

EANO guidelines for the diagnosis and treatment of ependymal tumors

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Abstract

Ependymal tumors are rare CNS tumors and may occur at any age, but their proportion among primary brain tumors is highest in children and young adults. Thus, the level of evidence of diagnostic and therapeutic interventions is higher in the pediatric compared with the adult patient population.

The diagnosis and disease staging is performed by craniospinal MRI. Tumor classification is achieved by histological and molecular diagnostic assessment of tissue specimens according to the World Health Organization (WHO) classification 2016. Surgery is the crucial initial treatment in both children and adults. In pediatric patients with intracranial ependymomas of WHO grades II or III, surgery is followed by local radiotherapy regardless of residual tumor volume. In adults, radiotherapy is employed in patients with anaplastic ependymoma WHO grade III, and in case of incomplete resection of WHO grade II ependymoma. Chemotherapy alone is reserved for young children <12 months and for adults with recurrent disease when further surgery and irradiation are no longer feasible. A gross total resection is the mainstay of treatment in spinal ependymomas, and radiotherapy is reserved for incompletely resected tumors. Nine subgroups of ependymal tumors across different anatomical compartments (supratentorial, posterior fossa, spinal) and patient ages have been identified with distinct genetic and epigenetic alterations, and with distinct outcomes. These findings may lead to more precise diagnostic and prognostic assessments, molecular subgroup-adapted therapies, and eventually new recommendations pending validation in prospective studies.

Key words

adults | children | ependymoma | molecular pathology | treatments

Ependymal tumors are rare central nervous system tumors.¹ According to the Central Brain Tumor Registry of the United States, the annual incidence of ependymal

tumors is estimated at 0.43 patients per 100000 population.² These tumors account for 1.8% of all primary CNS tumors and for 6.8% of all gliomas.² In children (0–19 y of

Importance of the study

This article reports the evidence-based guidelines on management of ependymal tumors in children and adults developed by a multidisciplinary task force of the European Association of Neuro-Oncology, composed of medical experts from different European countries representing the involved disciplines (neurology,

neurosurgery, neuropathology, radiation oncology, and pediatric oncology). These guidelines should aid all professionals involved in the management of patients with ependymal tumors in the daily clinical practice and could serve as a source of knowledge for institutions and insurance companies involved in cancer care in Europe.

age), ependymal tumors are proportionally more common and account for 5.2% of all primary CNS tumors.² Overall, these tumors affect males more frequently than females (1.3:1).

Ependymal tumors are of neuroectodermal origin and subdivided according to the World Health Organization (WHO) classification of CNS tumors into distinct entities and histological variants.³ The WHO classification also comprises a histological grading into 3 distinct grades of malignancy: WHO grades I, II, and III.

In addition to age and tumor grade, the prognosis is associated with tumor location (supratentorial, infratentorial, and spinal) and site-specific molecular genetics.⁴⁻⁷ Population-based epidemiological data reported a 5-year overall survival (OS) rate of 83.4% and a 10-year OS rate of 79.1% in patients with ependymal tumors.²

A recent molecular classification has distinguished 9 subgroups of ependymal tumors that appear to reflect more precisely than histology alone the biological, clinical, and histopathological heterogeneity across the major anatomical compartments, age groups, and tumor grades.⁶ Each of the 9 molecular subgroups is characterized by distinct DNA methylation profiles and associated genetic alterations.

Prospective studies on management of ependymoma patients have been performed in the pediatric population only, while smaller retrospective series are available for adult patients.⁸ In this guideline, we have separated the review of evidence concerning diagnosis and treatment recommendations for children and adults, recognizing that this is somewhat artefactual and may be replaced by molecular profiling-based stratification for treatment in the future.

Methods

The European Association of Neuro-Oncology (EANO) ependymoma task force assessed the available English literature up to December 31, 2016, sorted the scientific evidence into classes I–IV, and rated recommendations at levels A–C according to the European Federation of the Neurological Societies Guidelines.⁹ When sufficient evidence for recommendations was not available, the task force offered advice as a Good Practice Point. Specific recommendations for the therapeutic management of ependymomas in adults and children are reported in [Tables 1–6](#).

Table 1 Key recommendations for the treatment of newly diagnosed intracranial WHO grades II and III ependymomas in adults

	Class of Evidence	Level of Recommendation
Resection is recommended to obtain a histological diagnosis and should be a gross total resection whenever feasible. As the morbidity can be significant, detailed informed pre-operative counseling by a surgeon experienced in performing such surgery is important.	II	B
Postoperative MRI should be performed to evaluate the extent of resection.	n.a.	Good Practice Point
A second-look surgery should be considered when the result of the first resection has not been satisfactory.	III	C
Because a risk of CSF dissemination exists for all patients with newly diagnosed ependymoma, disease staging, including both craniospinal MRI and CSF cytology, is mandatory following surgery (not earlier than 2–3 wk).	n.a.	Good Practice Point
Postoperative conformal radiotherapy with doses up to 60 Gy is recommended for patients with WHO grade III (anaplastic) ependymomas regardless of the extent of resection.	II	B
Postoperative conformal radiotherapy with doses of 54–59.4 Gy is recommended for patients with WHO grade II ependymomas following incomplete resection.	III	C
Craniospinal irradiation (CSI) of 36 Gy is recommended in case of CSF or spinal dissemination with a boost up to 45–54 Gy on focal lesions.	IV	Good Practice Point
Because of the risk of asymptomatic and/or late relapses, patients should be followed long term with contrast-enhanced MRI.	n.a.	Good Practice Point

Table 2 Key recommendations for the treatment of newly diagnosed intracranial WHO grades II and III ependymomas in children

	Class of Evidence	Level of Recommendation
Resection is recommended to obtain a histological diagnosis and should be a gross total resection whenever feasible. As the morbidity can be significant, detailed informed preoperative counseling by a surgeon experienced in performing such surgery is important.	II	B
Postoperative MRI should be performed to evaluate the extent of resection.	n.a.	Good Practice Point
A second-look surgery should be considered when residual tumor is demonstrated on postoperative MRI and gross total resection is a realistic goal.	II	B
Because a risk of CSF dissemination exists for all patients with newly diagnosed ependymoma, a disease staging, including both craniospinal MRI and CSF cytology, is mandatory following surgery (not earlier than 2–3 wk)	n.a.	Good Practice Point
Postoperative conformal radiotherapy with doses up to 59.4 Gy is recommended in children older than 18 months.	II	B
Postoperative conformal radiotherapy with doses of 54 Gy is recommended in children between 12 months and 18 months or in older children with poor neurological status.	II	B
Chemotherapy alone is an option in children less than 18 months old, while it is recommended in children aged less than 12 months.	III	C
Craniospinal irradiation (CSI) is recommended in case of CSF or spinal dissemination with a boost on focal lesions with doses adapted to patient age.	IV	Good Practice Point
Because of the risk of asymptomatic and/or late relapses, patients should be followed long term with an enhanced MRI.	n.a.	Good Practice Point
Serial monitoring of cognitive and endocrine functions with specific batteries following radiotherapy is recommended whenever feasible.	n.a.	Good Practice Point

Clinical and Neuroimaging Diagnosis

The clinical presentation of ependymomas (see Supplementary material) depends primarily on patient age, tumor location, and tumor size.^{10–14}

MRI with contrast enhancement is the modality of choice for diagnosing ependymal tumors.^{15,16} CT can better depict calcifications, which are most commonly observed in subependymomas. Infratentorial ependymomas arise from the floor of the fourth ventricle, while supratentorial ependymomas can be located in the brain rather than in the ventricles. Intracranial ependymomas commonly appear as well-circumscribed mass lesions and have a heterogeneous appearance on T1-, T2-, and postcontrast MRI, displaying varying degrees of contrast enhancement.

Advanced imaging modalities may assist in diagnosis or management in some clinical scenarios; however, the available data from the literature are too scarce and do not allow for definitive recommendations for daily clinical practice. Diffusion-weighted imaging may be useful for differentiating pilocytic astrocytomas, medulloblastomas, and ependymomas in the posterior fossa.¹⁷ MR spectroscopy reveals elevated choline and reduced N-acetylaspartate levels.⁸ Perfusion MRI may display elevated cerebral blood volume values and have some prognostic value.¹⁸ Spinal cord ependymomas display more distinct borders than diffuse astrocytomas.¹⁴ Cyst formation and T2 hypointensity of the cyst wall due to blood products (“hemosiderin cap”) are suggestive of ependymoma. An associated syringomyelia is common.

Myxopapillary ependymoma (MPE) is typically located in the conus medullaris, cauda equina, and filum terminale region.

Neuropathological Diagnostics of Ependymal Tumors

Ependymal tumors are classified according to the WHO classification of CNS tumors 2016.³ Histological assessment is primarily based on hematoxylin/eosin-stained sections and some ancillary techniques, including silver impregnation for reticulin fibers, Alcian blue for demonstration of mucoid changes, and periodic acid–Schiff staining for glycogen. Immunohistochemically, ependymal tumors react positive for glial fibrillary acidic protein and protein S100 but usually lack nuclear positivity for OLIG2. Dot-like perinuclear and ring-like cytoplasmic immunoreactivity for epithelial membrane antigen is a characteristic feature.¹⁹ Nuclear immunoreactivity for v-rel avian reticuloendotheliosis viral oncogene homolog A (RELA) and expression of L1 cell adhesion molecule may help to identify RELA fusion-positive ependymomas.^{20,21} However, molecular testing for C11orf95-RELA fusion by fluorescent in situ hybridization or reverse-transcription PCR analysis is required for a firm diagnosis.³ Loss of nuclear expression of trimethylated histone 3 lysine 27 (H3-K27me3) distinguishes a prognostically unfavorable group of posterior fossa ependymomas (PF-EPNs) in children,²² largely corresponding to PF-EPN group A (see “New Molecular Subgroups” section below).^{6,23} Proliferative activity is commonly assessed by Ki-67 immunostaining; however, definite cutoffs for grading have not been defined.

The 2016 WHO classification of CNS tumors includes 5 distinct entities of ependymal tumors.³ Myxopapillary ependymoma WHO grade I is histologically characterized by cuboidal or elongated tumor cells forming fibrillary

Table 3 Key recommendations for the treatment of recurrent intracranial ependymomas in adults and children

	Class of Evidence	Level of Recommendation
Re-operation and/or re-irradiation should be proposed whenever possible. However, if only incomplete resection was achievable due to functional restrictions at first surgery, the same limitations will be faced at re-operation; hence, in these cases the indication for another incomplete resection should be made cautiously.	III	C
In patients with recurrent ependymomas who are no longer eligible for local treatments, chemotherapy might be warranted, particularly in patients with a good performance status.	III	C
In adults, either platinum compounds or temozolomide (based on a more favorable toxicity profile) should be considered. Options for participation in a clinical trial should be explored.	IV	Good Practice Point
In children, the choice of chemotherapeutic drugs depends on previous exposures. Options for participation in a clinical trial should be explored.	n.a.	Good Practice Point

processes toward fibrovascular cores typically showing perivascular mucoid degeneration. Mitotic activity is low. Subependymoma WHO grade I is characterized by clusters of bland to mildly pleomorphic, mitotically inactive cells embedded in an abundant fibrillary matrix with frequent microcystic changes and dystrophic calcifications. Ependymoma WHO grade II usually shows a solid, well-circumscribed growth and is composed of uniform cells forming perivascular pseudorosettes and, in some tumors, true ependymal rosettes. Mitotic activity is low while non-palisading necroses may be present in a fraction of cases. Three variants of ependymoma, each characterized by distinct histological features, are recognized in the WHO classification, namely papillary ependymoma, clear cell ependymoma, and tanycytic ependymoma. Ependymoma, RELA fusion-positive is a novel supratentorial ependymoma entity that is defined by the presence of a C11orf95-RELA fusion.^{6,20} It may correspond to WHO grade II or III, but patient outcome is worse compared with other types of supratentorial ependymomas.⁶ Anaplastic ependymoma WHO grade III carries histological features of anaplasia, in particular high mitotic activity and microvascular proliferation. Pseudopalisading necrosis may also be observed. However, accurate histological distinction of WHO grades II and III ependymomas is challenging and its role in predicting survival has been disputed.²⁴ Hence, WHO grading is inadequate to reliably predict the outcome in individual patients, and molecular subgrouping or single molecular markers may offer new perspectives for improved prognostic stratification.^{4,6,25-27}

Treatment of Newly Diagnosed Intracranial Ependymal Tumors in Adults

Adult intracranial ependymomas are rare tumors, and WHO grade II tumors are more frequent than WHO grade III (anaplastic) counterparts.¹⁰

Surgery is considered the first and crucial step of standard treatment. In the majority of studies, extent of resection has emerged as one of the most significant predictors of outcome.²⁸⁻³³ In a retrospective series of WHO grade

II ependymomas in adults,³¹ the 5- and 10-year OS rates were 86.1% and 81%, respectively. Preoperative KPS, extent of resection, and tumor location were independent prognostic factors for OS. In particular, gross total resection (GTR), defined as no residual disease on postcontrast T1- and T2-weighted images on a 3-month postoperative MRI, and infratentorial location were associated with a longer OS. GTR and tumor location were also independent factors predicting progression-free survival (PFS). Conversely, incomplete resection has an increased risk of tumor recurrence and CSF dissemination. However, in posterior fossa tumors, encasement of the cranial nerves and brainstem vasculature might limit resectability.³⁴ In case of persistent hydrocephalus despite tumor resection, shunting or endoscopic ventriculostomy needs to be performed.

Concepts regarding target volume for radiation therapy have evolved. In the past, patients with ependymoma often received craniospinal irradiation. However, numerous studies demonstrated the efficacy of local fields in the treatment of ependymoma, achieving good local control with low risk of spinal dissemination.³⁵ In adults, there is agreement that postoperative radiotherapy should be included in the standard of care for patients with anaplastic ependymoma (WHO grade III) and for patients with ependymomas (WHO grade II) after an incomplete resection.^{29,36} Conversely, the role of postoperative radiotherapy in patients with ependymoma WHO grade II undergoing GTR remains controversial.³⁷ In 2 large retrospective studies including patients with intracranial WHO grade II ependymomas,^{31,38} no significant association of radiotherapy with PFS or OS was found. However, in the French study,³¹ the subgroup of patients with incompletely resected tumors receiving postoperative radiotherapy had longer PFS and OS than those who did not.

Intracranial subependymoma is a rare WHO grade I tumor. Long-term survival can be expected after surgical removal, although poorly defined borders have been reported to be associated with a shorter PFS.³⁹ Postoperative radiotherapy has been employed in few patients after subtotal or partial resection.

Recommendations regarding treatment of intracranial ependymomas in adults are summarized in [Table 1](#).

Table 4 Key recommendations regarding nonsurgical treatment of WHO grades II and III ependymomas in children

CT Indication	CT Regimen	CT Timing	RT Indication	RT Timing	GTV (defined with MRI)	CTV	Total Dose, Gy	Dose/fraction, Gy	Technique
Localized tumor, age >18 mo	VEC ± cisplatin	Maintenance	Systematically	Postoperatively	Tumor bed and 3D identifiable residual disease	5–10 mm around GTV	59.4	1.8	3DCRT or IMRT or proton
Localized tumor, age >18 mo with visible residual tumor after surgery	VEC ± cisplatin ± high-dose methotrexate	Postoperatively	Stereotactic additional boost recommended within a prospective clinical trial with residue after chemotherapy	Postoperatively and post-chemotherapy	Tumor bed and 3D identifiable residual disease		59.4+8	4	3DCRT or IMRT or proton
Localized tumor, age 12–18 mo	Baby UK	Maintenance	To be discussed	Postoperatively	Tumor bed and 3D identifiable residual disease		54	1.6–1.8	
Localized tumor, age <12 mo	Baby UK	Postoperatively	NORT	NORT	–	–	–	–	
Metastatic tumor	VEC ± cisplatin	Before RT	Salvage treatment	Postoperatively or postchemotherapy	Tumors and 3D identifiable residual disease	CSI + boost 5–10 mm around GTV	24 or 36 depending on age + boost up to 59	1.8	
Local relapse	None outside clinical trial	–	Recommended	Postoperatively	3D identifiable disease	GTV+2 mm	59 or in a prospective trial 25 Gy/5 fractions or 24 Gy/3 fractions	1.8 or hypofractionation (5–8)	3DCRT or IMRT or proton or hypofractionated stereotactic irradiation

CT, chemotherapy; RT, radiotherapy; VEC, vincristine/etoposide/ cyclophosphamide regimen; GTV, growth tumor volume; CTV, clinical target volume; 3DCRT, 3D conformal radiotherapy; IMRT, intensity modulated radiotherapy;

Treatment of Newly Diagnosed Intracranial Ependymal Tumors in Children

More than half of all pediatric ependymomas occur in children younger than 3 years,⁴⁰ and about two thirds of tumors are located in the posterior fossa.³²

Surgery and radiotherapy are the mainstay of treatment for ependymomas in children.⁴¹ Extent of resection is the most important prognostic factor, but the site of the lesions (eg, posterior fossa tumors involving the ponto-cerebellar region) can limit surgery due to involvement of the lower cranial nerves and brainstem⁴²; thus, an incomplete resection is frequent in these patients. OS is around 70% at 5 years in case of GTR, but it is much lower with incomplete resection.^{43–45} A second-look surgery is increasingly undertaken when the first resection has been incomplete.^{46–48}

The benefit of postoperative radiotherapy has been shown in terms of local control and survival rates in children with intracranial ependymomas.⁴⁵ An Italian study⁴⁴ reported on attempted GTR followed by postoperative radiotherapy and showed a 7-year estimate of local control, event-free survival (EFS), and OS of 83.7%, 69%, and 81%, respectively. Data from St Jude Children's Research Hospital⁴⁵ showed improved local control, EFS, and OS with 59.4 Gy in 1.8 Gy fractions with 3D conformal radiotherapy without any apparent increase of late neurocognitive deficits. Therefore, postoperative radiotherapy with 59.4 Gy (1.8 Gy/fraction) has been advocated⁴⁵ for children older than 3 years, while for children as young as 18 months or children with altered neurological status, the doses can be lowered to 54 Gy.⁴⁹ This can be true even for children between 12 and 18 months. A recent retrospective study on 206 patients reported that the main pattern of relapse was within the radiation fields even at 59.4 Gy.⁵⁰ As local control remains the primary goal of treatment, the possibility to compensate for an incomplete surgery by applying a hypofractionated stereotactic boost in addition to conventional radiotherapy has been proposed.⁵¹ In an Italian prospective clinical trial, patients with residual disease after first surgery who received a boost of 8 Gy in addition to radiation and chemotherapy had a 5-year PFS rate higher than 58%.⁵² A prospective study has shown that hyperfractionated radiotherapy is safe but provides no outcome benefit compared with standard fractionated regimens.⁵³

The toxicity of radiotherapy in younger children is of concern, and intensity-modulated radiation therapy has been employed to limit late sequelae.⁴⁴ Merchant and colleagues⁵⁴ developed a model combining dose-volume data with clinical factors to predict intelligence quotient (IQ) outcomes and concluded that the radiation dose remains the most clinically significant determinant of IQ outcomes and that even low doses, such as <20 Gy, delivered to the supratentorial brain, have an impact on the IQ. Proton therapy could be an alternative to conventional photon radiotherapy.⁵⁵ In this regard, the Massachusetts General Hospital group reported the outcome of 70 children with localized ependymomas treated with proton therapy.⁵⁶ At a median follow-up of 46 months, local control and survival

were excellent and the complication rate particularly low. Proton therapy may be useful for PF-EPN,⁵⁷ as it can spare the dose exposure to supratentorial compartments of the brain and auditory structures. Supratentorial ependymomas, which are often large tumors and occur in children over 10 years of age, also could represent a good indication for proton therapy in order to reduce neurocognitive impairment, and in this regard the preliminary data are encouraging.⁵⁸

However, recent studies^{59–61} have suggested that brainstem toxicity, including radiation necrosis, with proton treatment can occur. Thus, it has been recommended to limit the dose to the brainstem. Another study reported more imaging changes in brainstem with protons than with photons.⁶² The benefit and risks of proton therapy need to be confirmed with modern proton treatments and in prospective studies.⁶³ A prospective study (NCT01288235) with proton therapy is ongoing in the US.

The role of chemotherapy in children remains unproven despite intensive investigation.⁶⁴ As there is reluctance to deliver radiation to very young children, postoperative chemotherapy has been frequently proposed, while in older children chemotherapy is delivered as an adjunct to radiotherapy. Postoperative chemotherapy, using various combinations of etoposide, vincristine, cyclophosphamide, platinum derivatives, and high-dose methotrexate, showed a 40% to 50% response rate.^{44,65–67} The role of intensified schedules of chemotherapy was suggested in baby protocols,⁶⁶ especially for supratentorial tumors.⁶⁸ In contrast, the use of immediate postoperative high-dose conformal radiotherapy in children under the age of 3 years led to 7-year PFS rates of 77%,⁴⁵ albeit long-term follow-up for toxicity on development is pending. Thus far, radiotherapy deferral strategies that use chemotherapy have been abandoned in most institutions for children aged more than 12 months.

Two randomized trials are currently comparing post-irradiation chemotherapy with observation.

Recommendations regarding treatment of intracranial ependymomas in children are summarized in [Tables 2, 3, and 4](#). A summary of prospective studies on radiotherapy in pediatric patients with ependymoma can be found in the [Supplementary material](#).

Treatment of Recurrent Intracranial Ependymal Tumors in Adults and Children

Standard salvage options for recurrent ependymomas have not been identified. However, re-operation as well as re-irradiation are increasingly employed.

Re-operation has been shown to be associated with improved prognosis.⁶⁹ Among children who underwent re-operation, there was a 5-year EFS of 19% in case of GTR, of 14% in case of incomplete resection, and of 8% without repeat surgery.⁷⁰ Re-irradiation is performed in adults as well as in children, using either a full course of fractionated irradiation^{69,71} or hypofractionated stereotactic irradiation^{72–76} or proton therapy,⁷⁷ and can achieve durable responses.

The role of chemotherapy for treatment of recurrent ependymoma in adults remains unclear and is considered only when local treatment options (surgery and radiotherapy) have been exhausted.^{78,79}

Similar to other gliomas, temozolomide (TMZ) has been used for the treatment of adult patients with ependymoma. Some case reports suggested that TMZ alone or in combination is active against recurrent WHO grade II or III ependymoma.^{80–84} A retrospective study of 18 patients with recurrent WHO grades II and III intracranial ependymomas failing re-operation or re-irradiation or both suggested an activity of TMZ in the standard schedule both in terms of response (22% complete + partial) and outcome (PFS 9.69 mo and OS 30.55 mo).⁸⁵ Responses were observed in chemotherapy-naïve patients only and in most cases were delayed in appearance. Conversely, in another retrospective study⁸⁶ of patients with WHO grade II intracranial ependymomas refractory to first-line chemotherapy with platinum compounds, TMZ in the standard schedule had a more limited activity with a response rate of 4%, a PFS of 2 months, and OS of 3 months. An explanation of this difference could be that all patients of this cohort⁸⁶ were heavily pretreated, while the majority of patients of the other cohort⁸⁵ were chemo naïve, thus receiving TMZ in an earlier phase of the disease. Temozolomide has also been used in combination with lapatinib in a single-arm phase II study in patients with recurrent intracranial and spinal ependymoma.⁸⁷ Lapatinib targets the epidermal growth factor receptor (ErbB1) and the related family member human epidermal growth factor receptor 2/neu (ErbB2), which are expressed on the surface of ependymoma cells. Fifty patients were enrolled in this trial and the treatment was overall well tolerated. Median PFS was 45 weeks for patients with WHO grade II, and 25.3 weeks for patients with WHO grade III anaplastic ependymomas. Responses to treatment correlated with higher ErbB2 mRNA expression in the tumor tissue. The rather modest activity of TMZ against ependymoma might be due to the lack of O⁶-methylguanine-DNA-methyltransferase (MGMT) promoter methylation in ependymoma cells^{88,89}; however, even when present, MGMT promoter methylation may not correlate with response to TMZ.⁸⁵

A few studies on the administration of platinum-based regimens, using either cisplatin or carboplatin, have been published. A retrospective study, including pediatric as well as adult patients, indicated a superiority of platinum-based over nitrosourea-based regimens.⁹⁰ Another retrospective series reported higher response rates in patients with progressive or recurrent ependymoma treated with cisplatin compared with nonplatinum regimens, but no difference in terms of PFS and OS was observed.⁹¹ Other drugs and regimens, such as tamoxifen and isotretinoin, were used in only single patients.⁹² The anti-angiogenic agent bevacizumab has been administered in a small cohort of 8 patients with recurrent WHO grade II or III adult intracranial ependymoma with a median PFS of 6.4 months and OS of 9.4 months.⁹³

Phase II studies in children with relapsing ependymomas have reported a low response rate with either standard⁹⁴ or high-dose chemotherapy.⁹⁵ Metronomic therapies have produced some long-term stabilizations.⁹⁶ Responses

have been reported with oral etoposide⁹⁷ or TMZ.⁹⁸ Bevacizumab, in association with either irinotecan⁹⁹ or lapatinib,¹⁰⁰ has proven disappointing. Targeted agents, such as erlotinib⁹⁷ and sunitinib,¹⁰¹ failed to show activity in unselected patient cohorts.

Recommendations regarding treatment of recurrent ependymomas are summarized in [Table 3](#).

Treatment of Ependymal Tumors of the Spinal Cord

Ependymal tumors of the spinal cord are more common in adults than in children.¹⁰ They include WHO grade I subependymoma and MPE, and WHO grades II and III (anaplastic) ependymoma. Spinal cord ependymomas have a better prognosis than spinal cord astrocytomas, but factors affecting prognosis have not been defined except for GTR.¹⁰² Advances in microsurgical techniques have allowed en bloc GTR over piecemeal subtotal resection (STR) as standard of care for spinal cord ependymomas. In the majority of cases a GTR can be performed with good functional results. Since good functional outcome is related to small tumor size and good neurological status at the time of surgery, resection is considered at an early stage of the disease.^{103,104} When GTR is not feasible because of infiltration of spinal cord or nerve roots, postoperative local radiotherapy is commonly employed. A recent review of the literature has been performed for 348 patients with WHO grades II and III spinal cord ependymomas who underwent surgery with known extent of resection (GTR or STR), with or without postoperative radiotherapy.¹⁰⁵ After multivariate analysis, extent of resection and tumor grade were independent prognostic factors for OS and PFS, and radiotherapy prolonged PFS in patients receiving STR: median PFS was 48 months in patients treated with STR alone and 96 months for patients treated with STR followed by radiotherapy. The optimal dose is still a matter of debate, with studies suggesting either better or equivalent results with doses >50 Gy.^{105,106}

Regarding conventional chemotherapy, a small study of 10 patients with recurrent intramedullary ependymoma has reported that continuous oral etoposide is well tolerated and may be active.¹⁰⁷ Bevacizumab can provide clinical benefit in some patients, although the changes on MRI do not meet the current criteria for radiological tumor response.¹⁰⁸

Recommendations regarding treatment of spinal cord ependymomas are summarized in [Table 5](#).

Large retrospective series on MPE have been performed, including a large multi-institutional series of 183 patients¹⁰⁹ that showed a 10-year OS of 92.4% and a 5- and 10-year PFS of 69.5% and 61.2%. MPE recurrence was local in 84% of patients, and leptomeningeal spread was observed in 9.3% of patients. Extent of resection was a major independent factor predicting local control, while younger age (<36 y) was a negative prognostic factor. However, the irregular shape, contact with surrounding nerve roots, and production of a myxoid matrix, particularly in the filum terminale, can make GTR particularly challenging with risks

Table 5 Key recommendations for the treatment of WHO grades II and III spinal cord ependymomas

	Class of Evidence	Level of Recommendation
Gross total resection is the goal of spinal ependymoma surgery.	II	B
Postoperative MRI should be performed to evaluate the extent of resection.	n.a.	Good Practice Point
Because a risk of CSF dissemination exists for all patients with newly diagnosed ependymoma, disease staging, including both craniospinal MRI and CSF cytology, is recommended following surgery (not earlier than 2–3 wk).	n.a.	Good Practice Point
In case of WHO grade III (anaplastic) ependymomas, postoperative radiotherapy with doses of 45–54 Gy is recommended regardless of the extent of resection.	III	C
In case of WHO grade II ependymomas following gross total resection, a watch-and-wait strategy is recommended.	III	C
In case of incomplete resection of a WHO grade II ependymoma, postoperative local radiotherapy is recommended with doses of 45–54 Gy.	II	B
Because of the risk of asymptomatic and/or late relapses, patients should be followed long term with an enhanced MRI.	n.a.	Good Practice Point

Table 6 Key recommendations for the treatment of MPEs WHO grade I

	Class of Evidence	Level of Recommendation
Gross total resection is recommended whenever feasible.	II	B
Postoperative MRI should be performed to evaluate the extent of resection.	n.a.	Good Practice Point
Because a risk of CSF dissemination exists for all newly diagnosed patients, disease staging, including both craniospinal MRI and CSF cytology, is recommended following surgery (not earlier than 2–3 wk).	n.a.	Good Practice Point
Postoperative radiotherapy with doses ≥ 50 Gy is recommended in case of incomplete resection.	II	B
In case of relapse, consideration should be given to re-operation, re-irradiation, and chemotherapy.	III	C
Because of the risk of asymptomatic and/or late relapses, patients should be followed long term with an enhanced MRI.	n.a.	Good Practice Point

of postoperative neurological disability. A strong correlation between capsular violation at surgery and recurrence has been found.¹¹⁰ An OS at 10 years exceeding 90% has been recently confirmed in an analysis by the Surveillance, Epidemiology, and End Results (SEER) program of 773 patients.¹¹¹ Presacral MPE shows a worse outcome compared with MPE of the filum terminale/cauda equina region.

Compared with patients treated with surgery alone, postoperative radiotherapy, especially with high doses (≥ 50 Gy), has been shown to increase the local control and PFS (10-y PFS from $\sim 40\%$ to 70%) with good tolerance and without substantial late toxicity.^{112,113} A small series on adult patients with spinal MPE has shown that patients treated by GTR followed by adjuvant radiotherapy had better local control than patients treated with GTR alone.¹¹⁴ However, prospective confirmatory data are needed.

MPE is very rare in children. Although patients frequently present with disseminated tumor and/or develop recurrent or progressive disease following treatments,¹¹⁵ the OS at 5

and 10 years in the SEER database is estimated at 97% and 95%, respectively.¹¹⁶ A recent series from Johns Hopkins Hospital¹¹⁷ indicated a significant reduction in local failure for patients receiving radiotherapy following STR or GTR. A smaller series¹¹⁸ also confirmed good local control with surgery and radiotherapy compared with GTR alone.

Recommendations on treatment of MPEs are summarized in [Table 6](#).

New Molecular Subgroups: Implications for Management

The aforementioned international molecular classification recognizes 9 molecular subgroups of ependymal tumors, 3 in each anatomical compartment of CNS: spine (SP), posterior fossa (PF), and supratentorial region (ST).⁶ One of the subgroups within each compartment corresponds to WHO grade I subependymomas (SEs: SP-SE, PF-SE, and

ST-SE), occurs exclusively in adults, and shows favorable prognosis, while the 2 other molecular subgroups within the spine predominantly correspond to the histological diagnoses of MPE (SP-MPE) and WHO grades II–III ependymoma (SP-EPN).⁶

Two molecular types of ependymomas have been identified in the posterior fossa, termed PF-EPN-A and PF-EPN-B (group A and group B). PF-EPN-A tumors occur predominantly in infants and young children, are often in a lateral location and difficult to resect completely, and are associated with a high recurrence rate.²³ Conversely, PF-EPN-B tumors occur largely in adolescents and young adults and are associated with a more favorable prognosis. Data from a recent retrospective study on 4 independent nonoverlapping cohorts of PF-EPNs¹¹⁹ found that patients with either group A or group B tumors appeared to benefit from GTR, with the survival rates being particularly poor for subtotaly resected PF-EPN-A, even in association with radiation therapy. Moreover, a large subset of patients with PF-EPN-B who received a GTR did not recur even without adjuvant radiotherapy. Based on these data, participants in a multidisciplinary international consensus conference¹²⁰ agreed that for PF-EPN-A tumors in patients older than 12 months, maximal safe resection and focal radiotherapy should be defined as standard of care; furthermore, due to the challenging localization of tumors, patients would benefit from being treated in specialized centers by experienced neurosurgeons. Conversely, for patients with PF-EPN-B tumors undergoing GTR, a randomized clinical trial comparing observation versus standard focal radiotherapy could be launched.

A number of ST-EPNs are characterized by fusions between C11orf95 and the RELA gene (ST-EPN-RELA)^{6,20} and occur in both children and adults. Retrospective studies have suggested that these tumors are associated with a poor prognosis, extent of resection not being significantly associated with outcome. Thus, in this patient population, postoperative radiotherapy seems to be recommended. Another molecular subgroup of ST-EPNs harbors recurrent fusion with the oncogene YAP1, is enriched in the pediatric population, and shows a favorable prognosis.^{6,20} Gain of chromosome arm 1q occurs in a subset of PF-EPN-A, PF-EPN-B, and ST-EPN-RELA tumors and has been shown to be an independent negative prognostic factor.^{26,121,122}

In conclusion, all these molecular subtypes with distinct prognosis will hopefully benefit from distinct personalized therapies. [Table 4](#)

Supplementary Material

Supplementary material is available at *Neuro-Oncology* online.

Funding

None.

Conflict of interest statement. No conflicts declared by the authors.

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