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REVIEW ARTICLE

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Exploring the unknown: rare primary brain tumors — diagnosis and treatment

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ABSTRACT

Rare primary brain tumors constitute a heterogeneous and clinically significant group of neoplasms that, despite comprising only 1–2% of all primary brain tumors, present unique diagnostic and therapeutic challenges. This review highlights the complexities associated with these tumors, encompassing their classification, diagnosis, and management. The introduction of molecular diagnostics by the 2021 WHO classification has revolutionized the understanding of these tumors, enabling precision medicine and tailored treatments.

Key findings include the importance of advanced imaging modalities, such as MRI and CT, coupled with histopathological and molecular studies for accurate diagnosis. A multidisciplinary approach remains central to management, with surgical resection as the cornerstone of treatment, often complemented by radiotherapy and, in some cases, chemotherapy. The review underscores the emerging role of targeted therapies, such as BRAF and mTOR inhibitors, which have shown promise in specific tumor subtypes.

Prognostic factors, including tumor grade, genetic mutations, extent of resection, and patient age, critically influence outcomes. While low-grade tumors like gangliogliomas demonstrate excellent survival rates following complete resection, high-grade tumors, such as medulloblastomas and pineoblastomas, necessitate aggressive multimodal treatments. Despite progress, significant gaps in knowledge persist, highlighting the need for large-scale research initiatives to refine diagnostic and therapeutic strategies further.

This study concludes by emphasizing the importance of personalized, patient-centered care and the need for continued innovation and collaboration in neuro-oncology. By addressing these challenges, the field can advance the understanding and management of rare primary brain tumors, ultimately improving patient outcomes and quality of life.

Keywords: rare primary brain tumors, molecular diagnostics, neuro-oncology, multidisciplinary treatment, targeted therapies

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Introduction

Primary brain tumors constitute a heterogeneous group of neoplasms originating from cells within the central nervous system (CNS). They represent approximately 2% of all human cancers. Gliomas form the largest subgroup, accounting for about 75% of primary brain tumors in adults. Among primary brain tumors, a smaller group of rare tumors exists, comprising only 1–2% of all primary brain tumors.

In 2021, the World Health Organization (WHO) introduced a new classification system for primary brain tumors, incorporating not only histological features but also molecular diagnostics. Although primary brain tumors constitute a small percentage of all malignant neoplasms, they have significant clinical relevance due to their location and potential impact on neurological functions. The diagnosis of these tumors requires advanced imaging techniques, such as magnetic resonance imaging (MRI) and computed tomography (CT), along

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with precise histopathological and molecular studies. Treating brain tumors is complex and often necessitates a multidisciplinary approach, including surgical interventions, radiotherapy, chemotherapy, and novel targeted therapies like immunotherapy [1].

The purpose of this paper is to review the characteristics, diagnostic challenges, and treatment strategies associated with rare primary brain tumors. The following research questions are addressed:

1. What are the diagnostic challenges in identifying rare primary brain tumors?
2. How does molecular and histopathological progress influence the management and treatment of these tumors?
3. What prognostic factors are critical in improving patient outcomes and quality of life?

Further research is essential to enhance our understanding of the biology of primary brain tumors and develop more effective therapeutic strategies, ultimately improving treatment outcomes and the quality of life for patients.

Rare brain tumors

Tumors of glial origin

Pilocytic astrocytoma

Pilocytic astrocytoma (PA) is a slow-growing, low-grade tumor (commonly classified as grade 1). It predominantly affects children and adolescents and is mainly located in the brainstem and cerebellar hemispheres. In adults, this tumor is rare, most often found supratentorially, and has a poorer prognosis compared to pediatric cases. Approximately 27% of these tumors are located in the cerebellum, 30% in the cerebral hemispheres, and others in the optic nerves (manifesting as optic nerve gliomas) [2].

Due to its slow growth, the clinical symptoms vary widely. Common presentations include epilepsy, hemiparesis, cranial nerve dysfunction, or signs of increased intracranial pressure such as headaches, nausea, and vomiting. Diagnosis is based on CT or MRI and confirmed through histopathological analysis from surgical biopsies. Approximately 15% of patients may have an *NF1* mutation, and the *KIAA1549-BRAF* fusion, which activates the *BRAF* gene, is frequently observed. The primary treatment is surgical resection, which may be complemented with radiotherapy or stereotactic radiotherapy. Chemotherapy, including agents like temozolomide or bevacizumab, is primarily used in cases involving optic nerve gliomas or pediatric populations. Bevacizumab has demonstrated potential for achieving prolonged responses [3–5].

Astroblastoma (MN1-altered)

Astroblastoma is a rare supratentorial tumor predominantly affecting young women between the ages of 10 and 30. The symptoms resemble those of other slow-growing tumors and typically include headaches, seizures, and focal neurological deficits. Astroblastomas are most frequently located in the frontal and parietal lobes. Molecular diagnostics often reveal *MN1* gene rearrangements on chromosome 22q12.1. Diagnosis is based on MRI and histopathological analysis from surgical specimens. Due to its rarity, there is no standardized treatment protocol. Surgical resection is the primary approach for both low-grade and high-grade tumors. Radiotherapy is commonly recommended for high-grade tumors or recurrent cases. The role of chemotherapy remains under investigation. Ten-year survival rates exceed 50% for many patients [3, 6–8].

Chordoid glioma

Chordoid gliomas are intermediate-grade tumors as per the WHO classification, and are typically located in the anterior third ventricle. They most often affect middle-aged individuals, with a female-to-male ratio of 2:1. Symptoms usually include headaches, visual disturbances, neurological deficits, and difficulty walking. Additional manifestations may be associated with dysfunctions of the thalamus or pituitary gland. Diagnosis is based on CT or MRI scans and confirmed histologically. These tumors are well-circumscribed, sometimes with cystic components. Molecular studies often identify *PRKCA* mutations. Surgical resection is the mainstay treatment, though partial resection may be necessary for tumors near critical structures such as the hypothalamus and optic chiasm. Postoperative radiotherapy or stereotactic radiotherapy is frequently employed to improve outcomes. Complete resection is associated with an excellent prognosis. Chemotherapy is not typically used [3, 9–18].

Pleomorphic xanthoastrocytoma

Pleomorphic xanthoastrocytoma (PXA) is a rare tumor that predominantly affects young adults (second to third decade of life) but can also occur in children. It is usually an intermediate-grade tumor (WHO grade 2), with 15–20% of cases classified as high-grade (WHO grade 3). PXAs are most often located supratentorially, particularly in the temporal lobes, but can also occur infratentorially or in the spinal cord. There are no specific symptoms unique to PXAs, but they often present with refractory seizures, headaches, visual disturbances, or paresthesia. Diagnosis is established using MRI or CT imaging and confirmed by histopathological examination. Molecular studies frequently identify *BRAF* mutations

or other *MAPK* pathway alterations, such as fusions in the *BRAF*, *RAF1*, *ALK*, or *ROS1* genes. Surgical resection is the primary treatment, with complete resection offering the best outcomes. For incomplete resections, adjuvant radiotherapy or stereotactic radiotherapy is recommended. High-grade cases may benefit from chemotherapy, including temozolomide or BRAF inhibitors for $BRAF^{V600}$ mutations. Prognosis is generally favorable, with 10-year survival rates of 61% and overall survival of approximately 70% [3, 19–22].

Neuronal tumors

Dysplastic cerebellar gangliocytoma associated with PTEN mutation (Lhermitte-Duclos disease)

Dysplastic cerebellar gangliocytoma (DCG), commonly referred to as Lhermitte-Duclos disease, is a highly differentiated tumor classified as grade 1. It is primarily located in the cerebellar hemisphere and is strongly associated with Cowden syndrome, a genetic condition linked to *PTEN* mutations. This tumor most frequently affects adults aged 20–40 years. Patients commonly present with symptoms such as headaches, ataxia, tremors, and visual disturbances. Magnetic resonance imaging is typically sufficient for diagnosis, as the imaging characteristics of DCG are well-defined. The primary treatment for DCG is surgical resection, which aims to alleviate symptoms and prevent further complications. Radiotherapy and chemotherapy are not used in the management of this tumor due to its benign and well-differentiated nature. Long-term outcomes are favorable if the tumor is adequately resected [3, 23, 24].

Central neurocytoma

Central neurocytoma is an intermediate-grade tumor (WHO grade 2) most commonly found in the lateral ventricles or the third ventricle. It occurs predominantly in adults aged 20-50 years old, and affects men and women equally. The clinical presentation often includes headaches associated with hydrocephalus caused by the obstruction of cerebrospinal fluid flow. Diagnosis relies on imaging studies, including CT or MRI, complemented by a histopathological examination of surgical specimens. Surgical resection is the primary treatment, aiming for complete removal of the tumor. For cases where complete resection is not feasible or in cases of recurrence, adjuvant radiotherapy or stereotactic radiotherapy is recommended. Chemotherapy may be considered in conjunction with radiotherapy, with agents such as temozolomide, lomustine, cisplatin, etoposide, cyclophosphamide, and vincristine showing efficacy in select cases. Ten-year survival rates exceed 80% for patients who receive comprehensive treatment [3, 9–11, 25–31].

Extraventricular neurocytoma

Extraventricular neurocytoma is a rare intermediate-grade tumor (WHO grade 2) that can occur in various locations outside the ventricular system. It predominantly affects young adults around the age of 30, and is much less common than central neurocytoma. Patients with extraventricular neurocytoma typically present with headaches and seizures. Molecular studies reveal *FGFR1:TACC1* fusions in approximately two-thirds of cases. Diagnosis is based on MRI findings and confirmed through histopathological evaluation. The primary treatment is surgical resection, which aims to achieve complete tumor removal. In cases of incomplete resection, adjuvant radiotherapy is recommended. Chemotherapy is generally not utilized for extraventricular neurocytomas due to their relatively indolent nature and limited evidence supporting its efficacy. With appropriate treatment, long-term outcomes are often favorable [3, 9–13, 32–35].

Glioneuronal tumors

Ganglioglioma

Ganglioglioma accounts for 0.5–1% of all primary brain tumors. It primarily affects young individuals, and is most commonly located in the temporal lobe, although it can also occur in other parts of the brain and spinal cord. These tumors are frequently associated with seizures and may lead to drug-resistant epilepsy. The diagnosis of ganglioglioma relies on MRI, with histopathological confirmation performed postoperatively. Surgical resection is the first-line treatment. Complete resection offers excellent outcomes, with 10-year survival rates exceeding 80%. In cases of partial resection, adjuvant radiotherapy is recommended. Chemotherapy is typically reserved for cases with more aggressive features. Temozolomide is the most commonly used agent, and for approximately 30% of patients with *BRAF* mutations (associated with poorer prognosis), targeted therapies such as BRAF and MEK inhibitors can be considered [3, 36–53].

Dysembryoplastic neuroepithelial tumor

Dysembryoplastic neuroepithelial tumor (DNET) is a rare, highly differentiated primary brain tumor typically diagnosed in individuals between 10 and 25 years of age. It most commonly occurs in the temporal lobes, accounting for approximately two-thirds of cases. Patients often present with severe seizures, which may be accompanied by psychiatric disturbances. Diagnosis is established through MRI or CT imaging, with histopathological analysis confirming the findings. Molecular studies frequently reveal *FGFR1* alterations in 75% of patients and $BRAF^{V600E}$ mutations in less than one-third of cases. Surgical intervention is the cornerstone of

treatment. Radiotherapy and chemotherapy are not generally used due to the tumor's low-grade nature. Malignant transformation is exceedingly rare. Active surveillance may be sufficient in cases with indolent behavior. For symptomatic tumors or cases requiring intervention, radiotherapy or chemotherapy (e.g., temozolomide or bevacizumab) can be applied in pediatric populations to improve outcomes. Surgery remains limited to cases where symptom relief is needed or malignant transformation occurs [3, 22, 54–57].

Cerebellar liponeurocytoma

Cerebellar liponeurocytoma is an exceptionally rare tumor of intermediate differentiation, typically located in the posterior fossa, with a preference for the cerebellar hemispheres. It predominantly occurs in adults around the age of 50. Diagnosis relies on imaging techniques such as MRI or CT, which identify the characteristic features of the tumor. Histopathological confirmation is required for definitive diagnosis. Surgical resection is the primary treatment. No standardized treatment protocols exist, but adjuvant radiotherapy may be used in cases of recurrence. Chemotherapy is not indicated for this tumor type. The 10-year survival rate is approximately 70%, provided adequate surgical management [3, 34, 58–61].

Subependymal giant-cell astrocytoma

Subependymal giant-cell astrocytoma (SEGA) is a highly differentiated tumor (grade 1 WHO) commonly associated with tuberous sclerosis complex (TSC). Approximately 10–15% of patients with TSC develop SEGA, but it can also occur sporadically in individuals without TSC. Tuberous sclerosis complex is characterized by mutations in the *TSC1* or *TSC2* genes, leading to hyperactivation of the mTOR signaling pathway and abnormal cellular proliferation. Intracranial manifestations of TSC include cortical tubers, subependymal nodules, and SEGA. Patients frequently present with seizures and may also experience hydrocephalus due to tumor growth. Diagnosis is primarily established using MRI. Surgical intervention is recommended in cases of hydrocephalus or increased intracranial pressure. For non-urgent cases, mTOR inhibitors such as everolimus have become first-line treatments. These agents significantly reduce tumor volume, prevent hydrocephalus, and alleviate seizures while improving other symptoms of TSC. Long-term treatment is often necessary to prevent recurrence. Radiotherapy is rarely used in SEGA due to limited efficacy and potential complications [3, 62–67].

Ependymal tumors

Ependymal tumors originate from ependymal glial cells lining the lateral ventricles and the spinal cord canal. They primarily occur in children and young adults, with two incidence peaks — at ages 5 and 35. In children and adolescents, ependymomas are most commonly found intracranially, whereas in adults, they are more frequently located within the spinal canal. In some cases, ependymomas are associated with neurofibromatosis type 2. According to the WHO grading system, ependymomas are classified into three categories: myxopapillary ependymoma and subependymoma (grade I), classic ependymoma (grade II), and anaplastic ependymoma (grade III). Grade I tumors biologically differ from grade II and III tumors as they do not infiltrate surrounding healthy brain tissue or spinal cord parenchyma, making complete surgical resection a potential cure. Clinically, children with intracranial ependymomas typically present with headaches, nausea, and vomiting, whereas in adults, spinal ependymomas can cause spastic paresis, paresthesia, and pain below the lesion site. Myxopapillary ependymoma, in particular, may present with back pain, perianal or leg pain, bladder dysfunction, and impotence. Diagnosis is based on MRI of the brain or CT of the head, followed by histopathological examination after surgical resection. Several factors negatively impact prognosis before treatment, including higher tumor grade, younger age, male sex, intracranial location, and the inability to achieve gross total resection. Treatment primarily involves surgery, followed by radiotherapy to prevent cerebrospinal fluid (CSF) dissemination. Chemotherapy plays a limited role, though in a small group of patients with recurrent tumors, platinum-based regimens have shown some efficacy, and temozolomide has been used in limited cases with poor response [68–78].

Embryonal tumors

Medulloblastoma

Medulloblastoma is a primary malignant embryonal brain tumor classified as grade 4 according to the WHO. It most commonly arises in the infratentorial region, specifically within the cerebellar hemispheres or the fourth ventricle. It belongs to the group of primary neuroectodermal tumors (PNET). Medulloblastoma is the most common brain tumor in children, accounting for 12–25% of pediatric cases, but it is relatively rare in adults, comprising only 0.4–1% of cases [79].

Medulloblastomas are categorized into the following subtypes:

1) classic medulloblastoma;
2) desmoplastic/nodular medulloblastoma;
3) medulloblastoma with extensive nodularity;
4) anaplastic medulloblastoma;
5) large-cell medulloblastoma.

Patients often present with severe headaches, nausea, and vomiting. Neurological signs such as ataxia or nystagmus may also be observed. In some cases, medulloblastoma is associated with genetic syndromes,

including Gorlin syndrome and Turcot syndrome. Diagnosis is achieved through imaging studies (CT or MRI), and confirmed by histopathological examination of tumor samples. The primary treatment modality is surgical resection, aiming to remove as much of the tumor as possible. Radiotherapy should commence within 4-6 weeks following surgery to avoid deterioration in prognosis; delays beyond this period are associated with poorer outcomes. Proton therapy is an emerging option due to its precision and reduced toxicity. Chemotherapy may be employed as induction therapy or as a neoadjuvant measure following radiotherapy in high-risk patients to reduce the likelihood of recurrence [80–85].

Pineal region tumors

Pineocytoma

Pineocytoma is a highly differentiated tumor that accounts for less than 1% of all primary brain tumors. It predominantly affects adults over the age of 40. Patients typically report symptoms such as headaches, dizziness, and vomiting, often resulting from increased intracranial pressure. The diagnosis is established through CT or MRI imaging, and confirmed by histopathological examination. Treatment involves complete surgical resection of the tumor. Pineocytomas generally have an excellent prognosis when completely removed, with minimal need for adjuvant therapies [70, 86].

Pineoblastoma

Pineoblastoma is a highly aggressive embryonal tumor classified as grade 4 by the WHO. It is a poorly differentiated neoplasm that has two incidence peaks: the first during the first two decades of life and the second before the age of 10. Methylation profiles vary between pediatric and adult cases, suggesting that pediatric pineoblastomas develop de novo, while adult cases may arise from pre-existing pineal parenchymal tumors or normal pineal tissue. Diagnosis is based on MRI or CT imaging and histopathological analysis of the tumor. Treatment involves radical surgery followed by combined radiotherapy and chemotherapy, often incorporating platinum-based agents. Favorable prognostic factors include younger age, the application of radiotherapy, and the absence of metastases. Despite its aggressive nature, a multimodal therapeutic approach can improve survival rates and quality of life [87–89].

Conclusions

The exploration of rare primary brain tumors reveals the complexity and diversity of these neoplasms, which, despite their low prevalence, hold profound clinical significance due to their impact on neurological function and patient outcomes.

Rare primary brain tumors represent a highly heterogeneous group of neoplasms with varying histological and molecular characteristics. This diversity underscores the importance of advanced diagnostic tools, including MRI, CT, and molecular diagnostics, to achieve accurate diagnoses. Histopathological confirmation remains the gold standard for distinguishing these tumors and tailoring treatment strategies.

The integration of molecular diagnostics into tumor classification, as outlined by the 2021 WHO guidelines, has revolutionized the understanding of tumor biology. Key molecular markers, such as *KIAA1549-BRAF* fusion in pilocytic astrocytomas or *PRKCA* mutations in chordoid gliomas, have facilitated precision medicine approaches. These advancements enable clinicians to identify actionable targets, and provide therapies tailored to specific genetic profiles, improving treatment efficacy.

The management of rare primary brain tumors requires a multidisciplinary approach involving neurosurgery, radiology, oncology, and pathology. Surgical resection remains the cornerstone of treatment for most tumor types, with radiotherapy and chemotherapy employed as adjuvant therapies based on tumor grade, location, and molecular characteristics. Emerging modalities, such as proton therapy, hold promise for reducing treatment-related toxicity.

Molecular insights have led to the development of targeted therapies, such as BRAF inhibitors for patients with mutations in the MAPK pathway or mTOR inhibitors for subependymal giant cell astrocytomas. These therapies demonstrate efficacy in specific tumor subtypes, offering hope for improved survival and quality of life. Further research into targeted agents is essential to expand their applicability and effectiveness.

Prognostic factors, including tumor grade, genetic mutations, extent of resection, and patient age, play critical roles in determining outcomes. Complete surgical resection is associated with favorable prognoses in tumors such as gangliogliomas and cerebellar liponeurocytomas. Conversely, high-grade tumors like medulloblastomas and pineoblastomas require aggressive multimodal treatments to mitigate the risk of recurrence.

Despite significant progress, substantial knowledge gaps remain in understanding the biology, progression, and optimal management of rare primary brain tumors. There is a pressing need for large-scale, collaborative research efforts and clinical trials to generate evidence-based treatment protocols. Advances in genomic and proteomic technologies should be harnessed to uncover novel therapeutic targets and improve diagnostic accuracy.

The rarity of these tumors demands an individualized approach to care, incorporating patient preferences, quality-of-life considerations, and access to specialized treatment centers. Improved awareness and education among healthcare professionals are crucial to ensure timely diagnoses and referrals.

To summarize, rare primary brain tumors present a unique and evolving challenge in neuro-oncology. A comprehensive understanding of their molecular and clinical features, combined with a collaborative, multidisciplinary approach to care, is essential to optimize patient outcomes. Continued investment in research and innovation will be instrumental in addressing the unmet needs of this patient population, ultimately advancing the field of neuro-oncology and improving lives.

Article Information and Declarations

Author contributions

E.D.: conceptualization, data search strategy, analysis, drafting of the manuscript; J.T.: preparation of the manuscript; J.Z.: analysis, critical revision of the manuscript; A.K.: analysis, critical revision of the manuscript, supervision.

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Conflict of interest

The authors declare no conflict of interest.

Supplementary material

None.

References

1. Louis DN, Perry A, Wesseling P, et al. The 2021 WHO Classification of Tumors of the Central Nervous System: a summary. Neuro Oncol. 2021; 23(8): 1231–1251, doi: 10.1093/neuonc/noab106, indexed in Pubmed: 34185076.
2. Crocetti E, Trama A, Stiller C, et al. RARECARE working group. Epidemiology of glial and non-glial brain tumours in Europe. Eur J Cancer. 2012; 48(10): 1532–1542, doi: 10.1016/j.ejca.2011.12.013, indexed in Pubmed: 22227039.
3. Crainic N, Furtner J, Pallud J, et al. Rare Neuronal, Glial and Glioneuronal Tumours in Adults. Cancers (Basel). 2023; 15(4), doi: 10.3390/cancers15041120, indexed in Pubmed: 36831464.
4. Dhawan S, Patil CG, Chen C, et al. Early versus delayed postoperative radiotherapy for treatment of low-grade gliomas. Cochrane Database Syst Rev. 2020; 1(1): CD009229, doi: 10.1002/14651858.CD009229.pub3, indexed in Pubmed: 31958162.
5. Zhang L, Li T, Qiao G, et al. Clinical characteristics and long-term surgical outcomes of spinal pilocytic astrocytoma: a report of twenty cases. Acta Neurochir (Wien). 2021; 163(11): 3005–3013, doi: 10.1007/s00701-020-04606-0, indexed in Pubmed: 33037477.
6. Englot DJ, Berger MS, Barbaro NM, et al. Factors associated with seizure freedom in the surgical resection of glioneuronal tumors. Epilepsia. 2012; 53(1): 51–57, doi: 10.1111/j.1528-1167.2011.03269.x, indexed in Pubmed: 21933181.
7. Moazzam AA, Wagle N, Shiroishi MS. Malignant transformation of DNETs: a case report and literature review. Neuroreport. 2014; 25(12): 894–899, doi: 10.1097/WNR.0000000000000184, indexed in Pubmed: 25003949.
8. Mhatre R, Sugur HS, Nandeesh BN, et al. MN1 rearrangement in astroblastoma: study of eight cases and review of literature. Brain Tumor Pathol. 2019; 36(3): 112–120, doi: 10.1007/s10014-019-00346-x, indexed in Pubmed: 31111274.
9. Perkins A, Liu G. Primary Brain Tumors in Adults: Diagnosis and Treatment. Am Fam Physician. 2016; 93(3): 211–217, indexed in Pubmed: 26926614.
10. Franceschi E, Frappaz D, Rudà R, et al. Rare Primary Central Nervous System Tumors in Adults: An Overview. Front Oncol . 2020; 10: 996, doi: 10.3389/fonc.2020.00996, indexed in Pubmed: 32676456.
11. Mesny E, Lesueur P. Radiotherapy for rare primary brain tumors. Cancer Radiother. 2023; 27(6-7): 599–607, doi: 10.1016/j.canrad.2023.06.008, indexed in Pubmed: 37481341.
12. Kubicky CD, Sahgal A, Chang EL, et al. Rare primary central nervous system tumors. Rare Tumors. 2014; 6(3): 5449, doi: 10.4081/rt.2014.5449, indexed in Pubmed: 25276324.
13. Lapointe S, Perry A, Butowski NA. Primary brain tumours in adults. Lancet. 2018; 392(10145): 432–446, doi: 10.1016/S0140-6736(18)30990-5, indexed in Pubmed: 30060998.
14. Liu WP, Cheng JX, Yi XC, et al. Chordoid glioma: a case report and literature review. Neurologist. 2011; 17(1): 52–56, doi: 10.1097/NRL.0b013e3181e7db67, indexed in Pubmed: 21192197.
15. Yang D, Xu Z, Qian Z, et al. Chordoid Glioma: A Neoplasm Found in the Anterior Part of the Third Ventricle. J Craniofac Surg. 2021; 32(3): e311–e313, doi: 10.1097/SCS.0000000000002514, indexed in Pubmed: 28708638.
16. Yao K, Duan Z, Du Z, et al. PRKCA D463H Mutation in Chordoid Glioma of the Third Ventricle: A Cohort of 16 Cases, Including Two Cases Harboring BRAFV600E Mutation. J Neuropathol Exp Neurol. 2020; 79(11): 1183–1192, doi: 10.1093/jnen/nlaa107, indexed in Pubmed: 33085976.
17. Yang B, Yang C, Du J, et al. Chordoid glioma: an entity occurring not exclusively in the third ventricle. Neurosurg Rev. 2020; 43(5): 1315–1322, doi: 10.1007/s10143-019-01161-w, indexed in Pubmed: 31422571.
18. Abdel Razek AA, Elsebaie NA, Zamora C, et al. Imaging of Neuronal and Mixed Glioneuronal Tumors. J Comput Assist Tomogr. 2020; 44(3): 356–369, doi: 10.1097/RCT.0000000000001010, indexed in Pubmed: 32217897.
19. Shaikh N, Brahmbhatt N, Kruser TJ, et al. Pleomorphic xanthoastrocytoma: a brief review. CNS Oncol. 2019; 8(3): CNS39, doi: 10.2217/cns-2019-0009, indexed in Pubmed: 31535562.
20. Thomas AA, Tucker SM, Nelson CJ, et al. Anaplastic pleomorphic xanthoastrocytoma with leptomeningeal dissemination responsive to BRAF inhibition and bevacizumab. Pediatr Blood Cancer. 2019; 66(1): e27465, doi: 10.1002/pbc.27465, indexed in Pubmed: 30255633.
21. Dono A, Lopez-Rivera V, Chandra A, et al. Predictors of outcome in pleomorphic xanthoastrocytoma. Neurooncol Pract. 2021; 8(2): 222–229, doi: 10.1093/nop/npaa076, indexed in Pubmed: 33898055.
22. Vatner RE, Niemierko A, Misra M, et al. Endocrine Deficiency As a Function of Radiation Dose to the Hypothalamus and Pituitary in Pediatric and Young Adult Patients With Brain Tumors. J Clin Oncol. 2018; 36(28): 2854–2862, doi: 10.1200/JCO.2018.78.1492, indexed in Pubmed: 30118397.
23. Dragoo DD, Taher A, Wong VK, et al. PTEN Hamartoma Tumor Syndrome/Cowden Syndrome: Genomics, Oncogenesis, and Imaging Review for Associated Lesions and Malignancy. Cancers (Basel). 2021; 13(13), doi: 10.3390/cancers13133120, indexed in Pubmed: 34206559.
24. Bruno F, Pellerino A, Bertero L, et al. Targeted Therapies in Rare Brain Tumours. Int J Mol Sci. 2021; 22(15), doi: 10.3390/ijms22157949, indexed in Pubmed: 34360713.
25. Karakula-Juchnowicz H, Morylowska-Topolska J, Juchnowicz D, et al. Paranoid Syndrome as the First Sign of Central Neurocytoma: A Case Report. J Psychiatr Pract. 2018; 24(5): 359–363, doi: 10.1097/PRA.0000000000000332, indexed in Pubmed: 30427824.
26. Pan DHC, Lee CC. The management of incidental central neurocytoma. Neurosurg Clin N Am. 2015; 26(1): 57–66, doi: 10.1016/j.nec.2014.09.010, indexed in Pubmed: 25432184.
27. Niiro T, Tokimura H, Hanaya R, et al. MRI findings in patients with central neurocytomas with special reference to differential diagnosis from other ventricular tumours near the foramen of Monro. J Clin Neurosci. 2012; 19(5): 681–686, doi: 10.1016/j.jocn.2011.06.030, indexed in Pubmed: 22410173.

28. Steinsiepe VK, Frick H, Jochum W, et al. Differential Diagnosis of Central Neurocytoma: Two Cases. J Neurol Surg A Cent Eur Neurosurg. 2021; 82(6): 599–603, doi: 10.1055/s-0040-1718693, indexed in Pubmed: 33352608.
29. Mozes P, Szanto E, Tiszlavicz L, et al. Clinical course of central neurocytoma with malignant transformation-an indication for craniospinal irradiation. Pathol Oncol Res. 2014; 20(2): 319–325, doi: 10.1007/s12253-013-9697-y, indexed in Pubmed: 24122623.
30. von Koch CS, Schmidt MH, Uyehara-Lock JH, et al. The role of PCV chemotherapy in the treatment of central neurocytoma: illustration of a case and review of the literature. Surg Neurol. 2003; 60(6): 560–565, doi: 10.1016/s0090-3019(03)00252-0, indexed in Pubmed: 14670681.
31. Johnson MO, Kirkpatrick JP, Patel MP, et al. The role of chemotherapy in the treatment of central neurocytoma. CNS Oncol. 2019; 8(3): CNS41, doi: 10.2217/cns-2019-0012, indexed in Pubmed: 31686534.
32. Choudhri O, Razavi SM, Vogel H, et al. Atypical and rare variants of central neurocytomas. Neurosurg Clin N Am. 2015; 26(1): 91–98, doi: 10.1016/j.nec.2014.09.003, indexed in Pubmed: 25432187.
33. Patil AS, Menon G, Easwer HV, et al. Extraventricular neurocytoma, a comprehensive review. Acta Neurochir (Wien). 2014; 156(2): 349–354, doi: 10.1007/s00701-013-1971-y, indexed in Pubmed: 24357019.
34. Xu Li, Ouyang Z, Wang J, et al. A clinicopathologic study of extraventricular neurocytoma. J Neurooncol. 2017; 132(1): 75–82, doi: 10.1007/s11060-016-2336-1, indexed in Pubmed: 27864704.
35. Romano N, Federici M, Castaldi A. Imaging of extraventricular neurocytoma: a systematic literature review. Radiol Med. 2020; 125(10): 961–970, doi: 10.1007/s11547-020-01198-8, indexed in Pubmed: 32335813.
36. Krauze A. Glioneuronal Tumors: Insights into a Rare Tumor Entity. Gliomas. 2021: 211–228, doi: 10.36255/exonpublications.gliomas.2021.chapter13.
37. Chamberlain MC. Recurrent ganglioglioma in adults treated with BRAF inhibitors. CNS Oncol. 2016; 5(1): 27–29, doi: 10.2217/cns.15.40, indexed in Pubmed: 26680369.
38. Slegers RJ, Blumcke I. Low-grade developmental and epilepsy associated brain tumors: a critical update 2020. Acta Neuropathol Commun. 2020; 8(1): 27, doi: 10.1186/s40478-020-00904-x, indexed in Pubmed: 32151273.
39. Vajramani GV, Dambatta S, Walker M, et al. Multiple gangliogliomas of the optic pathway. Br J Neurosurg. 2006; 20(6): 428–430, doi: 10.1080/02688690601101382, indexed in Pubmed: 17439099.
40. Rudà R, Capper D, Waldman AD, et al. EANO - EURACAN - SNO Guidelines on circumscribed astrocytic gliomas, glioneuronal, and neuronal tumors. Neuro Oncol. 2022; 24(12): 2015–2034, doi: 10.1093/neuonc/noac188, indexed in Pubmed: 35908833.
41. Kaley T, Touat M, Subbiah V, et al. BRAF Inhibition in *BRAF*^{V600}-Mutant Gliomas: Results From the VE-BASKET Study. J Clin Oncol. 2018; 36(35): 3477–3484, doi: 10.1200/jco.2018.78.9990, indexed in Pubmed: 30351999.
42. Alarifi N, Del Bigio MR, Beiko J. Adult gangliocytoma arising within the lateral ventricle: A case report and review of the literature. Surg Neurol Int. 2022; 13: 11, doi: 10.25259/SNI_814_2021, indexed in Pubmed: 35127211.
43. Leclerc A, Le Hello-Regnier E, Faisant M, et al. Ganglioglioma revealed by spontaneous intracerebral hematoma: A cohort study. Neurochirurgie. 2022; 68(5): e8–ee15, doi: 10.1016/j.neuchi.2022.02.008, indexed in Pubmed: 35257724.
44. Rolston JD, Han SJ, Cotter JA, et al. Gangliogliomas of the optic pathway. J Clin Neurosci. 2014; 21(12): 2244–2249, doi: 10.1016/j.jocn.2014.05.018, indexed in Pubmed: 25043166.
45. Melián KA, López FD, Imbroda JM, et al. Ganglioglioma espinal intramedular: caso clínico y revisión comparativa de la literatura. Neurocirugía. 2021; 32(3): 124–133, doi: 10.1016/j.neucir.2020.07.005.
46. Adachi Y, Yagishita A. Gangliogliomas: Characteristic imaging findings and role in the temporal lobe epilepsy. Neuroradiology. 2008; 50(10): 829–834, doi: 10.1007/s00234-008-0410-x, indexed in Pubmed: 18516598.
47. Lin X, Huang R, Zhang P, et al. Low-grade gangliogliomas in adults: A population-based study. Cancer Med. 2021; 10(1): 416–423, doi: 10.1002/cam4.3577, indexed in Pubmed: 33107220.
48. Southwell DG, Garcia PA, Berger MS, et al. Long-term seizure control outcomes after resection of gangliogliomas. Neurosurgery. 2012; 70(6): 1406–13; discussion 1413, doi: 10.1227/NEU.0b013e3182500a4c, indexed in Pubmed: 22353798.
49. Song JY, Kim JH, Cho YH, et al. Treatment and outcomes for gangliogliomas: a single-center review of 16 patients. Brain Tumor Res Treat. 2014; 2(2): 49–55, doi: 10.14791/btrt.2014.2.2.49, indexed in Pubmed: 25408925.
50. Liauw SL, Byer JE, Yachnis AT, et al. Radiotherapy after subtotally resected or recurrent ganglioglioma. Int J Radiat Oncol Biol Phys. 2007; 67(1): 244–247, doi: 10.1016/j.ijrobp.2006.08.029, indexed in Pubmed: 17045420.
51. Terrier LM, Bauchet L, Rigau V, et al. Club de Neuro-Oncologie of the Société Française de Neurochirurgie. Natural course and prognosis of anaplastic gangliogliomas: a multicenter retrospective study of 43 cases from the French Brain Tumor Database. Neuro Oncol. 2017; 19(5): 678–688, doi: 10.1093/neuonc/now186, indexed in Pubmed: 28453747.
52. Lucas JT, Huang AJ, Mott RT, et al. Anaplastic ganglioglioma: a report of three cases and review of the literature. J Neurooncol. 2015; 123(1): 171–177, doi: 10.1007/s11060-015-1781-6, indexed in Pubmed: 25862009.
53. Hunt SJ, Johnson PC. Melanotic ganglioglioma of the pineal region. Acta Neuropathol. 1989; 79(2): 222–225, doi: 10.1007/BF00294383, indexed in Pubmed: 2596271.
54. Kalra M, Subramani V. Rare pediatric brain tumors. Pediatr Hematol Oncol J. 2023; 8(3): 165–170, doi: 10.1016/j.phoj.2023.06.002.
55. Abongwa C, Cotter J, Tamrazi B, et al. Primary diffuse leptomeningeal glioneuronal tumors of the central nervous system: Report of three cases and review of literature. Pediatr Hematol Oncol. 2020; 37(3): 248–258, doi: 10.1080/08880018.2019.1711270, indexed in Pubmed: 31951480.
56. Debono B, Derrey S, Rabehenoina C, et al. Primary diffuse multinodular leptomeningeal gliomatosis: case report and review of the literature. Surg Neurol. 2006; 65(3): 273–82; discussion 282, doi: 10.1016/j.surneu.2005.06.038, indexed in Pubmed: 16488248.
57. Luzzi S, Elia A, Del Maestro M, et al. Dysembryoplastic Neuroepithelial Tumors: What You Need to Know. World Neurosurg. 2019; 127: 255–265, doi: 10.1016/j.wneu.2019.04.056, indexed in Pubmed: 30981794.
58. Al-Umran MR, Al-Umran SR, Arab AF, et al. Lateral ventricular liponeurocytoma: Review of literature and case illustration. Neurochirurgie. 2021; 67(6): 579–586, doi: 10.1016/j.neuchi.2021.03.004, indexed in Pubmed: 33766564.
59. Gembruch O, Junker A, Mönninghoff C, et al. Liponeurocytoma: Systematic Review of a Rare Entity. World Neurosurg. 2018; 120: 214–233, doi: 10.1016/j.wneu.2018.09.001, indexed in Pubmed: 30205225.
60. Radke J, Gehlhaar C, Lenze D, et al. The evolution of the anaplastic cerebellar liponeurocytoma: case report and review of the literature. Clin Neuropathol. 2015; 34(1): 19–25, doi: 10.5414/NP300783, indexed in Pubmed: 25250652.
61. Cho HJ, Myung JK, Kim H, et al. Primary diffuse leptomeningeal glioneuronal tumors. Brain Tumor Pathol. 2015; 32(1): 49–55, doi: 10.1007/s10014-014-0187-z, indexed in Pubmed: 24770606.
62. Bobeff K, Krajewska K, Baranska D, et al. Maintenance Therapy With Everolimus for Subependymal Giant Cell Astrocytoma in Patients With Tuberous Sclerosis - Final Results From the EMINENTS Study. Front Neurol. 2021; 12: 581102, doi: 10.3389/fneur.2021.581102, indexed in Pubmed: 33897576.
63. Ryoo JS, Khalid SI, Chaker AN, et al. Trends in survival and treatment of SEGA: National Cancer Database Analysis. Neurooncol Pract. 2021; 8(1): 98–105, doi: 10.1093/nop/npaa060, indexed in Pubmed: 33664974.
64. Roth J, Roach ES, Bartels U, et al. Subependymal giant cell astrocytoma: diagnosis, screening, and treatment. Recommendations from the International Tuberous Sclerosis Complex Consensus Conference 2012. Pediatr Neurol. 2013; 49(6): 439–444, doi: 10.1016/j.pediatrneurol.2013.08.017, indexed in Pubmed: 24138953.
65. Habib SL, Al-Obaidi NY, Nowacki M, et al. Is mTOR Inhibitor Good Enough for Treatment All Tumors in TSC Patients? J Cancer. 2016; 7(12): 1621–1631, doi: 10.7150/jca.14747, indexed in Pubmed: 27698899.
66. Pratt D, Penas-Prado M, Gilbert MR. Clinical impact of molecular profiling in rare brain tumors. Curr Opin Neurol. 2023; 36(6): 579–586, doi: 10.1097/WCO.0000000000001211, indexed in Pubmed: 37973025.
67. Louis DN, von Deimling A. Hereditary tumor syndromes of the nervous system: overview and rare syndromes. Brain Pathol. 1995; 5(2): 145–151, doi: 10.1111/j.1750-3639.1995.tb00588.x, indexed in Pubmed: 7670655.
68. Wu J, Armstrong TS, Gilbert MR. Biology and management of ependymomas. Neuro Oncol. 2016; 18(7): 902–913, doi: 10.1093/neuonc/now016, indexed in Pubmed: 27022130.
69. Chamberlain MC, Tredway TL, Chamberlain MC. Ependymomas. Curr Neurol Neurosci Rep. 2003; 3(3): 193–199, doi: 10.1007/s11910-003-0078-x, indexed in Pubmed: 12691623.
70. Rudà R, Bruno F, Pellerino A, et al. Ependymoma: Evaluation and Management Updates. Curr Oncol Rep. 2022; 24(8): 985–993, doi: 10.1007/s11912-022-01260-w, indexed in Pubmed: 35384591.

71. Gilbert MR, Ruda R, Soffietti R. Ependymomas in adults. Curr Neurol Neurosci Rep. 2010; 10(3): 240–247, doi: 10.1007/s11910-010-0109-3, indexed in Pubmed: 20425040.
72. Bertero L, Ricci AA, Tampieri C, et al. Ependymomas. Pathologica. 2022; 114(6): 436–446, doi: 10.32074/1591-951X-817, indexed in Pubmed: 36534422.
73. Reni M, Mazza E, Zanon S, et al. Ependymoma. Crit Rev Oncol Hematol. 2007; 63(1): 81–89, doi: 10.1016/j.critrevonc.2007.03.004, indexed in Pubmed: 17482475.
74. Saleh AH, Samuel N, Juraschka K, et al. The biology of ependymomas and emerging novel therapies. Nat Rev Cancer. 2022; 22(4): 208–222, doi: 10.1038/s41568-021-00433-2, indexed in Pubmed: 35031778.
75. Rudà R, Gilbert M, Soffietti R. Ependymomas of the adult: molecular biology and treatment. Curr Opin Neurol. 2008; 21(6): 754–761, doi: 10.1097/WCO.0b013e328317efe8, indexed in Pubmed: 18989122.
76. Schwartz TH, Kim S, Glick RS, et al. Supratentorial ependymomas in adult patients. Neurosurgery. 1999; 44(4): 721–731, doi: 10.1097/00006123-199904000-00018, indexed in Pubmed: 10201296.
77. Leeper H, Felicella MM, Walbert T. Recent Advances in the Classification and Treatment of Ependymomas. Curr Treat Options Oncol. 2017; 18(9): 55, doi: 10.1007/s11864-017-0496-7, indexed in Pubmed: 28795287.
78. Schwartz TH, McCormick PC. Intramedullary ependymomas: clinical presentation, surgical treatment strategies and prognosis. J Neurooncol. 2000; 47(3): 211–218, doi: 10.1023/a:1006414405305, indexed in Pubmed: 11016737.
79. Fonseca A, Al-Karmi S, Vasiljevic A, et al. Rare Embryonal Brain Tumours. Brain Tumors in Children. 2018: 289–316, doi: 10.1007/978-3-319-43205-2_13.
80. Rare Embryonal Brain Tumours. http://ouci.dntb.gov.ua/en/works/4rjPkOw4/ (30.01.2025).
81. Millard NE, De Braganca KC. Medulloblastoma. J Child Neurol. 2016; 31(12): 1341–1353, doi: 10.1177/0883073815600866, indexed in Pubmed: 26336203.
82. Northcott PA, Robinson GW, Kratz CP, et al. Medulloblastoma. Nat Rev Dis Primers. 2019; 5(1): 11, doi: 10.1038/s41572-019-0063-6, indexed in Pubmed: 30765705.
83. Cotter JA, Hawkins C. Medulloblastoma: WHO 2021 and Beyond. Pediatr Dev Pathol. 2022; 25(1): 23–33, doi: 10.1177/10935266211018931, indexed in Pubmed: 35168417.
84. Gottardo NG, Gajjar A. Current therapy for medulloblastoma. Curr Treat Options Neurol. 2006; 8(4): 319–334, doi: 10.1007/s11940-006-0022-x, indexed in Pubmed: 16942675.
85. Smoll NR, Drummond KJ. The incidence of medulloblastomas and primitive neurectodermal tumours in adults and children. J Clin Neurosci. 2012; 19(11): 1541–1544, doi: 10.1016/j.jocn.2012.04.009, indexed in Pubmed: 22981874.
86. Villà S, Miller RC, Krengli M, et al. Primary pineal tumors: outcome and prognostic factors--a study from the Rare Cancer Network (RCN). Clin Transl Oncol. 2012; 14(11): 827–834, doi: 10.1007/s12094-012-0869-0, indexed in Pubmed: 22914906.
87. Li BK, Vasiljevic A, Dufour C, et al. Pineoblastoma segregates into molecular sub-groups with distinct clinico-pathologic features: a Rare Brain Tumor Consortium registry study. Acta Neuropathol. 2020; 139(2): 223–241, doi: 10.1007/s00401-019-02111-y, indexed in Pubmed: 31820118.
88. Clark AJ, Sughrue ME, Aranda D, et al. Contemporary management of pineocytoma. Neurosurg Clin N Am. 2011; 22(3): 403–7, ix, doi: 10.1016/j.nec.2011.05.004, indexed in Pubmed: 21801989.
89. Nakamura M, Saeki N, Iwadate Y, et al. Neuroradiological characteristics of pineocytoma and pineoblastoma. Neuroradiology. 2000; 42(7): 509–514, doi: 10.1007/s002349900243, indexed in Pubmed: 10952183.