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ORIGINAL ARTICLE - TUMOR - MENINGIOMA

Posterior fossa meningiomas: perioperative predictors of extent of resection, overall survival and progression-free survival

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Abstract

Background Posterior fossa meningiomas (PFMs) often represent surgical challenges due to their proximity to neurovascular structures. Factors predicting the extent of resection (EOR), overall survival (OS), and progression-free survival (PFS) were identified and integrated in a prediction tool to offer evidence-based personalized therapeutic strategies.

Methods All meningiomas managed surgically from 1990 to 2010 from a single-center were reviewed. A classification tree was created using the classification and regression tree recursive partitioning analysis that incorporated patient and tumor data available before surgery in order to predict the rates of gross total resection (GTR).

Results A total of 198 patients were identified (female-to-male ratio, 2.7; mean age, 59.1 years) and compared with 1271 supratentorial meningiomas (STMs) operated in the same institution during the same time period. GTR was achieved less often (59.6% versus 81.9%; $p < 0.01$) in PFMs than STMs. Preoperative neurological symptoms were predictive of higher Simpson grades (OR, 2.19 [1.05; 4.58]; $p = 0.04$). Age was associated with reduced OS (OR, 1.08 [1.04;1.12]; $p < 0.001$). A KPS ≥ 70 was associated with higher survival rates (OR, 2.70 [2.19;2.92]; $p = 0.02$). Higher WHO grades were associated with reduced OS (OR, 3.56 [1.02;12.47]; $p = 0.05$). The GTR rate varies from 80% in patients without a preoperative deficit to 40% patients with a preoperative deficit, younger than 60 years old, and with adjacent bone invasion.

Conclusions This study provides a classification tree of the predictors of EOR in PFMs, based upon preoperative demographic, clinical, and radiological variables. An evidence-based management protocol with estimated EORs may guide the decision-making process in PFMs.

Keywords Posterior Fossa · Meningioma · Overall survival · Progression-free survival

Introduction

Intracranial meningiomas are usually benign lesions, representing 30% of all primary intracranial tumors [33, 44]. The incidence of diagnosed meningiomas increases steadily in view of an aging population and the greater availability of magnetic resonance imaging (MRI) [23, 41]. In patients with growing and/or symptomatic meningiomas, the surgical resection is the mainstay treatment option. In 1957, Simpson published a classification of the extent of resection (EOR) and suggested proactive, surgical management in order to minimize the risk of recurrence [40]. Since then, various reports have confirmed the relationship between the EOR and meningioma recurrence, resulting in aggressive surgical management to obtain complete resection [13, 15, 29, 34]. In low-

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grade meningiomas with complete resection, a good disease-control with a low chance of recurrence can be achieved [2, 15, 17]. However, depending on the tumor's size, location, and anatomical relationships with the surrounding structures, complete resection of the meningioma can be challenging [30]. Furthermore, distinct genetic alterations associated to the various anatomic locations are reported [35, 38] and should be considered in the management of the meningiomas. Meningioma surgery has improved greatly over the past decades [7, 28, 39] and more and more authors advocate surgical strategies even in the elderly nowadays [4, 21, 31]. Gross total resection (GTR) is also associated with morbidity as well as mortality; the advent of stereotactic radiosurgery and radiotherapy put aggressive surgical treatment of meningiomas into a new light [1, 6, 19]. Therefore, the identification of preoperative factors predicting the EOR, overall survival (OS) and progression-free survival (PFS) is of paramount importance [5, 16, 20, 27, 32].

Intracranial meningiomas should not be considered a uniform clinical entity: for example, their location and World Health Organization (WHO) grade may lead to various patterns of evolution [11, 24]. Posterior fossa meningiomas (PFMs) in particular, which represent 10% amongst all meningiomas [36], are a surgical challenge due to their proximity to important neurovascular structures: thus, clinical and radiological data should be integrated in a prediction tool, to stratify patients more adequately and to eventually determine personalized therapeutic strategy. Such predictive models of the outcomes of meningiomas' surgery have already been reported, but were not intended specifically for PFM [11].

In this study, the preoperative factors associated with EOR, OS, and PFS in PFMs are reviewed and discussed. Finally, a decision tree for the management of PFMs is presented with the rates of GTR in various surgical situations.

Methods and materials

Patient cohort

Data were retrospectively (1990 to 2002) and prospectively (2003 to 2010) acquired from a databank of Oslo University Hospital (OUH), which covers an area of approximately 3 million inhabitants and constitutes circa 56% of the Norwegian population.

All patients who underwent surgical resection of a PFM at OUH during the study period were included, resulting in a total of $n = 198$ surgeries performed on $n = 198$ patients. Preoperative imaging studies (or reports for older cases) were reviewed to confirm tumor location, contrast enhancement, and presence of calcification. PFMs were defined according to Al-Mefty [8] and classified as follows; 1) Cerebello-pontine angle (CPA); 2) Inferior aspect of the tentorium (IT); 3) Petroclival (PC); or 4) Foramen magnum (FM).

All patients were operated on by the neurosurgical teams of OUH. The EOR was assessed using the Simpson grading system [40], based on the surgical report in conjunction with postoperative imaging. Gross total resection (GTR) was defined as Simpson grade I, II, or III resections, according to the European Association of Neuro-Oncology (EANO) [12].

The histopathological diagnosis of meningioma, as well as the WHO grading were confirmed by a senior neuropathologist. The WHO grading system was used to classify the histology of meningiomas. The WHO criteria changed during the study period: from 1990 to 2001, the tumors were classified as benign, atypical, or anaplastic. From 2001 onwards, the WHO-grading system divided the tumors into grades I, II, and III. For this study, we re-coded the tumors operated before 2001 in the following manner: benign = WHO grade I, atypical = WHO grade II, and anaplastic = WHO grade III.

The postoperative image surveillance was left open to the treating physician's discretion and has not followed a rigorous scheme. Tumor progression was defined as any retreatment for tumor recurrence by means of surgery, conventional fractionated radiotherapy, or stereotactic radiosurgery. PFS was calculated from time of surgery to time of retreatment or censoring. OS was defined as the period between index surgery and all-cause mortality, or otherwise, date of the last follow-up.

Ethics

The study was regulated by the Personal Data Act/Personal Health Data Filing System Act and approved by the Data Protection Official at OUH (2017/5204). Informed consent was not required, according to the Personal Data Act/Personal Health Data Filing System Act.

Statistical analysis

Statistical analysis was performed using R v3.5.1 (https://www.r-project.org). The significant p value was defined at 0.05. A multivariate analysis was performed, using a linear generalized model approach. The variables considered for the Cox regression multivariate analysis were age, sex, preoperative Karnofsky Performance Scale as well as the WHO histopathological grade and postoperative radiation therapy. A classification tree was created using the classification and regression tree (CART) recursive partitioning analysis (RPA) [10] that incorporated the available patient and tumor data before surgery in order to predict the GTR rate.

Results

Baseline demographics and symptoms upon admission

Baseline demographics and symptoms upon admission are summarized in Table 1. A total of 198 PFMs were retrieved (144 females; female-to-male ratio, 2.7; mean age, 59.1 ± 12.9 years) and compared to 1271 supratentorial meningiomas (STMs) operated in the same institution, during the same time period. Gender distribution and age were similar in both groups, but the mean preoperative KPS was significantly lower in PFMs than in STMs (78. ± 13 versus 82 ± 12, $p = 0.003$). The median follow-up was of 8 years.

As far as the presenting symptoms are concerned, only 5.1% and 5.5% of the infra- and supra-tentorial meningiomas were asymptomatic. A neurological deficit was most commonly seen in both groups, but significantly less often in PFMs (75.8% versus 57.8%; $p < 0.01$). Seizures as a presenting symptom were significantly less frequent in the PFM group (33.1% versus 7.1%; $p < 0.01$). Signs of raised intracranial pressure (ICP) were the second most presenting symptom in PFMs and occurred significantly more often than in STMs (45.5% versus 29.6%; $p < 0.01$).

Tumors characteristics

Tumor characteristics are summarized in Table 1. Pertaining to WHO grade, no difference was found between PFMs and STMs. However, tumors invading the adjacent bone structures were significantly less frequent in the PFM group than in the STM group (9.1% versus 20.1%; $p < 0.01$).

Surgical management

PFMs had significantly higher Simpson grades compared to STMs ($p < 0.01$). GTR (Simpson grades I, II, or III) was achieved less often than in STMs (59.6% versus 81.9%; $p < 0.01$, see Table 1).

Predictive factor-associated Simpson scores are shown in Table 2. When accounting for other co-variables in the multivariate analysis, the presence of preoperative neurological symptoms was predictive of a higher Simpson grade in patients with PFMs (OR, 2.19 [1.05; 4.58]; $p = 0.04$). Age, gender, KPS ≥ 70, and the presence of bone invasion were not predictive for the Simpson score. Likewise, none of these factors were predictive for GTR in PFMs.

Classification tree of EOR's probability in infratentorial meningiomas

The classification tree of EOR's probability is shown in Fig. 1: as they were identified as preoperative predictors of EOR in PFM, the presence of a preoperative deficit, patient's age, preoperative KPS, and bone invasion were implemented in hierarchical order, using the recursive partitioning analysis (Table 2). For example, the GTR rate varies from 80% in patients without a preoperative deficit to 40% patients with a preoperative deficit, younger than 60 years old, with adjacent bone invasion.

OS and PFS

Age was significantly associated with reduced OS in PFMs (OR, 1.08 [1.04;1.12]; $p < 0.001$). Furthermore, patients with KPS > 70 had higher OS rates than patients with KPS < 70 (OR, 2.70 [2.19;2.92]; $p = 0.02$). Patients with higher WHO grade meningiomas had an overall reduced OS (OR, 3.56 [1.02;12.47]; $p = 0.05$). Gender, Simpson grade and postoperative radiotherapy were not predictive for OS. Results are shown in Table 3. Figure 2 illustrates the Kaplan-Meier curve of the OS according to KPS (A) and WHO grade (B).

In PFMs, KPS ≥ 70 was the only parameter found to be associated with increased PFS (OR, 0.26 [0.07;1.00]; $p = 0.05$), as shown in Table 3. The Kaplan-Meier curves of PFS according to KPS and age are shown in Fig. 3.

Discussion

In this monocentric, population-based study of 198 patients with surgically managed PFMs, baseline demographics, preoperative clinical data, and outcomes were assessed. They were compared to 1271 STMs operated at the same institution, during the same time period. To the best of our knowledge, for the first time, predictive factors for EOR as well as OS and PFS were analyzed and organized in a classification tree of GTR probability. In their case-series, the group of Roberti et al. previously reported the outcome of 161 PFMs [36]; neither OS nor PFS analysis were provided. The authors concluded that the complete or partial removal of meningiomas can be performed safely and effectively. Here, we complete the picture by showing how different variables factor into EOR, the OS, and the PFS.

PFM: a specific entity

PFMs constitute a subset of intracranial meningiomas, not only due to the anatomical or surgical specificities of the posterior fossa, but also because their clinical presentation and behavior may differ from their supratentorial counterparts [14, 25, 26, 36]. Considering the baseline demographics, age and gender were similar in the supra- and infratentorial cohorts; however, patients with PFMs presented more frequently with reduced KPS, neurological deficits, and elevated ICP at admission (Table 1). Furthermore, GTR was achieved less frequently than

Table 1 Baseline demographics, preoperative status, pathological, and radiological postoperative characteristics of a cohort of 198 patients with surgically managed posterior fossa meningiomas

	Posterior fossa ($n = 198$)		Supratentorial ($n = 1271$)		
	n	%	*n*	%	*p* value
Age	59.1 ± 12.9	–	58 ± 20.1	–	0.26
Sex	144 F/54 M	–	889 F/382 M	–	0.43
Preoperative KPS	78.7 ± 13	–	81.6 ± 11.9	–	0.003
PFMs location					
CPA	80	40.4%	–		–
IT	63	35%	–		–
PC	37	20.5%	–		–
FM	18	10%	–		–
Presenting symptoms					
Asymptomatic	10	5.1%	70	5.5%	0.92
Seizures	14	7.1%	421	33.1%	< 0.01
Raised ICP	90	45.5%	376	29.6%	< 0.01
Neurological deficit	150	75.8%	735	57.8%	< 0.01
WHO grade					0.69
I	183	92.4%	1177	92.6%	
II	12	6.1%	65	5.1%	
III	3	1.5%	29	2.3%	
Bone invasion	18	9.1%	256	20.1%	< 0.01
Simpson grade					< 0.01
I	26	13.1%	551	43.4%	
II	84	42.4%	419	33%	
III	8	4%	71	5.6%	
IV	78	39.4%	224	17.5%	
V	2	1%	6	0.5%	
GTR	118	59.6%	1041	81.9%	< 0.01

KPS, Karnofsky Performance Scale; PF, posterior fossa; CPA, cerebello-pontine angle; IT, inferior surface of the tentorium; PC, petro-clival; FM, foramen magnum; ICP, intra-cranial pressure; M, male; F, female; WHO, World Health Organization; GTR, gross total resection

Table 2 Factors associated with higher Simpson grade. *p* values and odd ratios were calculated using the Cox model multivariate analysis

	Odd ratio	*p*
Age	0.99 [0.98;1.00]	0.30
Sex		
Female	Réf.	
Male	1.16 [0.81;1.67]	0.41
Preoperative Karnofsky		
< 70	Réf.	
≥ 70	0.96 [0.51;1.83]	0.91
Preoperative symptoms		
No	Réf.	
Yes	2.19 [1.05;4.58]	0.04
Bone invasion		
No	Réf.	
Yes	1.02 [0.58;1.78]	0.96

in STMs (Table 1). This might be due to the more difficult access to the posterior fossa and the higher complexity of the lesions, when compared to the supratentorial meningiomas. Lastly, patients with PFMs had worse long-term outcomes, when adjusted for age. This is in line with previously reported data showing that the location plays a major role in the recurrence of meningiomas [24, 30, 43]. This is also supported by recently published data, showing that meningiomas in different anatomic regions present distinct genetic alterations, which are specific to their locations [38]. Therefore, the above-mentioned specificities of PFMs lead to varying overall EOR, OS, and PFS after surgery. This should certainly be taken into account in their management.

Intracranial meningiomas should not be considered a uniform entity, but rather be sub-categorized as done with histopathology. It becomes evident that the Simpson grading is not the sole prognostic factor for long-term radiological and clinical outcome.

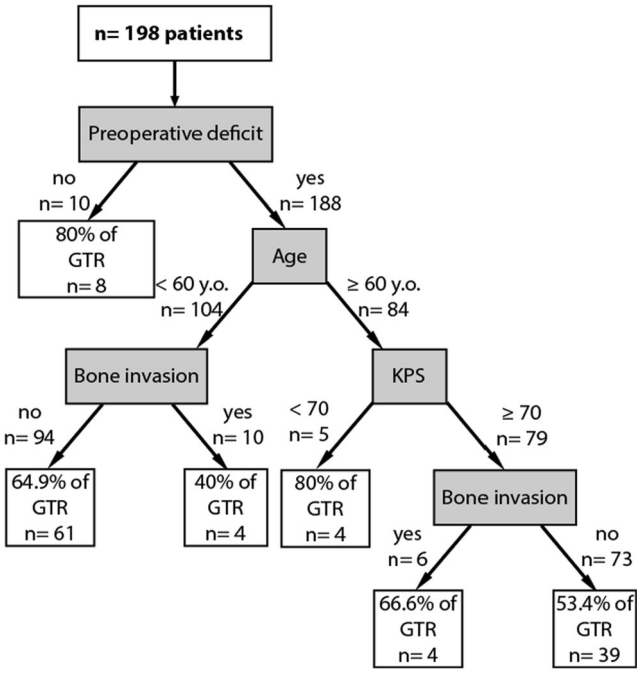

Fig. 1 Classification tree of gross total resection (GTR) probability of posterior fossa meningiomas based on preoperative variables (gray boxes), hierarchically organized. The presence of a preoperative deficit, age over or under 60 years, KPS, and adjacent bone invasion were analyzed. For example, a patient with preoperative deficit, older than 60 years with a KPS < 70 will have an 80% probability of GTR

Preoperative status and EOR

The presence of preoperative neurological symptoms was predictive of higher postoperative Simpson grades. The increased anatomo-surgical complexity, especially with cranial nerve (CN) involvement, might have prevented the complete resection in certain cases [18, 29, 34]. In their case-series, Roberti et al. [36] reported that CN deficits were the most common finding at presentation; 37% of the patients had oculomotor impairment, 38% trigeminal dysfunction, and 42% presented with vestibulo-cochlear impairment, although serviceable hearing was preserved in 93%. The authors reported a GTR of 57%, which is comparable to our cohort [36]. Gousias et al. [13] recently analyzed the outcomes of 901 consecutive patients with WHO grade I to III meningiomas who underwent surgical resection, showing that the Simpson grade was an independent predictor of the PFS [13]. Hence, achieving a maximal resection of the meningioma remains the main goal of the surgery [9, 15, 37]. The implementation of our classification tree in the preoperative discussion may provide useful information as with regard to the probability of achieving GTR. At last, when GTR is not feasible, adjuvant therapies can be streamlined upfront.

Table 3 Predictive factors of overall survival and progression-free survival. *p* values and odd ratios were calculated using the Cox model multivariate analysis. RT: radiation therapy

	Overall survival		Progression-free survival	
	Odd ratio	*p*	Odd ratio	*p*
Age	1.08 [1.04;1.12]	< 0.001	0.98 [0.95;1.01]	0.19
Sex				
Female	Réf.		Réf.	
Male	1.38 [0.66;2.86]	0.39	1.56 [0.68;3.56]	0.29
Preoperative Karnofsky				
< 70	Réf.		Réf.	
≥ 70	0.37 [0.15;0.88]	0.02	0.26 [0.07;1.00]	0.05
WHO grade				
I	Réf.		Réf.	
II and III	3.56 [1.02;12.47]	0.05	0.98 [0.12;8.37]	0.99
Simpson grade	1.23 [0.85;1.76]	0.27	1.20 [0.82;1.76]	0.34
Postoperative RT				
No	Réf.		Réf.	
Yes	0.44 [0.15;1.31]	0.14	0.48 [0.13;1.79]	0.27

Preoperative performance

A higher preoperative KPS was associated with increased PFS and OS; this observation was also made by Kressner et al. [22]; the authors also showed that 294 patients improved their KPS after surgical treatment by a mean of 2.3% [22]. An even higher postoperative clinical improvement (up to 21% increased KPS) has been reported by Umansky et al. in a small cohort of 37 patients [42]. However, none of these studies were focused on PFMs. Even though the KPS is a key factor in the decision-making process, it can be improved by the surgery itself. Thus, KPS inferior to 70% may not be an absolute contraindication to surgery in selected cases. Predictive factors of PFS in infra-tentorial meningiomas are summarized in Table 3.

Perspectives in the surgical management of PFMs

Considering all the preoperative variables reviewed in this article, a decision tree is presented in Fig. 1, summarizing the rate of GTR in PFMs according to age, preoperative KPS, presence of bone invasion, and presence of a preoperative neurological deficit. Using these data, this decision tree may help in determining the individual risk for incomplete resection and plan a two-staged treatment with surgical debulking followed by adjuvant therapy for patients at risk. On the other hand, the risk of the recursive partitioning analysis is to produce an over-fitted model based on our data that may not be extrapolated to other populations. For example, patients without preoperative neurological deficit have a superior rate of GTR, when compared to those with preoperative neurological deficit. This is probably due to the clinical context, as surgeons tend to aim for elective, maximal surgical

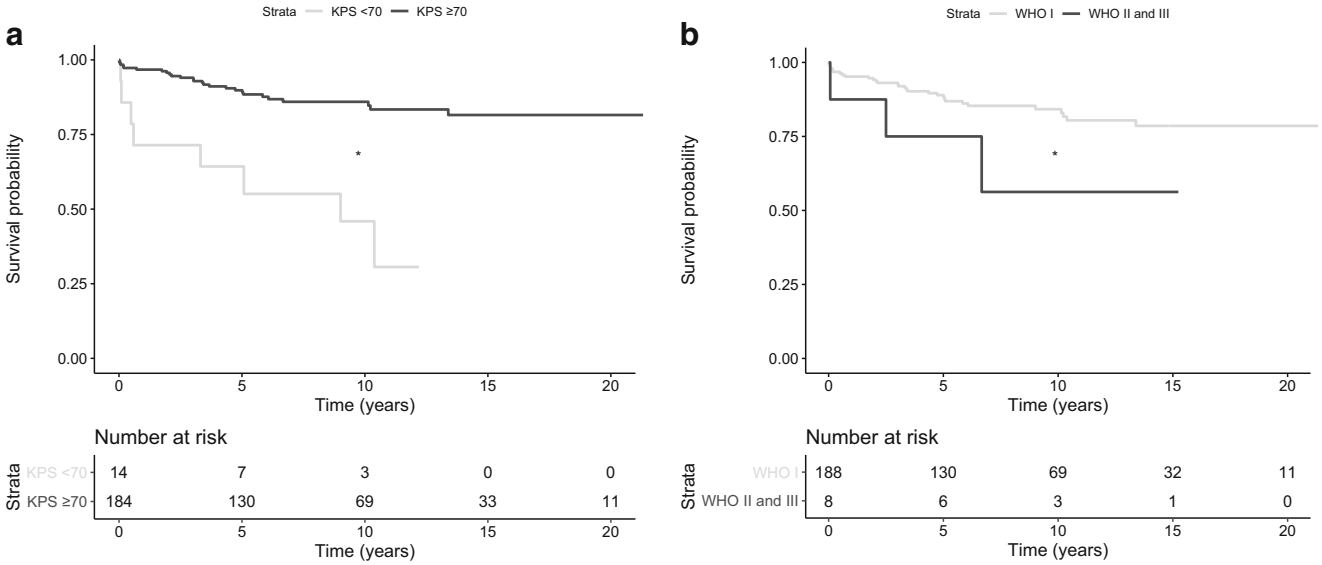

Fig. 2 Kaplan-Meier curves of a cohort of 198 posterior fossa meningiomas managed by surgery. A: overall survival (OS) in patients with preoperative Karnofsky Performance Scale < 70% and ≥ 70%. B: OS in patients with WHO I and WHO II/III posterior fossa meningiomas. *: statistically significant difference

resection with accurate preoperative planning in cases where no preoperative deficit is found. Surprisingly, patients with KPS < 70 had superior rate of GTR when compared to patients with KPS ≥ 70. This may be due to the fact that in cases with preoperative KPS < 70, only those patients with a favorable clinical situation (no other co-morbidities, pre-planned elective surgery) were operated. A similar explanation can be advocated regarding the age, as the patients ≥ 60 years may have superior rate of GTR when compared to patients < 60 years. Finally, patients with bone invasion had increased rates of GTR, because in our cohort the bone invasion concerned mainly the posterior fossa convexity, not the petrous bone or the clivus.

Therefore, The CART might bear a potential recruitment bias, owned to the fact that surgery was only proposed to carefully selected patients. However, it hopefully will serve as a good basis for the establishment of a management protocol.

This study is the first to provide a classification tree of the predictors of EOR in PFMs. As presented in Fig. 1, the EOR is very high for patients without any preoperative deficit. In fact, the absence of clinical signs testifies against the involvement

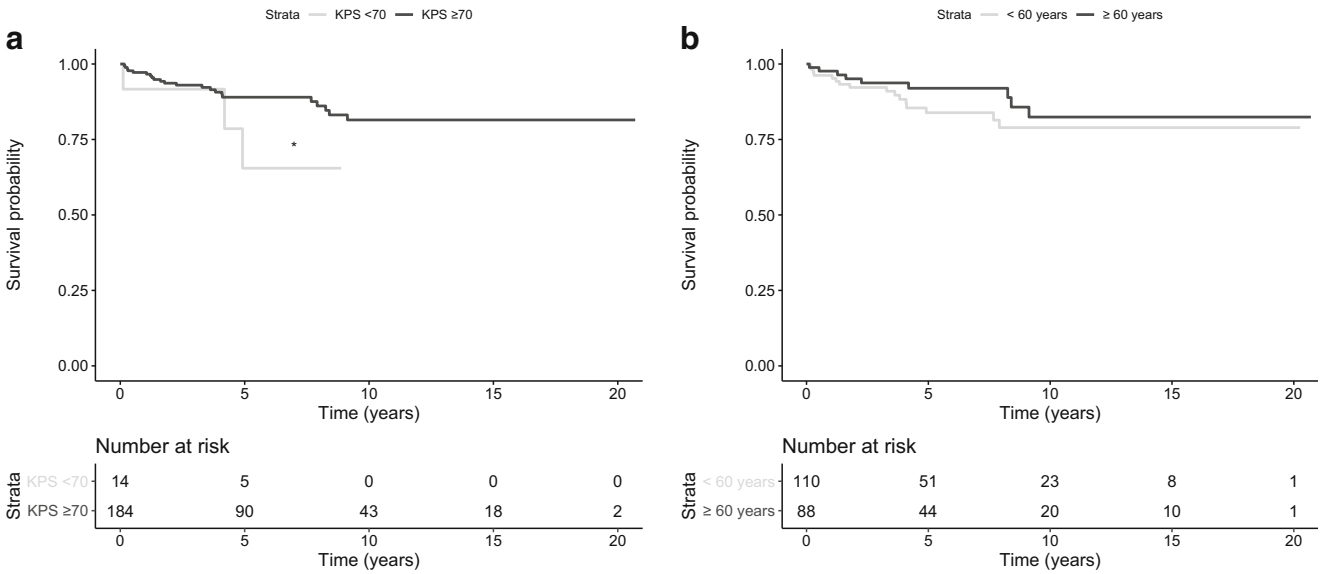

Fig. 3 Kaplan-Meier curves of a cohort of 198 posterior fossa meningiomas managed by surgery. A: progression-free survival (PFS) according Karnofsky Performance Scale < 70 and ≥ 70 . B: PFS according to age < 60 and ≥ 60. *: statistically significant difference

of any neural or vascular structures, rendering PFMs surgery more straightforward. In contrast, surgeons might be more reluctant to aim for a maximal, single-staged surgery, to patients with CN involvement or entrapment of critical vascular structures. This might result in a pre-planned debulking followed by close radio-clinical follow-up or radiotherapy.

Strengths and limitations

The main strengths of this clinical study are the clinical setting, the number of patients as well as the length of follow-up up to 21 years. Loss of follow-up was minimal since all patients with a postoperative complication or recurrence were systematically re-referred to our tertiary center. Only one patient was lost to follow-up, moving abroad. The data stem from one neurosurgical center with mostly homogenous surgical practices. All patients with a histologically proven meningioma were included, which reduces selection bias.

The retrospective data collection before 2003 is a limitation. Moreover, tumors' grading were done according to two different WHO classifications, as mentioned in the methods section. Due to the long period of data collecting starting in 1990, tumor size and molecular biomarkers of proliferation such as Mib-1 were not available for all patients, despite being known factors influencing OS and/or PFS [3]. Furthermore, surgical and monitoring techniques evolved dramatically during the study period. Regarding mortality, no disease-specific survival was registered.

The choice to regroup all PFMs together for the statistical analysis and the data interpretation may also be subject to question: meningiomas do not represent a homogenous pathology and may present with different patterns of evolution and therapeutic managements, especially depending of their location and WHO grade. The global results presented may therefore not be representative of these specific subgroups of meningiomas. As previously mentioned, there is a risk of the recursive partitioning analysis to produce an over-fitted model based on our data that may not be extrapolated to other populations. Also, the CART might bear a recruitment bias because surgery was performed on carefully selected patients.

In our cohort of patients, the RPA analysis (represented by the decision tree) identified populations at risk of poor EOR, regarding to selected preoperative characteristics. The predictive value of our decision tree needs to be tested in a validation cohort.

Conclusion

PFMs constitute a distinct subset of intra-cranial meningiomas with specific predictors of EOR, rates of GTR, OS, and PFS. Considering preoperative demographics, clinical, and radiological variables, a management protocol with an estimated EOR can be implemented in the decision-making process for PFMs.

Compliance with ethical standards

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent The study was regulated by the Personal Data Act/Personal Health Data Filing System Act and approved by the Data Protection Official at OUH (2017/5204). Informed consent was not required according to the Personal Data Act/Personal Health Data Filing System Act.

References

1. Aboukais R, Zairi F, Reyns N, Le Rhun E, Touzet G, Blond S, Lejeune JP (2014) Surgery followed by radiosurgery: a deliberate valuable strategy in the treatment of intracranial meningioma. Clin Neurol Neurosurg 124:123–126. https://doi.org/10.1016/j.clineuro.2014.06.035
2. Adegbite AB, Khan MI, Paine KW, Tan LK (1983) The recurrence of intracranial meningiomas after surgical treatment. J Neurosurg 58:51–56. https://doi.org/10.3171/jns.1983.58.1.0051
3. Barrett OC, Hackney JR, McDonald AM, Willey CD, Bredel M, Fiveash JB (2019) Pathologic predictors of local recurrence in atypical meningiomas following gross total resection. Int J Radiat Oncol Biol Phys 103:453–459. https://doi.org/10.1016/j.ijrobp.2018.09.019
4. Brokinkel B, Holling M, Spille DC, Hess K, Sauerland C, Bleimuller C, Paulus W, Wolfer J, Stummer W (2017) Surgery for meningioma in the elderly and long-term survival: comparison with an age- and sex-matched general population and with younger patients. J Neurosurg 126:1201–1211. https://doi.org/10.3171/2016.2.JNS152611
5. Chen WC, Magill ST, Wu A, Vasudevan HN, Morin O, Aghi MK, Theodosopoulos PV, Perry A, McDermott MW, Sneed PK, Braunstein SE, Raleigh DR (2018) Histopathological features predictive of local control of atypical meningioma after surgery and adjuvant radiotherapy. J Neurosurg:1–8. https://doi.org/10.3171/2017.9.JNS171609
6. Combs SE, Ganswindt U, Foote RL, Kondziolka D, Tonn JC (2012) State-of-the-art treatment alternatives for base of skull meningiomas: complementing and controversial indications for neurosurgery, stereotactic and robotic based radiosurgery or modern fractionated radiation techniques. Radiat Oncol 7:226. https://doi.org/10.1186/1748-717X-7-226
7. Curry WT, McDermott MW, Carter BS, Barker FG 2nd (2005) Craniotomy for meningioma in the United States between 1988 and 2000: decreasing rate of mortality and the effect of provider

caseload. J Neurosurg 102:977–986. https://doi.org/10.3171/jns.2005.102.6.0977
8. DeMonte F, McDermott MW, Al-Mefty O Al-Mefty's meningiomas. Thieme Medical, New York
9. Ehresman JS, Garzon-Muvdi T, Rogers D, Lim M, Gallia GL, Weingart J, Brem H, Bettegowda C, Chaichana KL (2018) The relevance of Simpson grade resections in modern neurosurgical treatment of World Health Organization grade I, II, and III meningiomas. World Neurosurg 109:e588–e593. https://doi.org/10.1016/j.wneu.2017.10.028
10. Fors MM, Viada CE, Gonzalez P (2017) Use of recursive partitioning analysis in clinical trials and meta-analysis of randomized clinical trials, 1990–2016. Rev Recent Clin Trials 12:3–7. https://doi.org/10.2174/1574887111666160916144658
11. Gennatas ED, Wu A, Braunstein SE, Morin O, Chen WC, Magill ST, Gopinath C, Villaneueva-Meyer JE, Perry A, McDermott MW, Solberg TD, Valdes G, Raleigh DR (2018) Preoperative and postoperative prediction of long-term meningioma outcomes. PLoS One 13:e0204161. https://doi.org/10.1371/journal.pone.0204161
12. Goldbrunner R, Minniti G, Preusser M, Jenkinson MD, Sallabanda K, Houdart E, von Deimling A, Stavrinou P, Lefranc F, Lund-Johansen M, Moyal EC, Brandsma D, Henriksson R, Soffietti R, Weller M (2016) EANO guidelines for the diagnosis and treatment of meningiomas. Lancet Oncol 17:e383–e391. https://doi.org/10.1016/S1470-2045(16)30321-7
13. Gousias K, Schramm J, Simon M (2016) The Simpson grading revisited: aggressive surgery and its place in modern meningioma management. J Neurosurg 125:551–560. https://doi.org/10.3171/2015.9.JNS15754
14. Harrison MJ, al-Mefty O (1997) Tentorial meningiomas. Clin Neurosurg 44:451–466
15. Hasseleid BF, Meling TR, Ronning P, Scheie D, Helseth E (2012) Surgery for convexity meningioma: Simpson grade I resection as the goal: clinical article. J Neurosurg 117:999–1006. https://doi.org/10.3171/2012.9.JNS12294
16. Hwang WL, Marciscano AE, Niemierko A, Kim DW, Stemmer-Rachamimov AO, Curry WT, Barker FG 2nd, Martuza RL, Loeffler JS, Oh KS, Shih HA, Larvie M (2016) Imaging and extent of surgical resection predict risk of meningioma recurrence better than WHO histopathological grade. Neuro-Oncology 18:863–872. https://doi.org/10.1093/neuonc/nov285
17. Ildan F, Erman T, Gocer AI, Tuna M, Bagdatoglu H, Cetinalp E, Burgut R (2007) Predicting the probability of meningioma recurrence in the preoperative and early postoperative period: a multivariate analysis in the midterm follow-up. Skull Base 17:157–171. https://doi.org/10.1055/s-2007-970554
18. Jaaskelainen J (1986) Seemingly complete removal of histologically benign intracranial meningioma: late recurrence rate and factors predicting recurrence in 657 patients. A multivariate analysis. Surg Neurol 26:461–469
19. Kaul D, Budach V, Wurm R, Gruen A, Graaf L, Habbel P, Badakhshi H (2014) Linac-based stereotactic radiotherapy and radiosurgery in patients with meningioma. Radiat Oncol 9:78. https://doi.org/10.1186/1748-717X-9-78
20. Kim JH, Jang WY, Jung TY, Kim IY, Lee KH, Kang WD, Kim SK, Moon KS, Jung S (2017) Predictive factors for surgical outcome in anterior clinoidal meningiomas: analysis of 59 consecutive surgically treated cases. Medicine (Baltimore) 96:e6594. https://doi.org/10.1097/MD.0000000000006594
21. Konglund A, Rogne SG, Lund-Johansen M, Scheie D, Helseth E, Meling TR (2013) Outcome following surgery for intracranial meningiomas in the aging. Acta Neurol Scand 127:161–169. https://doi.org/10.1111/j.1600-0404.2012.01692.x
22. Kressner M, Arlt F, Riepl W, Meixensberger J (2018) Prognostic factors of microsurgical treatment of intracranial meningiomas - a multivariate analysis. PLoS One 13:e0202520. https://doi.org/10.1371/journal.pone.0202520
23. Larjavaara S, Haapasalo H, Sankila R, Helen P, Auvinen A (2008) Is the incidence of meningiomas underestimated? A regional survey. Br J Cancer 99:182–184. https://doi.org/10.1038/sj.bjc.6604438
24. Mansouri A, Klironomos G, Taslimi S, Kilian A, Gentili F, Khan OH, Aldape K, Zadeh G (2016) Surgically resected skull base meningiomas demonstrate a divergent postoperative recurrence pattern compared with non-skull base meningiomas. J Neurosurg 125:431–440. https://doi.org/10.3171/2015.7.JNS15546
25. Markham JW, Fager CA, Horrax G, Poppen JL (1955) Meningiomas of the posterior fossa; their diagnosis, clinical features, and surgical treatment. AMA Arch Neurol Psychiatry 74:163–170
26. Martinez R, Vaquero J, Areitio E, Bravo G (1983) Meningiomas of the posterior fossa. Surg Neurol 19:237–243
27. Mascarella MA, Tewfik MA, Aldosari M, Sirhan D, Zeitouni A, Di Maio S (2016) A simple scoring system to predict the resectability of skull base meningiomas via an endoscopic ENDONASAL approach. World Neurosurg 91:582–591 e581. https://doi.org/10.1016/j.wneu.2016.04.093
28. Maurice-Williams RS, Kitchen ND (1992) Intracranial tumours in the elderly: the effect of age on the outcome of first time surgery for meningiomas. Br J Neurosurg 6:131–137
29. McGovern SL, Aldape KD, Munsell MF, Mahajan A, DeMonte F, Woo SY (2010) A comparison of World Health Organization tumor grades at recurrence in patients with non-skull base and skull base meningiomas. J Neurosurg 112:925–933. https://doi.org/10.3171/2009.9.JNS09617
30. Meling TR, Da Broi M, Scheie D, Helseth E (2018) Meningiomas: skull base versus non-skull base. Neurosurg Rev. https://doi.org/10.1007/s10143-018-0976-7
31. Meling TR, Da Broi M, Scheie D, Helseth E (2018) Skull base versus non-skull base meningioma surgery in the elderly. Neurosurg Rev. https://doi.org/10.1007/s10143-018-1005-6
32. Nanda A, Konar SK, Maiti TK, Bir SC, Guthikonda B (2016) Stratification of predictive factors to assess resectability and surgical outcome in clinoidal meningioma. Clin Neurol Neurosurg 142:31–37. https://doi.org/10.1016/j.clineuro.2016.01.005
33. Ostrom QT, Gittleman H, Xu J, Kromer C, Wolinsky Y, Kruchko C, Barnholtz-Sloan JS (2016) CBTRUS statistical report: primary brain and other central nervous system tumors diagnosed in the United States in 2009–2013. Neuro-Oncology 18:v1–v75. https://doi.org/10.1093/neuonc/now207
34. Palma L, Celli P, Franco C, Cervoni L, Cantore G (1997) Long-term prognosis for atypical and malignant meningiomas: a study of 71 surgical cases. J Neurosurg 86:793–800. https://doi.org/10.3171/jns.1997.86.5.0793
35. Preusser M, Brastianos PK, Mawrin C (2018) Advances in meningioma genetics: novel therapeutic opportunities. Nat Rev Neurol 14:106–115. https://doi.org/10.1038/nrneurol.2017.168
36. Roberti F, Sekhar LN, Kalavakonda C, Wright DC (2001) Posterior fossa meningiomas: surgical experience in 161 cases. Surg Neurol 56:8–20 discussion 20-21
37. Rydzewski NR, Lesniak MS, Chandler JP, Kalapurakal JA, Pollom E, Tate MC, Bloch O, Kruser T, Dalal P, Sachdev S (2018) Gross total resection and adjuvant radiotherapy most significant predictors of improved survival in patients with atypical meningioma. Cancer 124:734–742. https://doi.org/10.1002/cncr.31088
38. Sahm F, Schrimpf D, Stichel D, Jones DTW, Hielscher T, Schefzyk S, Okonechnikov K, Koelsche C, Reuss DE, Capper D, Sturm D, Wirsching HG, Berghoff AS, Baumgarten P, Kratz A, Huang K, Wefers AK, Hovestadt V, Sill M, Ellis HP, Kurian KM, Okuducu AF, Jungk C, Drueschler K, Schick M, Bewerunge-Hudler M, Mawrin C, Seiz-Rosenhagen M, Ketter R, Simon M, Westphal M,

Lamszus K, Becker A, Koch A, Schittenhelm J, Rushing EJ, Collins VP, Brehmer S, Chavez L, Platten M, Hanggi D, Unterberg A, Paulus W, Wick W, Pfister SM, Mittelbronn M, Preusser M, Herold-Mende C, Weller M, von Deimling A (2017) DNA methylation-based classification and grading system for meningioma: a multicentre, retrospective analysis. Lancet Oncol 18: 682–694. https://doi.org/10.1016/S1470-2045(17)30155-9

39. Sicking J, Voss KM, Spille DC, Schipmann S, Holling M, Paulus W, Hess K, Steinbicker AU, Stummer W, Grauer O, Wolfer J, Brokinkel B (2018) The evolution of cranial meningioma surgery-a single-center 25-year experience. Acta Neurochir 160:1801–1812. https://doi.org/10.1007/s00701-018-3617-6
40. Simpson D (1957) The recurrence of intracranial meningiomas after surgical treatment. J Neurol Neurosurg Psychiatry 20:22–39
41. Solheim O, Torsteinsen M, Johannesen TB, Jakola AS (2014) Effects of cerebral magnetic resonance imaging in outpatients on observed incidence of intracranial tumors and patient survival: a national observational study. J Neurosurg 120:827–832. https://doi.org/10.3171/2013.12.JNS131312
42. Umansky F, Ashkenazi E, Gertel M, Shalit MN (1992) Surgical outcome in an elderly population with intracranial meningioma. J Neurol Neurosurg Psychiatry 55:481–485
43. Voss KM, Spille DC, Sauerland C, Suero Molina E, Brokinkel C, Paulus W, Stummer W, Holling M, Jeibmann A, Brokinkel B (2017) The Simpson grading in meningioma surgery: does the tumor location influence the prognostic value? J Neuro-Oncol 133: 641–651. https://doi.org/10.1007/s11060-017-2481-1
44. Wiemels J, Wrensch M, Claus EB (2010) Epidemiology and etiology of meningioma. J Neuro-Oncol 99:307–314. https://doi.org/10.1007/s11060-010-0386-3

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