Journal of Cancer Research and Clinical Oncology (2025) 151:166
https://doi.org/10.1007/s00432-025-06215-9

CASE REPORT

Multifocal medulloblastoma in an adult: a case report and review of the literature

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Received: 2 March 2025 / Accepted: 26 April 2025 / Published online: 15 May 2025

Abstract

Background Medulloblastoma (MB) is a highly aggressive tumor originating in the cerebellum, predominantly affecting children. Adult medulloblastoma is rare, leading to a lack of a standardized treatment protocol. Although multimodal strategies from pediatric MB have improved outcomes in adult patients, challenges persist, including early diagnosis difficulties, treatment toxicity, recurrence risks, targeted therapies, and controversies over chemotherapy timing and regimen.

Case description We present a clinical case involving a 53-year-old male patient diagnosed with multifocal medulloblastoma, who presented with symptoms of dizziness. Cranial magnetic resonance imaging (MRI) revealed space-occupying lesions in the right cerebellar infratentorial region and the right temporal pole, which were initially suspected to be meningiomas. The patient subsequently underwent surgical resection of the subtentorial lesion, which was pathologically confirmed to be a medulloblastoma. Molecular classification through genetic testing classified it as the SHH subtype. Postoperatively, the patient received sequential radiotherapy and chemotherapy. After radiotherapy, the lesion in the temporal pole disappeared, and the patient recovered well. Disease-free survival of this patient was more than 2 years, during which the patient returned to the hospital for follow-up every three months. Currently, the patient is in good condition with no significant treatment sequelae or signs of recurrence.

Conclusion Adult medulloblastoma is rare, and adult multifocal medulloblastoma is even rarer. The adult patient with multifocal medulloblastoma we report underwent surgery followed by sequential radiotherapy and chemotherapy, resulting in a favorable prognosis. This may suggest that postoperative radiotherapy combined with chemotherapy could be effective in controlling adult medulloblastoma.

Keywords Medulloblastoma · Adult Medulloblastoma · Multifocal Medulloblastoma · Sequential radiotherapy and chemotherapy

Introduction

Medulloblastoma (MB) is an aggressive tumor that occurs in the cerebellum and belongs to the family of primitive neuroectodermal tumors (PNETs) (Williams et al. 2019; Laneve and Caffarelli 2020). As early as 1910, James Homer Wright first described MB as a unique central nervous system tumor and proposed that it might originate from restricted neuronal precursor cells, termed "neuroblasts"(Wright 1910). With the advent of the molecular era, many hypotheses regarding the cellular origin of MB have been challenged and refuted, including the assumption of originating from undifferentiated cells in the subventricular zone(Laneve and Caffarelli 2020). Despite extensive research over many years, the exact cellular origin of MB remains unclear, however, it is established that each subgroup of MB has different cellular origins(Sheng et al. 2024).

MB is one of the most common central nervous system malignancies in children but can also occur in adults(Yuile et al. 2022). In comparison, adult MB is very rare, with an

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annual incidence rate of approximately 0.6 cases per million people(Beier et al. 2018; Dirven et al. 2020; Spyridonidis et al. 2020), accounting for only 0.4-1% of adult central nervous system tumors(Kool et al. 2014; Dirven et al. 2020). The median age of MB in adults is between 20 and 40 years, mainly affecting young individuals under the age of 40(Majd and Penas-Prado 2019), with case reports in patients over the age of 60 being particularly rare(Murase et al. 2018).

Moreover, MB usually occurs in the posterior fossa, a relatively hidden location, making its diagnosis and treatment more challenging(Liu et al. 2020). The clinical manifestations of patients are also not specific and are related to the location and size of the tumor. Common clinical manifestations include hydrocephalus, headache, dizziness, nausea, vomiting, unsteady gait, and truncal ataxia(Zaresharifi et al. 2024). Furthermore, since the radiological presentation of medulloblastoma is not consistent and an accurate conclusion cannot be drawn from imaging data alone, the gold standard for diagnosing medulloblastoma remains histopathological examination(Al-Halabi et al. 2011).

To date, MB is classified into four distinct histological subtypes: classic medulloblastoma, desmoplastic/nodular, extensive nodularity, and large cell/anaplastic (LC/A) (Eibl et al. 2021; Siegfried and Delisle 2021). At the molecular level, MB is also categorized into four molecular subtypes: WNT, SHH, Group 3, and Group 4 (Louis et al. 2021). CTNNB1 mutations are associated with the WNT subtype, PTCH/SMO/SUFU alterations correspond to the SHH subtype, MYC amplification or overexpression is linked to Group 3, and CDK6 as well as MYCN amplification is characteristic of Group 4. Further studies also found significant differences in treatment response and survival among MB patients with different molecular subtypes(Archer et al. 2017). For instance, the WNT subtype generally has a good prognosis(Brandes and Franceschi 2014), while the SHH subtype may benefit from molecular targeted therapy(Kool et al. 2014). However, for patients with mutations in the SMO downstream pathway, SMO inhibitors may be ineffective or develop resistance, necessitating the development of new strategies(Ramaswamy and Taylor 2017).

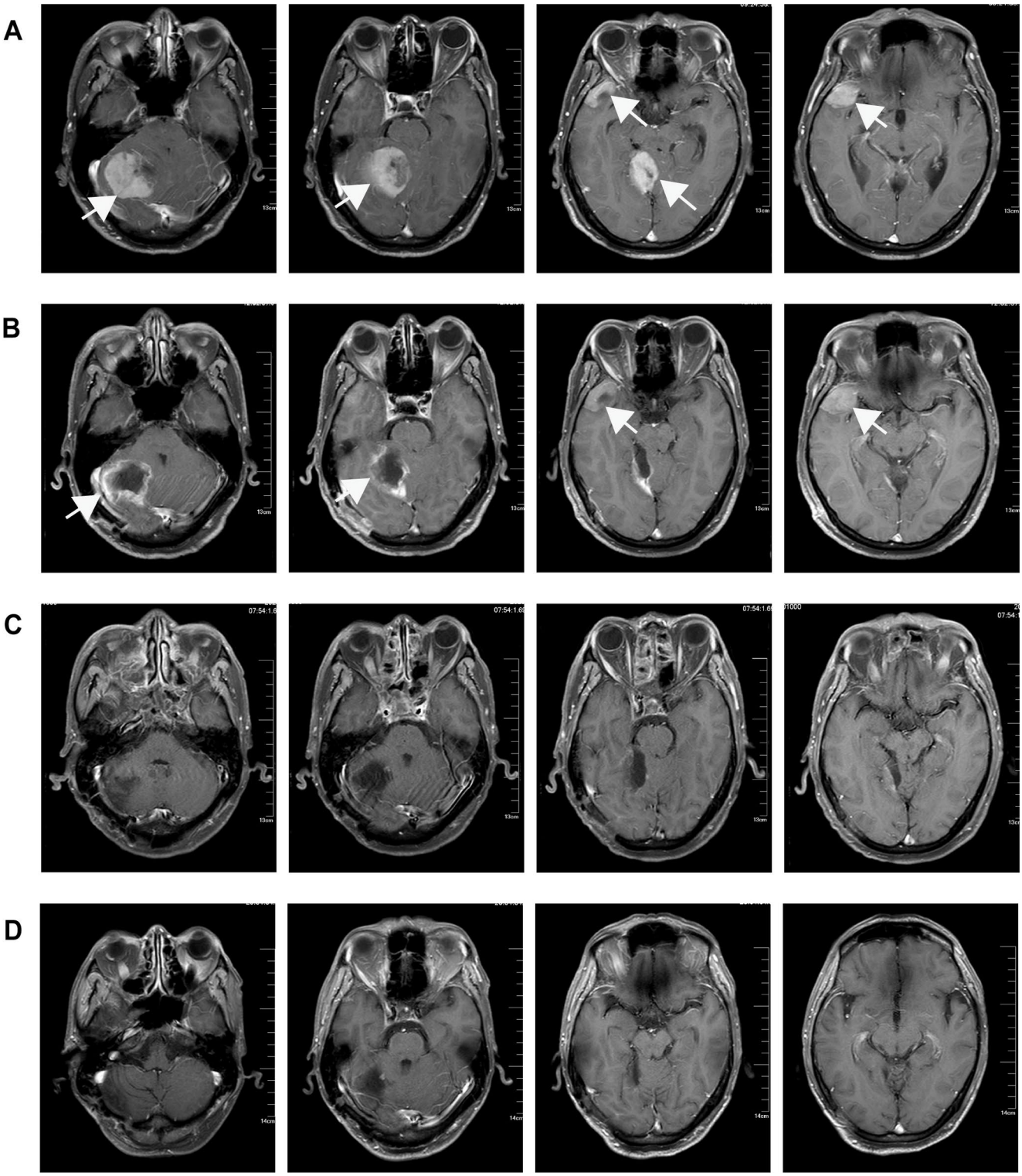
Given the exceedingly low incidence of adult MB, conducting prospective studies poses significant challenges and such studies are therefore scarce(Majd and Penas-Prado 2019). There are currently no established official treatment guidelines for medulloblastoma in adult patients. The treatment for adult MB are primarily extrapolated from data obtained from pediatric MB patient cohorts and retrospective analyses(Penas-Prado et al. 2020).

Fig. 1 MRI examination at different stages of treatment. (**A**) Preoperative MRI examination showed the lesions were located in the right infratentorial cerebellum and the right temporal skull (white arrows). The enhanced scan was not uniformly enhanced, and the lamellar low signal without intensification could be seen. (**B**) Postoperative MRI examination showed most of the right cerebellar lesions were removed. The lesion margin and adjacent dura were significantly enhanced (white arrows). In the right temporal skull, the sublamellar lesions were slightly larger than that before operation, with uneven enhancement (white arrows). The cerebellum and the fourth ventricle were slightly compressed, the supratentorial ventricle was slightly enlarged, and the midline structure was centered. (**C**) Postradiotherapy MRI examination showed the dural enhancement at the edge and adjacent to the right cerebellar operative area was less than before. There was no definite indication of the lesions in the right temporal skull. (**D**) After all treatments, MRI examination showed the right posterior cranial fossa changed after the operation, the right cerebellar hemispherical lamellar softening lesion formed and the surrounding gliosis. No significant enhancement was observed.

Case report

The patient, a 53-year-old male, presented to the hospital with dizziness accompanied by fatigue and poor appetite for over ten days. He first went to a local hospital and Computed Tomography (CT) examination of the head revealed intracranial space occupying lesions. Then he came to our hospital for further diagnosis and treatment. Upon admission, we conducted a detailed physical examination and did not find any obvious positive signs. There were no significant findings in his past medical history, personal history, or family history. Cranial magnetic resonance imaging (MRI) revealed two mass lesions: one located under the right cerebellar tentorium and the other beneath the inner table of the right temporal skull (Figure 1A). The lesions exhibited slightly elongated T2 and T1 signals, with isointense signals on DWI. The dimensions were approximately 44 mm × 45 mm × 43 mm and 27 mm × 20 mm × 26 mm (anteroposterior diameter × transverse diameter × craniocaudal diameter), respectively. The enhanced scan showed heterogeneous enhancement with band-like hypointense areas within the lesions that did not enhance, surrounded by slight elongation of T2 and T1 edema. The lesion had a broad base connected to the adjacent meninges, causing compression of the cerebellum and fourth ventricle, leading to tonsillar herniation, slight expansion of the supratentorial ventricles, and the midline structures were centered. Comprehensive examinations including chest CT, abdominal ultrasound, thyroid, and cervical lymph nodes did not reveal any other issues, ruling out distant metastasis.

After the imaging and hematology tests, he underwent a focal lesion excisional biopsy under general anesthesia. After removing a portion of the cerebellar tissue, revealing the lesion located at the posterior inferior aspect of the right cerebrum, with sizes approximately 44 mm × 45 mm × 43 mm. And more importantly, the tumor showed an



aggressive and invasive growth, indistinct borders from surrounding tissues. Intraoperatively, the cerebellar lesion was fully excised, and biopsies were obtained from the cerebellar tentorium for both frozen and permanent pathological analysis. In contrast, the lesion in the right temporal region was not resected. Immunohistochemistry staining according to standard procedures demonstrated that the positive rate of the Ki-67 (marker of proliferation) index was about 40%, and positivity for CD6, Syn, Vimentin, CD99 and SOX-10 were observed. However, staining for CD34, S-100, SSTR-2, CgA, EMA, PR, CK, STAT-6, INI-1 and GFAP-1 were negative. Based on morphological and immunohistochemical

results, the diagnosis was consistent with MB. Tumor tissue was analyzed using a comprehensive approach that included Next-Generation Sequencing (NGS), Fluorescence In Situ Hybridization (FISH), and methylation-specific PCR. This analysis revealed an activating mutation in the SMO gene (p.L412F) and a deletion of chromosome 17. Notably, no mutations were detected in the TP53 or CTNNB1 genes, nor was there any amplification of the MYCN or MYC genes. Additionally, promoter region methylation of the MGMT gene was not observed, and co-deletion of 1p36 and 19q13 was absent. Based on the comprehensive pathological morphology and molecular testing results, the molecular subtype of this patient's MB was classified as SHH-4 group with a TP53 wild-type status.

One month after surgery, the patient underwent a cranial MRI examination (Figure 1B). Postoperative changes were observed in the right occipital skull and adjacent soft tissue, with the enhanced scan showing significant reinforcement at the lesion edges and adjacent dura mater. Slightly elongated T2 and T1 mass shadows were visible beneath the inner table of the right temporal skull, with a few long T1 and T2 signal shadows inside. The lesion measured approximately 32 mm × 20 mm × 26 mm (anteroposterior diameter × transverse diameter × craniocaudal diameter), representing an increase in size compared to preoperative measurements. The enhanced scan showed heterogeneous reinforcement, with band-like hypointense areas within the lesions that did not enhance. Small blood vessel shadows were observed in the perilesional area, accompanied by mild T2 and T1 signal prolongation indicative of surrounding edema. The lesion had a broad base connected to the adjacent meninges, causing slight compression of the cerebellum and fourth ventricle, slight expansion of the supratentorial ventricles, and the midline structures remained centered.

Subsequently, the patient began to receive craniospinal irradiation, with a dose of 36 Gy delivered in 18 fractions, once daily, five days per week. An additional 14 Gy was administered to the subtentorial tumor bed, increasing the total dose to 50 Gy; an additional 24 Gy was delivered to the right temporal pole lesion, resulting in a cumulative dose of 60 Gy. During radiotherapy, the patient experienced mild bone marrow suppression along with symptoms including headache, dizziness, and nausea. We administered symptomatic supportive treatments, which included managing myelosuppression, alleviating cerebral edema, controlling nausea and vomiting, and preventing seizures. These interventions significantly alleviated the patient's symptoms and gradually improved his overall condition. One month following the completion of radiotherapy, the patient returned for a follow-up visit. During this visit, the patient reported no significant symptoms, and the physical examination revealed no specific positive signs. A repeat cranial MRI demonstrated that the enhanced scan showed reduced enhancement at the lesion edges and adjacent dura mater compared to the baseline images. The previously observed abnormal signals beneath the inner table of the right temporal skull were no longer observed (Figure 1C). Additionally, the compression of the cerebellum and fourth ventricle, as well as the expansion of the supratentorial ventricles, were notably alleviated compared to previous imaging.

After thorough evaluation, we have determined that the most appropriate course of action for the patient is to administer six cycles of chemotherapy using the Etoposide-Cisplatin regimen. Specifically, Etoposide was administered at a dose of 100 mg/m^2 intravenously on days one, two, and three, while Cisplatin was given at a dose of 80 mg/m^2 intravenously on day one. This treatment cycle was repeated every 3–4 weeks. Following chemotherapy, the patient experienced mild to moderate bone marrow suppression accompanied by symptoms such as nausea, vomiting, and reduced appetite. We provided targeted supportive care, which effectively alleviated the patient's symptoms and enabled him to complete six cycles of chemotherapy. After the end of all treatment (May 22, 2023), the patient returned for regular follow-up visits every three months. In the most recent follow-up on March 25, 2025, the patient's condition was good with no signs of recurrence or metastasis observed (Figure 1D).

Discussion

Adult multifocal medulloblastoma (MMB) is extremely rare, with the first documented case reported in 1988 (Shen and Yang 1988). To date, only seven cases have been reported(Shen and Yang 1988; Spagnoli et al. 1990; Gliemroth et al. 1998; Ciccarino et al. 2012; Balik et al. 2015; Saad et al. 2017; Troncon et al. 2020) (Table 1). After reviewing these literatures, we found that among the seven patients, there were four males and three females, with an average age of 39.9 years (range 31–54 years). All patients presented with 2 to 5 lesions. The common symptom reported by all patients was headache. Additional symptoms included dizziness, vomiting, gait disorder, intention tremor, dysmetria, ataxia and diplopia. The most common site of occurrence was the cerebellar hemisphere (7/7), consistent with the most common site for adult MB, followed by the cerebellar vermis (3/7), with other sites including the left occipital lobe, pontocerebellar angle, bilateral caudate nucleus, and left temporal lobe(Troncon et al. 2020). Unfortunately, only three patients(Balik et al. 2015; Saad et al. 2017; Troncon et al. 2020) underwent genetic testing, and all of them were confirmed to be SHH subgroup, the most common type of adult MB. One patient developed a rare

Table 1 Reported cases of multifocal Medulloblastomas in adults

Case, Year	Gender, Age	Number of lesions	Clinical manifestation	Tumor location	Spinal metastasis	Molecular classification	TP-53 mutation	Proliferative index (Ki-67)	Therapeutic regimen	Number of surgical excisions	Chemotherapy regimen	Survival
1 1988	Male 31	3	Headache, vomiting	Cerebellar hemispheres	Unspecified	Unspecified	Unspecified	Unspecified	Surgery + Craniospinal radiation	3	-	Recurred 1 year later, recurred again after a second operation and died
2 1990	Female 36	3	Headache, gait disturbance, intention tremor, and nystagmus	Cerebellar hemispheres	No	Unspecified	Unspecified	Unspecified	Surgery + radiation	Unknown	-	Unspecified
3 1998	Male 54	2	Headache, nausea, vomiting, nystagmus, gait disorders, and bilateral dysmetria	Cerebellar hemispheres, left occipital lobe	No	Unspecified	Unspecified	Unspecified	Biopsy + Craniospinal radiation	0	-	Unspecified
4 2012	Male 31	2	Headache, ataxia	Cerebellar hemispheres, left occipital lobe	No	Unspecified	Unspecified	Unspecified	Surgery + 2 cycles of chemotherapy + craniospinal radiotherapy	2	Cisplatin + etoposide + cyclofosfamide	No recurrence after 6 months of follow-up
5 2015	Female 39	3	Headache	Cerebellar vermis, left hemisphere	Unknown	SHH	Unspecified	Unspecified	Surgery	Gross total tumor resection	-	Died of acute diffuse cerebellar swelling 12 days after surgery
6 2017	Male 41	5	Headache, dizziness	Cerebellar vermis and hemispheres, bilateral caudate nuclei, and left temporale lobe	No	SHH	Negative	Unspecified	Biopsy	0	-	Unspecified
7 2020	Female 47	3	Headache, vomiting	Cerebellar vermis, cerebellar hemispheres	No	SHH	Negative	30-40%	Surgery + craniospinal radiation + 6 cycles of chemotherapy	2	Cisplatin + lomustine + vincristine	No progression for 30 months after diagnosis

Table 1 (continued)

Case, Year	Gender, Age	Number of lesions	Clinical manifestation	Tumor location	Spinal metastasis	Molecular classification	TP-53 mutation	Proliferative index (Ki-67)	Therapeutic regimen	Number of surgical excisions	Chemotherapy regimen	Survival
8/Our case	Male 53	2	Headache	Cerebellar hemisphere, right temporal lobe	No	SHH	Negative	30-40%	Surgery + craniospinal radiation + 6 cycles of chemotherapy	1	Etoposide + cisplatin	No recurrence after 22 months of follow-up

postoperative acute diffuse cerebellar swelling (DCS) and died 12 days after surgery(Balik et al. 2015). Our report is the eighth case, involving a 53-year-old male who presented with two lesions simultaneously, one located in the right subtentorial region of the cerebellum and the other in the right temporal pole; genetic testing confirmed it as the SHH subtype. Although the chemotherapy regimens used by the three patients receiving chemotherapy were not the same, it appears that the patients receiving chemotherapy seemed to have a better prognosis than those who did not.

Contrary to expectations, MMB in children appears to be less common than in adults, with only two cases have been reported. Smucker(Smucker and Smith 2006) et al. reported in 2006 on a 2.5 year old boy who presented with sexual clumsiness and difficulty walking. Multifocal connective tissue hyperplasia MB and Gorlin syndrome[also known as nevoid basal cell carcinoma syndrome (NBCCS)], were confirmed by pathologic findings, DNA sequencing, clinical manifestations and family history. His father had NBCCS, and his mother also had a history of large tumors in her family. MB is one of the secondary diagnostic criteria for NBCCS(Fujii and Miyashita 2014), and about 3% of NBCCS patients will develop MB(Smucker and Smith 2006). Ionizing radiation that treats MB may also cause basal cell carcinoma(BCC) to develop in the irradiated area over a long period of time(Campbell et al. 2005). In 2022, a 10-year-old boy with synchronous multifocal classic MB was reported, presenting with bilateral vision loss(Borni et al. 2022). MRI Showed 4 lesions with Spinal metastasis. This was the only one of the 9 patients with MMB with spinal metastasis. In general, MB is more prone to leptomeningeal dissemination rather than spinal cord metastasis(Goyal et al. 2018).

Although cases of MMB are rare and the clinical presentation is complex, the treatment of these patients follows the core treatment principles of MB. Currently, MB treatment includes surgical resection, radiotherapy, and chemotherapy, but there are certain differences between countries, regions, centers, and even within centers. Surgery is the preferred treatment method because it is the most effective means of relieving symptoms, as well as providing a definitive diagnosis and laying the foundation for subsequent treatment(Franceschi et al. 2019). The standard for surgery is maximal safe resection; however, if the lesion involves the brainstem, aggressive resection is not recommended(Choi 2023). The efficacy of radiotherapy is affirmative, whether it is received before, during, or after surgery, and it benefits patient survival(Ma et al. 2020). The appropriate dose for the tumor bed or posterior fossa is currently under discussion and related studies have found that in adults, a local radiotherapy dose exceeding 54 Gy can achieve a 70–90% 5-year disease control rate, while the

percentage significantly decreases when the dose is below 50 Gy(Brandes and Franceschi 2014).

With the standard implementation of this comprehensive treatment model, the five-year event-free survival rate for children with MB exceeds 60% and overall survival rate exceeds 70%(von Bueren et al. 2016). According to different risk stratifications, combined treatments have also shown promising results in adult MB patients(Hadi et al. 2018; Manfreda et al. 2023), with 5-year survival rates exceeds 60%(Eibl et al. 2021). Although there is no unified consensus on whether adult MB patients should undergo adjuvant chemotherapy, the timing and regimen of chemotherapy, statistical analyses have found that adult patients receiving postoperative radiotherapy combined with chemotherapy had improved outcomes compared to radiotherapy alone(Kann et al. 2017; Majd et al. 2021). A single-institution retrospective study indicated that adding chemotherapy during radiotherapy improved patients' PFS and OS, but the study included only average-risk adult patients (no metastasis and no residual lesions after surgery) (Franceschi et al. 2020). Additionally, Banu Atalar et al. found that chemotherapy was beneficial to local control and reduced local recurrence rate(Atalar et al. 2018).The commonly used chemotherapy regimen for adult MB is the Packer regimen (eight doses of vincristine 1·5 mg/m^2 [maximum of ^{2} mg] during radiotherapy, followed by a maximum of eight cycles of lomustine 75 mg/m^2 on day 1, cisplatin 70 mg/m^2 on day 1 and vincristine 1.5 mg/m^2 [maximum of 2 mg] on days 1, 8, and 15 of 6 week cycles) was developed with and without radiotherapy dose reduction(Franceschi et al. 2019). Cisplatin - etoposide regimen can be used as an alternative or for recurrence(Sherwood et al. 2023). The patient we report underwent sequential chemoradiotherapy postoperatively, with the cisplatin-etoposide regimen, which has so far been beneficial to the patient's survival. Combining previous reports with the cases we reported, we can find that it appears that surgery combined with craniospinal radiotherapy and 6 cycles of adjuvant chemotherapy are more beneficial for tumor control and survival in patients.

Unfortunately, those who survive long after the end of comprehensive treatment often experience severe side effects. The most common≥G3 toxicities were ototoxicity, motor dysfunction, and cognitive dysfunction. Others include anxiety-depressive states, hypothalamic-pituitary dysfunction, and cranial nerve dysfunction. All of these significantly impairs their quality of life(Saraf et al. 2022). What's more, even if initial treatment is successful, about 30% of MB patients still experience tumor recurrence(Sheng et al. 2024). Late-stage relapses are more common in adult patients, which usually occurs more than 4 years after treatment(Troncon et al. 2020). Because of the potential risk of relapse, long-term monitoring becomes an important part of the management of adult patient.

With the deepening understanding of the cell source, pathogenesis and subtype of medulloblastoma, personalized targeted therapy may become a reality in the future. Vismodegib is one of the currently approved SMO inhibitors, but it has not been widely adopted due to rapid development of resistance(Shih 2021). Meanwhile, reduced dose conventional radiotherapy, conformal radiotherapy, and proton radiotherapy are potential alternative radiotherapy approaches currently under exploration in some clinical trials. Maura Massimino and colleagues found that reduced-dose craniospinal irradiation combined with chemotherapy is feasible for adult patients with standard-risk (no distant metastases, postoperative residual lesions < 1.5 cm^2 or no residual lesions, non-large cell/anaplastic histology) medulloblastoma(Massimino et al. 2020). A small retrospective study showed that compared with photon craniospinal radiotherapy, proton craniospinal radiotherapy can better protect the surrounding organs at risk without compromising the efficacy, and is well tolerated, reducing the incidence of acute radiation-related toxicities (such as hematologic and gastrointestinal toxicities) (Breen et al. 2024).

In conclusion, synchronous MMB is quite rare in both adult and pediatric patients, with only 7 adult cases and 2 pediatric cases reported so far. Due to the limited number of cases reported in the literature, the pathogenesis and prognosis of MMB remains unclear. This study reports a case of MMB in an adult patient who received sequential radiotherapy and chemotherapy postoperatively and had a good prognosis. Moreover, this patient belongs to the most common SHH subtype of adult MB, providing a reference direction for a deeper understanding of the characteristics of adult multifocal MB and exploring more effective treatment options. Future research and clinical trials are needed to further explore personalized treatment plans to improve treatment outcomes, reduce the risk of recurrence, and enhance the quality of life for patients.

Acknowledgements We would like to express our deepest gratitude to all those who have provided their support and assistance in the completion of this project.

Author contributions Cha Luo prepared the manuscript and figures. Fei Zhang, Hongting Jiang, Ying Zeng and Zhonglian Wang performed data analysis and interpretation. Qing Ye, Wei Jian and Jing Zhang contributed to discussion and interpretation. Cha Luo, Qiaofen Fu and Xiaofeng Zhu edited and approved the final manuscript. All authors have read and agreed to the published version of the manuscript.

Funding This study was supported by the National Natural Science Foundation of China (No. 82160529), the Yunnan Revitalization Talent Support Program (grant no. RLQB20220014), Yunnan Health Training Project of High Level Talents (grant no. H-2024021)and the 535 Talent Project of the First Affiliated Hospital of Kunming Medical

University (No. 2023535D17).

Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval The studies involving humans were approved by the Ethics Committee of the First Affiliated Hospital of Kunming Medical University, under approval number (2024) Ethical L No. 119.

Patient consent for publication The patient provided written informed consent for publication of patient data and associated images.

Competing interests The authors declare no competing interests.

References

Al-Halabi H, Nantel A, Klekner A et al (2011) Preponderance of Sonic Hedgehog pathway activation characterizes adult Medulloblastoma. Acta Neuropathol (Berl) 121:229–239. https://doi.org/10.1007/s00401-010-0780-0

Archer TC, Mahoney EL, Pomeroy SL (2017) Medulloblastoma: molecular classification-based personal therapeutics. Neurother J Am Soc Exp Neurother 14:265–273. https://doi.org/10.1007/s13311-017-0526-y

Atalar B, Ozsahin M, Call J et al (2018) Treatment outcome and prognostic factors for adult patients with Medulloblastoma: the rare cancer network (RCN) experience. Radiother Oncol 127:96–102. https://doi.org/10.1016/j.radonc.2017.12.028

Balik V, Trojanec R, Holzerova M et al (2015) An adult multifocal Medulloblastoma with diffuse acute postoperative cerebellar swelling: immunohistochemical and molecular genetics analysis. Neurosurg Rev 38:1–10 discussion 10. https://doi.org/10.1007/s10143-014-0556-4

Beier D, Proescholdt M, Reinert C et al (2018) Multicenter pilot study of radiochemotherapy as first-line treatment for adults with Medulloblastoma (NOA-07). Neuro-Oncol 20:400–410. https://doi.org/10.1093/neuonc/nox155

Borni M, Abdelmouleh S, Cherif I et al (2022) Pediatric synchronous multifocal and disseminated cerebrospinal classic Medulloblastoma revealed by bilateral decreased visual acuity: A case report. Childs Nerv Syst ChNS Off J Int Soc Pediatr Neurosurg 38:2211–2215. https://doi.org/10.1007/s00381-022-05546-z

Brandes AA, Franceschi E (2014) Shedding light on adult medulloblastoma: Current management and opportunities for advances. Am Soc Clin Oncol Educ Book e82–e87. https://doi.org/10.14694/EdBook_AM.2014.34.e82

Breen WG, Geno CS, Waddle MR et al (2024) Proton versus photon craniospinal irradiation for adult Medulloblastoma: A dosimetric, toxicity, and exploratory cost analysis. Neuro-Oncol Adv 6:vdae034. https://doi.org/10.1093/noajnl/vdae034

Campbell RM, Mader RD, Dufresne RG (2005) Meningiomas after Medulloblastoma irradiation treatment in a patient with basal cell nevus syndrome. J Am Acad Dermatol 53:S256–259. https://doi.org/10.1016/j.jaad.2005.03.033

Choi JY (2023) Medulloblastoma: current perspectives and recent advances. Brain Tumor Res Treat 11:28–38. https://doi.org/10.14791/btrt.2022.0046

Ciccarino P, Rotilio A, Rossetto M et al (2012) Multifocal presentation of Medulloblastoma in adulthood. J Neurooncol 107:233–237. https://doi.org/10.1007/s11060-011-0746-7

Dirven L, Luerding R, Beier D et al (2020) Neurocognitive functioning and health-related quality of life in adult Medulloblastoma patients: long-term outcomes of the NOA-07 study. J Neurooncol 148:117–130. https://doi.org/10.1007/s11060-020-03502-y

Eibl T, Hammer A, Yakubov E et al (2021) Medulloblastoma in adults–reviewing the literature from a Surgeon's point of view. Aging 13:3146–3160. https://doi.org/10.18632/aging.202568

Franceschi E, Hofer S, Brandes AA et al (2019) EANO–EURACAN clinical practice guideline for diagnosis, treatment, and follow-up of post-pubertal and adult patients with Medulloblastoma. Lancet Oncol 20:e715–e728. https://doi.org/10.1016/S1470-2045(19)30669-2

Franceschi E, Minichillo S, Mura A et al (2020) Adjuvant chemotherapy in average-risk adult Medulloblastoma patients improves survival: A long term study. BMC Cancer 20:755. https://doi.org/10.1186/s12885-020-07237-x

Fujii K, Miyashita T (2014) Gorlin syndrome (nevoid basal cell carcinoma syndrome): update and literature review. Pediatr Int Off J Jpn Pediatr Soc 56:667–674. https://doi.org/10.1111/ped.12461

Gliemroth J, Kehler U, Knopp U et al (1998) A multifocal cerebellar and supratentorial Medulloblastoma in an adult. Acta Neurochir (Wien) 140:723–724. https://doi.org/10.1007/s007010050169

Goyal A, Cajigas I, Ibrahim GM et al (2018) Surgical treatment of intramedullary spinal metastasis in Medulloblastoma: case report and review of the literature. World Neurosurg 118:42–46. https://doi.org/10.1016/j.wneu.2018.06.250

Hadi I, Roengvoraphoj O, Niyazi M et al (2018) Medulloblastoma in adults: A retrospective single institution analysis. Strahlenther Onkol Organ Dtsch Rontgengesellschaft Al 194:225–234. https://doi.org/10.1007/s00066-017-1235-5

Kann BH, Lester-Coll NH, Park HS et al (2017) Adjuvant chemotherapy and overall survival in adult Medulloblastoma. Neuro-Oncol 19:259–269. https://doi.org/10.1093/neuonc/now150

Kool M, Jones DTW, Jäger N et al (2014) Genome sequencing of SHH Medulloblastoma predicts genotype-related response to smoothened Inhibition. Cancer Cell 25:393–405. https://doi.org/10.1016/j.ccr.2014.02.004

Laneve P, Caffarelli E (2020) The Non-coding side of Medulloblastoma. Front Cell Dev Biol 8:275. https://doi.org/10.3389/fcell.2020.00275

Liu X, Ding C, Tan W, Zhang A (2020) Medulloblastoma: molecular understanding, treatment evolution, and new developments. Pharmacol Ther 210:107516. https://doi.org/10.1016/j.pharmthera.2020.107516

Louis DN, Perry A, Wesseling P et al (2021) The 2021 WHO classification of tumors of the central nervous system: A summary. Neuro-Oncol 23:1231–1251. https://doi.org/10.1093/neuonc/noab106

Ma AK, Freedman I, Lee JH et al (2020) Tumor location and treatment modality are associated with overall survival in adult

Medulloblastoma. Cureus 12:e7061. https://doi.org/10.7759/cureus.7061
Majd N, Penas-Prado M (2019) Updates on management of adult Medulloblastoma. Curr Treat Options Oncol 20:64. https://doi.org/10.1007/s11864-019-0663-0
Majd NK, Mastall M, Lin H et al (2021) Clinical characterization of adult Medulloblastoma and the effect of first-line therapies on outcome; the MD Anderson cancer center experience. Neuro-Oncol Adv 3:vdab079. https://doi.org/10.1093/noajnl/vdab079
Manfreda L, Rampazzo E, Persano L et al (2023) Surviving the hunger games: metabolic reprogramming in Medulloblastoma. Biochem Pharmacol 215:115697. https://doi.org/10.1016/j.bcp.2023.115697
Massimino M, Sunyach MP, Barretta F et al (2020) Reduced-dose craniospinal irradiation is feasible for standard-risk adult Medulloblastoma patients. J Neurooncol 148:619–628. https://doi.org/10.1007/s11060-020-03564-y
Murase M, Saito K, Abiko T et al (2018) Medulloblastoma in older adults: A case report and literature review. World Neurosurg 117:25–31. https://doi.org/10.1016/j.wneu.2018.05.216
Penas-Prado M, Theeler BJ, Cordeiro B et al (2020) Proceedings of the comprehensive oncology network evaluating rare CNS tumors (NCI-CONNECT) adult medulloblastoma workshop. Neuro-Oncol Adv 2:vdaa097. https://doi.org/10.1093/noajnl/vdaa097
Ramaswamy V, Taylor MD (2017) Medulloblastoma: from myth to molecular. J Clin Oncol 35:2355–2363. https://doi.org/10.1200/JCO.2017.72.7842
Saad AG, Balik V, Parvez A, El Jamal SM (2017) Multifocal Supra and infratentorial Medulloblastoma in an adult: histologic, immunohistochemical, and molecular evaluation of a rare case and review of the literature. Appl Immunohistochem Mol Morphol 25:e89. https://doi.org/10.1097/PAI.0000000000000447
Saraf A, Yock TI, Niemierko A et al (2022) Long-term outcomes and late toxicity of adult Medulloblastoma treated with combined modality therapy: A contemporary single-institution experience. Neuro-Oncol 24:2180–2189. https://doi.org/10.1093/neuonc/noac126
Shen W, Yang C (1988) Multifocal cerebellar Medulloblastoma: CT findings. J Comput Assist Tomogr 12:894. https://doi.org/10.1097/00004728-198809010-00037
Sheng H, Li H, Zeng H et al (2024) Heterogeneity and tumoral origin of Medulloblastoma in the single-cell era. Oncogene 43:839–850. https://doi.org/10.1038/s41388-024-02967-9
Sherwood M, Climans S, Ramos R et al (2023) Review of 20 years of adult Medulloblastoma treatment: chemotherapy prescription trends and survival. Neuro-Oncol Pract 10:186–194. https://doi.org/10.1093/nop/npac074
Shih HA (2021) An early foray with targeted therapy and inspiring novel approaches to combat adult Medulloblastoma. Neuro-Oncol 23:1814–1815. https://doi.org/10.1093/neuonc/noab179
Siegfried A, Delisle M-B (2021) Médulloblastome. Anatomie pathologique. Neurochirurgie 67:28–38. https://doi.org/10.1016/j.neuchi.2017.12.006
Smucker PS, Smith JL (2006) Multifocal desmoplastic Medulloblastoma in an african-American child with nevoid basal cell carcinoma (gorlin) syndrome. Case report. J Neurosurg 105:315–320. https://doi.org/10.3171/ped.2006.105.4.315
Spagnoli D, Tomei G, Masini B et al (1990) A case of multifocal cerebellar Medulloblastoma in an adult patient. J Neurosurg Sci 34:323–325
Spyridonidis T, Papathanasiou N, Spiliotopoulou M et al (2020) Adult Medulloblastoma depicted with 99mTc-HYNIC-[D-Phe1, Tyr3-octreotide] SPECT/CT. Clin Nucl Med 45:1001–1002. https://doi.org/10.1097/RLU.0000000000003341
Troncon I, Guerriero A, Rossi S et al (2020) Multifocal Medulloblastoma in an adult patient: description of a rare presentation and review of the literature. Case Rep Pathol 2020:1–6. https://doi.org/10.1155/2020/4502878
von Bueren AO, Kortmann R-D, von Hoff K et al (2016) Treatment of children and adolescents with metastatic Medulloblastoma and prognostic relevance of clinical and biologic parameters. J Clin Oncol Off J Am Soc Clin Oncol 34:4151–4160. https://doi.org/10.1200/JCO.2016.67.2428
Williams AP, Garner EF, Stafman LL et al (2019) UAB30, A novel rexinoid agonist, decreases stemness in group 3 Medulloblastoma human cell line xenografts. Transl Oncol 12:1364–1374. https://doi.org/10.1016/j.tranon.2019.07.003
Wright JH, A KIND OF TUMOR NOT, GENERALLY RECOGNIZED (1910) J Exp Med 12:556–561. https://doi.org/10.1084/jem.12.4.556
Yuile AK, Kastelan M, Lee AP et al (2022) The use of Sonidegib in the adjuvant and advanced phases of Sonic Hedge Hog Mutant Medulloblastomas. Oxf Med Case Rep 2022:omac019. https://doi.org/10.1093/omcr/omac019
Zaresharifi N, Abbaspour E, Yousefzade-Chabok S et al (2024) Rare incidence of parietal lobe metastasis in an adult with desmoplastic/nodular Medulloblastoma: A case report and review of the literature. Int J Surg Case Rep 115:109322. https://doi.org/10.1016/j.ijscr.2024.109322