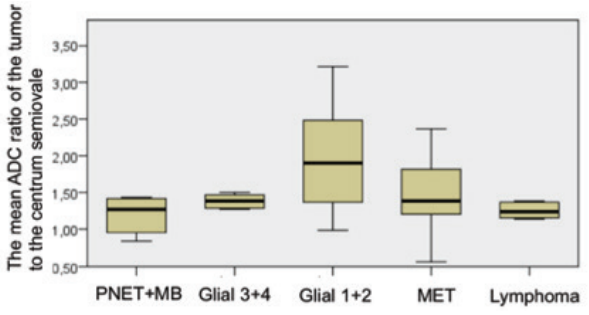

Figure 1. Box plot diagram obtained from Kruskal-Wallis test, shows the distribution of the mean ADC ratios of the tumor to the centrum semiovale for five groups (PNET+MB, glial 3+4 tumors, glial 1+2 tumors, MET, lymphoma).

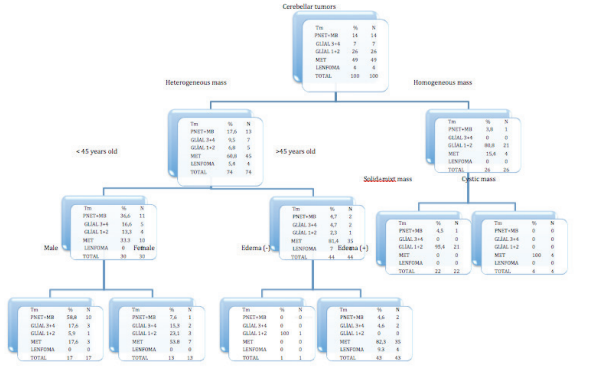

Figure 2. The algorithm for discriminating cerebellar tumors by the findings of the current study.

Patients with heterogeneous tumors were divided into two groups as patients younger (30 cases) and older (44 cases) than 45 years old. And the older group was further divided into two groups as tumors with peri-tumoral edema (43 cases) and tumors with no peri-tumoral edema (1 case). The latter tumor was a grade 2 EP. Patients older than 45 years old and having heterogeneous tumors with at least minimal peri-tumoral edema were all possessing highly malignant tumors with poor prognosis either metastasis (35 cases; 81.3%) or primary cerebellar lymphoma (4 cases; 9.3%) or PNET+MB (2 cases; 4.6%) or grade 3+4 glioma (2 cases; 4.6%).

Younger group of patients who had heterogeneous tumors were further divided into two groups as male (17 cases) and female gender (13 cases). On one hand, male patients with heterogeneous cerebellar tumors who were younger than 45 years old, had most commonly PNET+MB (10 cases; 58.8%) followed by MET (3 cases; 17.6%), glial 3+4 tumor (3 cases; 17.6%) and glial 1+2 tumor (only 1 case; 5.9%). On the other hand, female patients with heterogeneous cerebellar tumors who were also younger than 45 years old, had most commonly MET (7 cases; 53.8%) followed by glial 1+2 tumors (3 cases; 23%), glial 3+4 tumors (2 cases; 15.3%), PNET+MB (only 1 case; 7.6%).

Metastases were by far the most frequent tumor type in this series as expected. List of primary malignancies is given at Table 4.

Table 4. List of primary malignancies

Primary malignancy	Number of patients
Non-small cell lung carcinoma	16
Small cell lung carcinoma	12
Ductal carcinoma	10
Renal cell carcinoma	4
Adenocarcinoma	3
Malign melanoma	1
Prostate cancer	1
Choriocarcinoma	1
Gastric neuroendocrine tumor	1

Classically brain metastases are well-defined lesions and multiple in number with marked edema on MR and that

finding can cause hydrocephalus, ascending and descending herniation, brain stem compression and death.[6] In this series, majority of the cerebellar metastases, except 4 pure cystic lesions and 2 tumors with homogeneous enhancement, had heterogeneous enhancement and all of them showed at least minimal peri-tumoral edema. One of the small cell lung cancer metastases was composed of a smooth margin-cyst with an heterogeneously enhancing mural nodule.

PA is a common cerebellar tumor in children but in contrast, rarely develops and has a worse prognosis and higher mortality rate in adults[7,8] Two PAs (2/3) in this series, had a large cyst with an homogeneously enhancing mural nodule and the remaining PA was a solid tumor reflecting the general imaging patterns.[7] Our patients had a mean age of 26.6 years and in all cases peri-tumoral edema was not detected.

HB is a common intracranial vascular tumor in von Hippel-Lindau disease but, it may also arise without the presence of that disease in the cerebellum.[9,10] In the current study, two of eleven patients with HB had von Hippel-Lindau disease and bilateral cerebellar tumors. All of the HBs were composed of a smooth-margin cyst and a homogeneously enhancing mural nodule. Up to 60-70% of hemangioblastomas may have prominent signal voids[9,11] but in our series only 9% (1/11) of the cases had signal void on T2 weighted images.

HGGs representing WHO grade 3 and grade 4 gliomas, are frequent intracranial tumors however, cerebellar localization is very rare.[12-16] They usually arise in the fifth or sixth decade of life and our five HGG cases had a mean age of 42.4 years. Although the most common diffential diagosis for all cerebellar mass lesions is metastasis, in 80% of the HGG cases in this series, signal void vessels were detected at the periphery of the tumor and that finding may suggest HGG in the cerebellum. Differentiation of HGGs from metastasis or MB or lymphoma by means of the mean ADC values and ratios was not statistically significant. MR spectroscopy and perfusion which were not used in the current study, may be utilized for discrimination of HGGs from other differential diagnoses.[16]

MB is the most common malignant tumor in the posterior fossa in children however, it is rare in adults and have different imaging characterictics.[17-19] MBs in children most often arises from the vermis but in contrast, adult MB tends to occur at the cerebellar hemispheres.[18,19] All MBs in this series, were located at one of the cerebellar hemispheres (off-lateral origin) and 4 cases had additional vermian involvement. In only one case, signal void was noted and peri-tumoral edema was not detected in another case. All MBs were heterogenous masses and had heterogenous enhancement.

Although 4th ventricule is a prevalent location for infratentorial EPs, cerebellar hemispheres may also be the origin.[20] There is no sex propensity[21], but in this series all four EPs were female. 3 EPs heterogenously enhanced and the remaining had homogenous enhancement. Glial fibrillary acidic protein (GFAP) was positive in 75% of the cases (3/4). Peri-tumoral edema was not noted for 3 EPs and in only one case, minimal edema was detected.

Primary cerebellar LGGs are rare.[22] Absence of enhancement is generally the rule for LGGs however, tiny enhancement may be encountered. Nevertheless, an enhancement in a brain tumor should be regarded as an alarming sign for progression and in this series, 75% of the LGGs (3/4) had tiny or heterogeneous enhancement. The number of the patients were very insufficient in the current study but cerebellar LGGs may demonstrate enhancement either tiny or heterogeneous, more frequently than the supra-tentorial ones. In other words, cerebellar LGGs may have a more tendency to enhancement than supra-tentorial LGGs. That point is remained to be validated with larger number of samples.

GS is a type of glioblastoma composed of glial and additional sarcomatous components. They are highly aggressive tumors and commonly arise from the supra-tentorial cortex.[23,24] Primary cerebellar GS is very rare and our 2 cases (21 and 39 years of age) showed heterogenous enhancement with predominant peri-tumoral edema and vermian involvement on MR. They all demostrated necrosis, high vascularity, mitosis rate and Ki-67 labeling index values on pathological examination.

LDD is a rare benign slowly growing cerebellar tumor which is a hamartoma actually, also called dysplastic cerebellar gangliocytoma. MR imaging findings including striation and high T2 signal in cerebellum, enlargement of the involved hemisphere and vermis without enhancement, thickened folia without destruction are pathognomonic and there is no need to histopathological assessment for definitive diagnosis.[25,26] Our two cases had high ADC values as described in the literature.[27] However, we have noted signal void vessels within the involved cerebellum in both patients and that point was not discussed before. One of the LDD had calcification on CT and caused ascending herniation while the other case induced descending tonsillar herniation.

In the current study, all primary cerebellar lymphomas were women in contrast to supra-tentorial primary CNS lymphoma cases in which male predominancy is seen.[28] Supratentorial location is found in 75%-85% of the lymphoma cases and primary cerebellar origin is very rare.[29] As it is well-known, it is a highly cellular tumor, the reason for low ADC values and all tumors in this series showed heterogenous enhancement with high Ki-67 labeling indexes indicating high proliferation. 3/4 of the lymphoma cases had multiple cerebellar masses.

There were several limitations in our study. First of all, a larger number of patients is necessary to end up with firm conclusions about differentiation of cerebellar mass lesions. The relatively small number of patients in this series is due to our rigid exclusion criteria. Secondly, advanced MRI techniques, besides diffusion-weighted imaging which was performed in some of the patients, were not obtained for each patient. Third, because only the mass lesions of the cerebellum were involved within the study, the most common pathology or space occupying lesion of the cerebellum and also a mimicker of tumors; stroke or infarction was not mentioned in the study. However, despite these limitations, we argue that the current study overviewed and has important implications regarding discrimination of cerebellar tumors in adults.

In conclusion, cerebellar tumors in adults may be differentiated from each other by using some MR imaging clues and patient characteristics.

References

1. *Burger PC, Scheithauer BW. Tumors of the Central Nervous System (Afip Atlas of Tumor Pathology) 1 st ed. Washington; 2007.*
2. *Norden AD, Wen PY, Kesari S. Brain metastases. Curr Opin Neurol 2005;18:654-661.*
3. *Sharma V, Prabhash K, Noronha V, Tandon N, Joshi A. A systematic approach to diagnosis of cystic brain lesions. South Asian J Cancer 2013;2:98-101.*
4. *Rumboldt Z, Camacho DL, Lake D, Welsh CT, Castillo M. Apparent diffusion coefficients for differentiation of cerebellar tumors in children. AJNR Am J Neuroradiol 2006;27:1362-1369.*
5. *Provenzale JM, Mukundan S, Barboriak DP. Diffusion-weighted and perfusion MR imaging for brain tumor characterization and assessment of treatment response. Radiology 2006;239:632-649.*
6. *Ghods AJ, Munoz L, Byrne R. Surgical treatment of cerebellar metastases. Surg Neurol Int 2011;2:159.*
7. *Koeller KK, Rushing EJ. From the archives of the AFIP: pilocytic astrocytoma: radiologic-pathologic correlation. Radiographics 2004;24:1693-1708.*
8. *Johnson DR, Brown PD, Galanis E, Hammack JE. Pilocytic astrocytoma survival in adults: analysis of the Surveillance, Epidemiology, and End Results Program of the National Cancer Institute. J Neurooncol. 2012;108:187-193.*
9. *Bonneville F, Sarrazin JL, Marsot-Dupuch K, Iffenecker C, Cordoliani YS, Doyon D, et al. Unusual lesions of the cerebellopontine angle: a segmental approach. Radiographics 2001;21:419-438.*
10. *Slater A, Moore NR, Huson SM. The natural history of cerebellar hemangioblastomas in von Hippel-Lindau disease. AJNR Am J Neuroradiol 2003;24:1570-1574.*
11. *Ho VB, Smirniotopoulos JG, Murphy FM, Rushing EJ. Radiologic-pathologic correlation: hemangioblastoma. AJNR Am J Neuroradiol 1992;13:1343-1352.*
12. *Kulkarni AV, Becker LE, Jay V, Armstrong DC, Drake JM. Primary cerebellar glioblastomas multiforme in children. Report of four cases. J Neurosurg 1999;90:546-550.*
13. *Demir MK, Hakan T, Akinci O, Berkman Z. Primary cerebellar glioblastoma multiforme. Diagn Intervent Radiol 2005;11:83-86.*
14. *Gopalakrishnan CV, Dhakoji A, Nair S, Menon G, Neelima R. A retrospective study of primary cerebellar glioblastoma multiforme in adults. J Clin Neurosci 2012;19(12):1684-1688.*
15. *Katz DS, Poe LB, Winfield JA, Corona RJ, Jr. A rare case of cerebellar glioblastoma multiforme in childhood: MR imaging. Clin Imaging 1995;19:162-164.*
16. *Kuroiwa T, Numaguchi Y, Rothman MI, Zoarski GH, Morikawa M, Zagardo MT, et al. Posterior fossa glioblastoma multiforme: MR findings. AJNR Am J Neuroradiol 1995;16:583-589.*
17. *Partap S, Curran EK, Propp JM, Le GM, Sainani KL, Fisher PG. Medulloblastoma incidence has not changed over time: a CBTRUS study. J Pediatr Hematol Oncol 2009;31:970-971.*
18. *Rodallec M, Colombat M, Krainik A, Kalamarides M, Redondo A, Feydy A. Diffusion-weighted MR imaging and pathologic findings in adult cerebellar medulloblastoma. J Neuroradiol 2004;31:234-237.*
19. *Koeller KK, Rushing EJ. From the archives of the AFIP: medulloblastoma: a comprehensive review with radiologic-pathologic correlation. Radiographics 2003;23:1613-1637.*
20. *Koeller KK, Sandberg GD, Armed Forces Institute of P. From the archives of the AFIP. Cerebral intraventricular neoplasms: radiologic-pathologic correlation. Radiographics 2002;22:1473-1505.*
21. *Prince MR, Chew FS. Ependymoma of the fourth ventricle. AJR Am J Roentgenol 1991;157:1278.*
22. *Sanai N, Chang S, Berger MS. Low-grade gliomas in adults. J Neurosurg 2011;115:948-965.*
23. *Kozak KR, Mahadevan A, Moody JS. Adult gliosarcoma: epidemiology, natural history, and factors associated with outcome. Neuro Oncol 2009;11:183-191.*
24. *Pakos EE, Goussia AC, Zina VP, Pitouli EJ, Tsekeris PG. Multi-focal gliosarcoma: a case report and review of the literature. J Neuro Oncol 2005;74:301-304.*
25. *Meltzer CC, Smirniotopoulos JG, Jones RV. The striated cerebellum: an MR imaging sign in Lhermitte-Duclos disease (dysplastic gangliocytoma). Radiology 1995;194:699-703.*
26. *Kulkantrakorn K, Awwad EE, Levy B, Selhorst JB, Cole HO, Leake D, et al. MRI in Lhermitte-Duclos disease. Neurology 1997;48:725-731.*
27. *Wei G, Zhang W, Li Q, Kang X, Zhao H, Liu X, et al. Magnetic resonance characteristics of adult-onset Lhermitte-Duclos disease: An indicator for active cancer surveillance? Mol Clin Oncol 2014;2:415-420.*
28. *Kiewe P, Loddenkemper C, Anagnostopoulos I, Reinwald M, Thiel E, Korfel A. High-dose methotrexate is beneficial in parenchymal brain masses of uncertain origin suspicious for primary CNS lymphoma. Neuro Oncol 2007;9:96-102.*
29. *Ayuso-Peralta L, Orti-Pareja M, Zurdo-Hernandez M, Jimenez-Jimenez FJ, Tejeiro-Martinez J, Ricoy JR, et al. Cerebral lymphoma presenting as a leukoencephalopathy. J Neurol Neurosurg Psychiatry 2001;71:243-246.*