

Petroclival Meningiomas: A Simple System That Could Help in Selecting the Approach

Gerardo Guinto, MD*[‡]

Eli Hernández, MD^{§¶}

Eric Estrada, MD[¶]

David Gallardo, MD[§]

Miguel Kageyama, MD[§]

Norma Aréchiga, MD[‡]

Gerardo Y. Guinto-Nishimura,
MD^{||}

*Committee of Neurosurgery in the Universidad Nacional Autónoma de México, Mexico City, Mexico; [‡]Centro Médico ABC, Mexico City, Mexico; [§]Hospital Ángeles del Pedregal, Mexico City, Mexico; [¶]Department of Neurosurgery, Hospital de Especialidades del Centro Médico Nacional Siglo XXI, Mexico City, Mexico; ^{||}Department of Neurosurgery, Instituto Nacional de Neurología y Neurocirugía, Mexico City, Mexico

Correspondence:

Gerardo Guinto, MD,
Centro Medico ABC,
Carlos Graef Fernandez #154,
Consultorio 150,
Tlaxala, Santafe,
Alcaldia Cuajimalpa de Morelos,
Mexico City, Mexico CP 05300.
Email: gguinto@prodigy.net.mx

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BACKGROUND: Petroclival meningiomas (PCM) represent a neurosurgical challenge due to their strategic location close to the brainstem.

OBJECTIVE: To assess the applicability of a retrosigmoid approach (RSA) by analyzing the degree of displacement of the middle cerebellar peduncle (MCP) elicited by PCM.

METHODS: Patients with PCM were prospectively included and divided into those whose imaging studies showed that the posterior end of the MCP was displaced by the tumor and were eligible for and underwent RSA (group A) and those who were not eligible for RSA and who underwent surgery via a posterior transpetrosal approach (group B). We compared tumor behavior, clinical characteristic of patients and surgical results.

RESULTS: Twenty patients with PCM were enrolled and allocated to group A (n = 15) or group B (n = 5). The clinical manifestations were more severe in group B; tumors in this group were larger and gross total removal was achieved in only 1 patient (20%). In comparison, in 12 cases on group A, tumors could be totally removed (80%) and all of these patients could recover their quality of life after surgery.

CONCLUSION: To our knowledge, this study is the first to consider displacement of the MCP when establishing a suitable surgical approach for PCM. Our results suggest that the RSA becomes increasingly suitable when peduncle displacement is greater. By using this method, it was also possible to identify two types of tumors: *petroclivals* (group A) and *clivopetrosals* (group B), that show some specific clinical and surgical differences.

KEY WORDS: Petroclival meningioma, Posterior fossa, Retrosigmoid approach, Skull base surgery, Transpetrosal approach

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Petroclival meningioma (PCM) is undoubtedly one of the most difficult tumors to remove in skull base surgery.¹ They are tumors that originate within the suture between the temporal bone and the upper two-thirds of the clivus and remain medial to the fifth cranial nerve.²

Many surgical approaches have been described for the resection of a PCM, the most frequently reported being the anterior transpetrosal approach, the posterior transpetrosal approach, and the retrosigmoid approach

(RSA).^{3–7} The RSA is thought to be the most suitable option, mainly because it can be performed easily and promptly and provides adequate exposure of the surgical area.^{8–12} Many skull base surgeons have proposed criteria that can be used as the rationale to select a specific approach.^{3,12–16} However, these criteria vary widely due to the variable biological behavior of PCM and the preference of the surgeon.

The purpose of this study was to determine the applicability of an RSA for the resection of PCM, by focusing exclusively on the tumor component in the posterior fossa and based on a simple method designed to evaluate the degree of displacement of the middle cerebellar peduncle (MCP). We also compared the clinical manifestations, tumor characteristics, surgical difficulties, and prognostic aspects between resulting groups.

ABBREVIATIONS: FIESTA, fast imaging employing steady-state acquisition; GTR, gross total removal; MCP, middle cerebellar peduncle; NTR, nontotal removal; PCM, petroclival meningioma; RSA, retrosigmoid approach

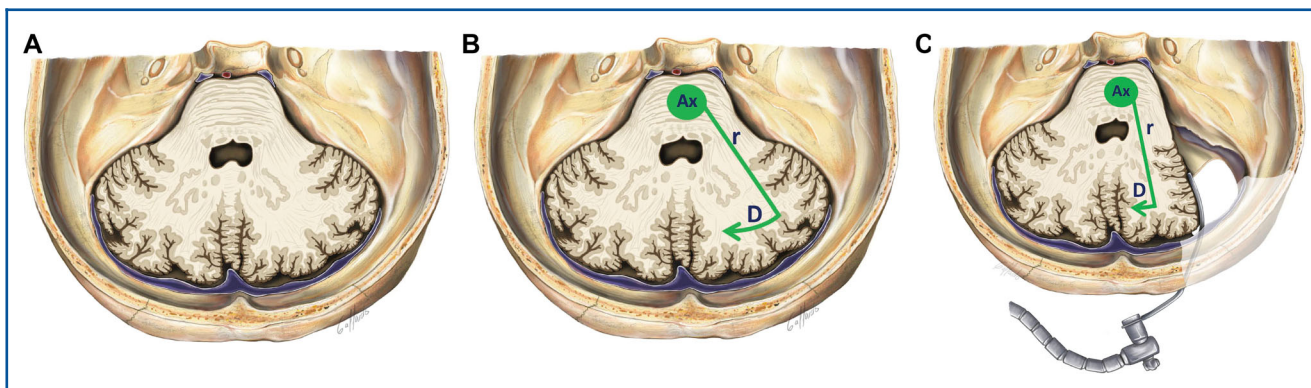


FIGURE 1. A, The posterior fossa and the structures therein are encompassed by approximately one-quarter of 1 circle. B, Using a retrosigmoid approach, the cerebellum is moved backwards, rotating around the axis, which is the brainstem and with the middle cerebellar peduncle as the radius of movement. C, The exposure achieved by this approach will depend on the degree of displacement of the cerebellar/middle cerebellar peduncle binomial around the brainstem. Ax = axis; D = direction; r = radius of movement.

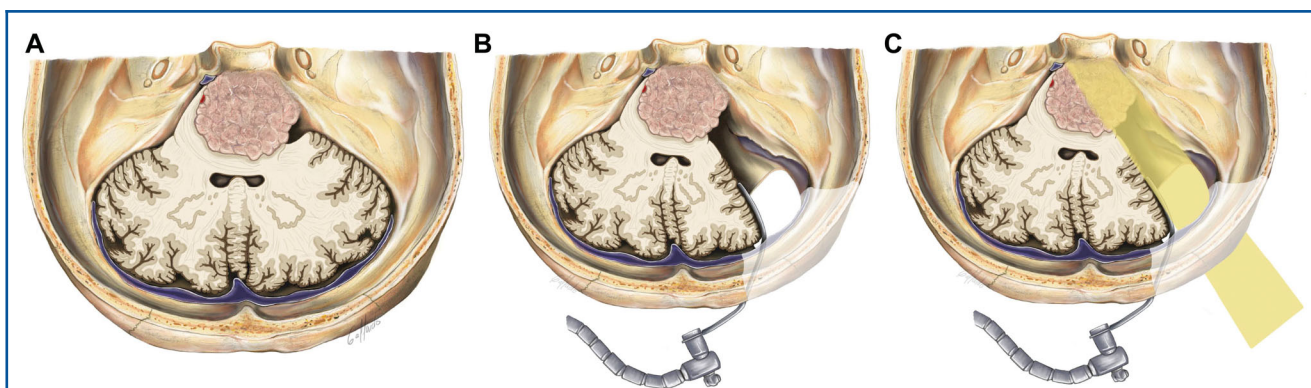


FIGURE 2. A, Tumor located closer to the midline. B, Displacement of the cerebellum/middle cerebellar peduncle binomial after using a retrosigmoid approach. C, The microscope light (yellow) exposes only half of the tumor.

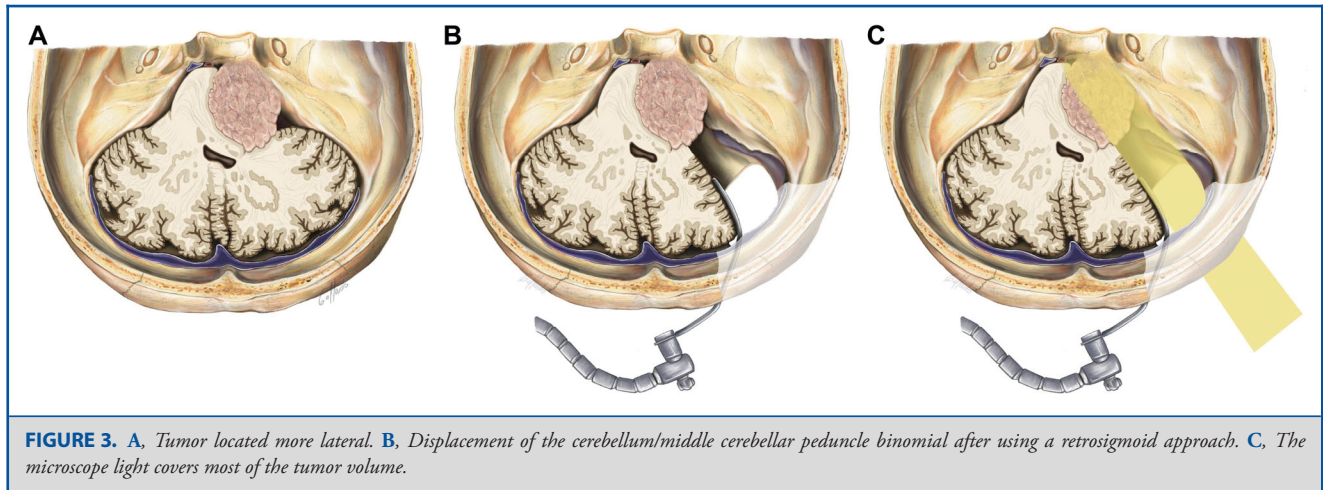
METHODS

Theoretical Basis

Using an RSA, surgical exposure is achieved by displacing the cerebellum backward. In this way, the cerebellum turns slightly around an axis (ie, the brainstem), and the MCP participates as the radius of movement (Figure 1). Thus, deep structures are exposed depending on the degree of displacement of the cerebellum/MCP binomial. Therefore, if a PCM is close to the rotation axis (brainstem), the natural displacement of the cerebellum/MCP binomial intended during a standard RSA will not be sufficient to achieve an adequate exposure (Figure 2). Conversely, if the tumor is discretely eccentric, even by a few millimeters, it will be appropriately exposed (Figure 3). It is clear that the natural obstruction in the surgical view is the MCP and so theoretically, by assessing the degree of posterior displacement of the MCP caused by the tumor, particularly the part of this structure that is closest to the surgeon's viewpoint, ie, its junction with the cerebellum, it would be able to know the applicability of an RSA. This point may be located along a line that we designate as the peduncular line, which links the most lateral

edge of the floor of the fourth ventricle and the surface of the pia exactly at the junction between the cerebellum and the MCP where the cerebellar folia end, and the smooth surface of the peduncle begins (Figure 4).

If we analyze the cases shown in Figure 4A and 4B, the 2 PCMs have almost the same shape and size but the one in Figure 4A is more complex than the one in Figure 4B, differing only by the discrete separation from the middle line of the tumor on the right. This eccentric location of the tumor causes major posterior displacement of the MCP and improves surgical exposure from a posterolateral perspective. To objectively quantify this issue, we designed a simple system (Figures 4C and 4D) that starts by drawing a straight line running along the back edge of the petrous portion of the temporal bone (dashed red line). A second line, perpendicular to the first line (solid red line) is drawn crossing the bulky section of the tumor (usually the center). We designate this line as the “tumor line,” which is divided into 3 sections (numbered 1, 2, and 3). Next, the “peduncular line” (the solid blue line) is established, as previously mentioned. A final line is set (the dotted line), perpendicular to the tumor line, but passing through the center of the peduncular line. If this last line (dotted) is placed at the second marking (no. 2) or between marks



1 and 2, the tumor exposure provided by RSA will be limited (Figure 4E). However, if the dotted line is placed passing the second marking (between marks 2 and 3) along the “tumor line,” tumor visualization will be sufficiently wide when the RSA is performed (Figure 4F).

Patients

All patients with radiological images suggestive of PCM and with symptoms related were prospectively included in the study over a period of 5 y (January 2012 to December 2016). None of them had previously undergone tumor surgery. The only exclusion criterion was intraoperative identification of the cisternal portion of the trigeminal nerve was not lateral to the tumor. All patients underwent a thorough neurological evaluation when admitted. They also underwent standard preoperative examinations, including magnetic resonance imaging (MRI). Based on the MRI findings and by applying the system to identify the degree of displacement of the peduncular line, patients were allocated to 1 of 2 groups: those showing a favorable tumor positioning that may be subsequently exposed by an RSA (group A) and those lacking this feature (group B) and were operated on through a posterior transpetrosal approach.

All the surgical procedures were performed by the same surgeon. The study protocol was approved by the Hospital’s Ethics Committee 6 mo before recruiting the first patient. All patients signed an informed consent form at the time of admission for surgery.

A computed tomography scan was obtained 6 to 8 h after surgery to identify any possible immediate complication. In total, 6 wk after surgery, MRI was performed to evaluate the extent of macroscopic tumor resection. To simplify the analysis, only 2 criteria were considered: absence of residual tumor in both, surgical field and postoperative MRI, termed gross total removal (GTR). The remaining cases were considered as nontotal removal (NTR). At the end of the follow-up period, a final assessment was made to establish the morbidity after the procedure and the quality of life (QoL) based on the Karnofsky Performance Scale score. The mean follow-up duration was 65 (range, 28-90) mo.

Statistical Analyses

Continuous variables are summarized as the mean \pm standard deviation and categorical variables as the frequency of cases and percentage per group. Categorical variables were compared between the 2 groups using Fisher’s exact test, and continuous variables were

compared using the Mann-Whitney *U*-test. All statistical analyses were performed using LibreOffice version 5.3 (Document Foundation, Berlin, Germany) and MATLAB version R2019a (MathWorks Inc, Natick, Massachusetts). A *P* value $< .05$ was considered statistically significant.

RESULTS

In total, 20 patients met the study inclusion criterion and comprised 13 women and 7 men of mean age 51.05 (range, 22-67) y. In total, 15 patients were allocated to group A and 5 to group B and were classified in increasing order according to the size (maximum diameter) of the tumor (Figure 5).

Table 1 summarizes the clinical findings, tumor size, occurrence of hydrocephalus, degree of resection, and preoperative and postoperative QoL. There was no significant between-group difference in age or sex (Table 2). Symptoms had been present for longer and the clinical manifestations were more severe in group B. There was a significant between-group difference in tumor size because patients in group B had larger tumors. This size differentiation was obtained only by measuring the displacement of the peduncular line. The fact that the largest tumors were located in group B was more related to the central location of the lesions, since in this site they caused less displacement of the MCP. Clinical manifestations were more diverse in group A and predominantly related to cranial nerve deficits, although with an early onset, but being relatively milder in severity. Preoperative QoL was better in group A than in group B, which was surely related both to the smaller size of the tumors in group A, as well as to their more eccentric location.

GTR was achieved in a significantly greater proportion of patients in group A (12/15) than in group B. No differences were actually found regarding the characteristics of the tumors in both groups, in respect to arachnoid plane, consistency, vascular supply, or neurovascular adherence. Examples of GTR and NTR are shown in Figure 6 for group A and in Figure 7 for group B. Patients on group B had more neurological deficit after surgery, but it did not represent a significant change in postoperative

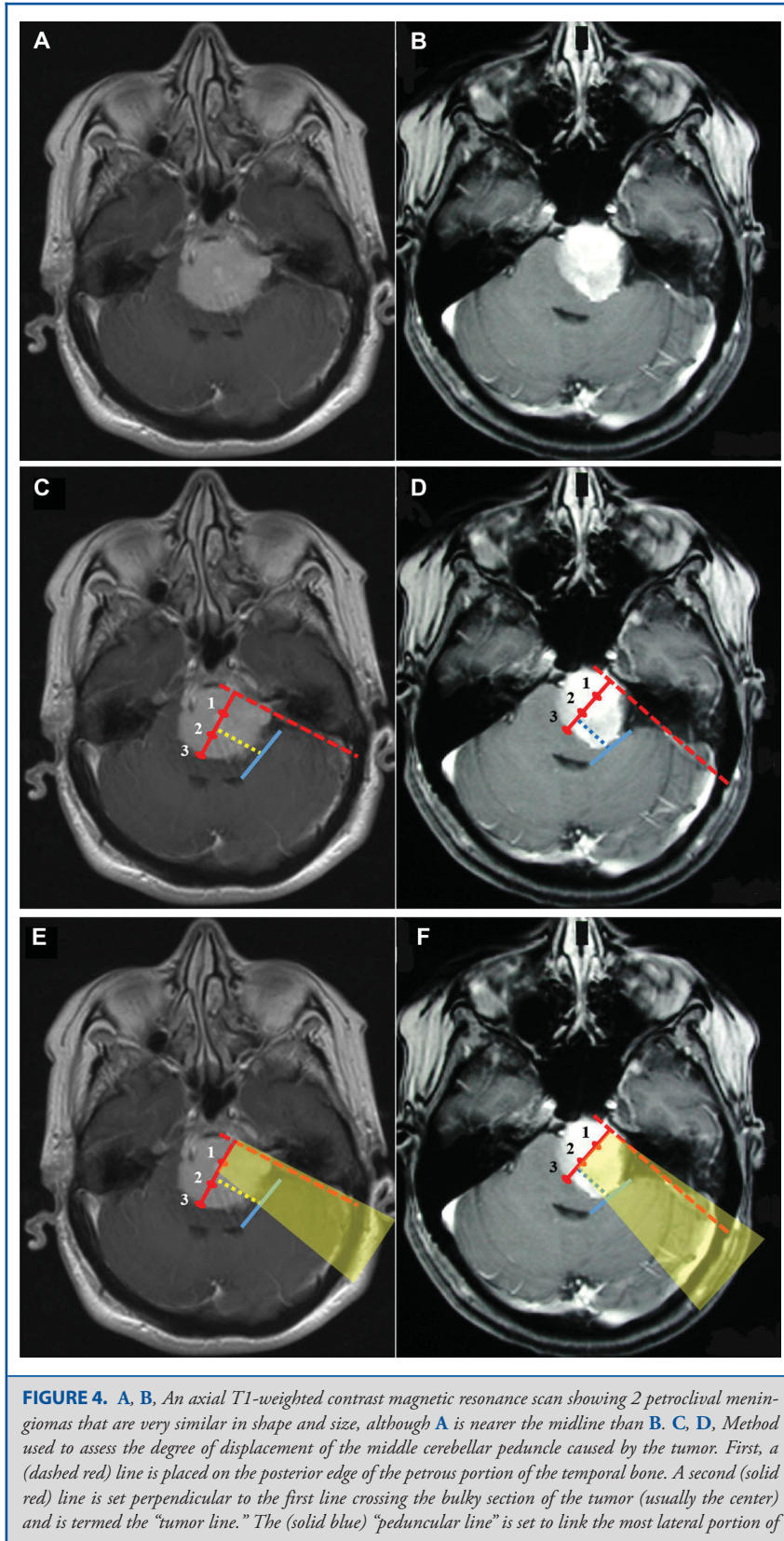


FIGURE 4. (Continued) the floor of the fourth ventricle and the surface of the pia at the junction between the cerebellar folia and the smooth surface of the middle cerebellar peduncle. The last (dotted) line is drawn perpendicular to the “tumor line” but crossing the center of the “peduncular line.” **E, F,** If the former dotted line is located at the second marking on the “tumor line” or between marks 1 and 2 **E,** exposure of the tumor by a retrosigmoid approach will be rather limited. However, if this dotted line is located between marks 2 and 3, an appropriate exposure will be achieved **F.** The expected microscope light projection for each case is represented in yellow.

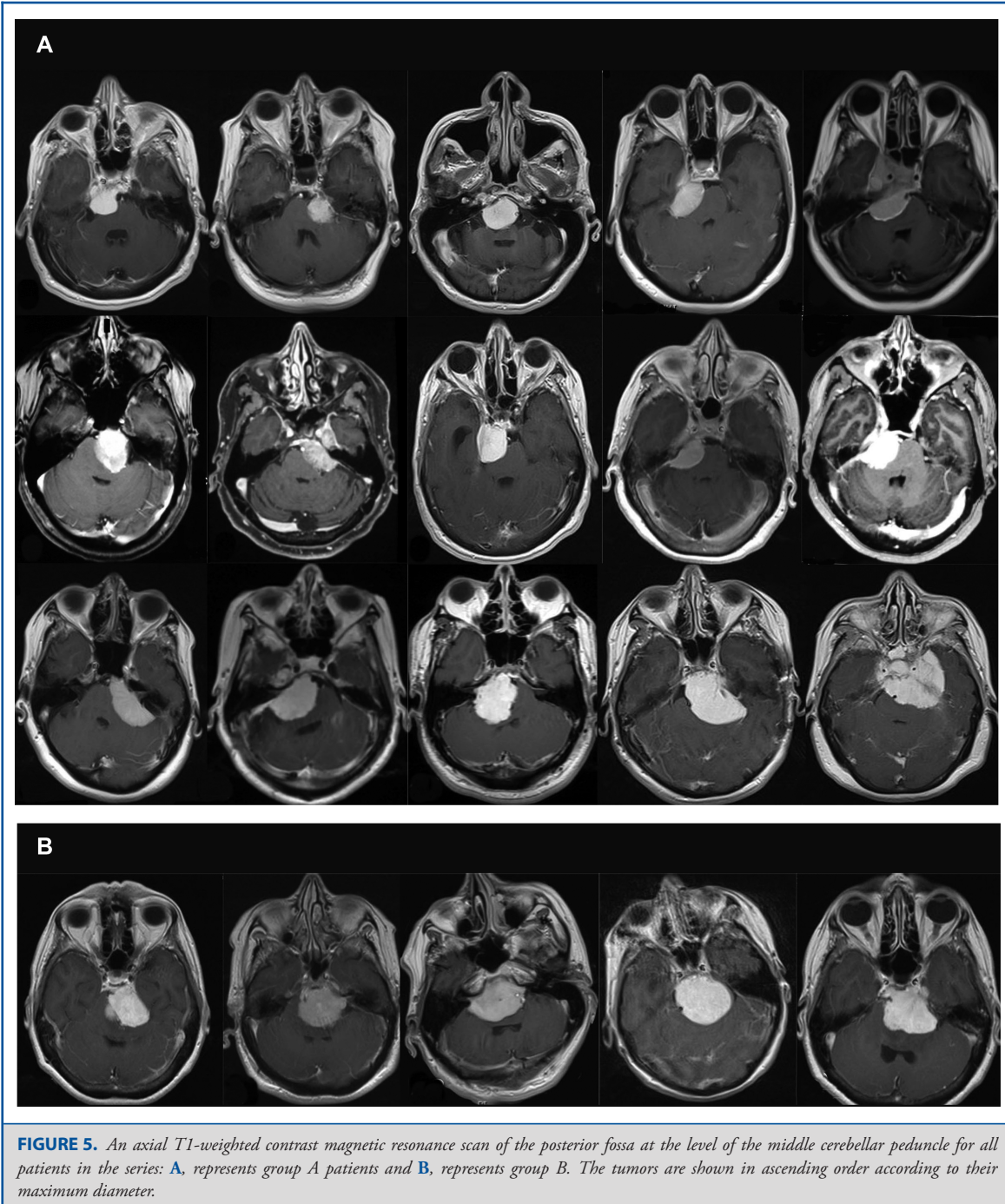


FIGURE 5. An axial T1-weighted contrast magnetic resonance scan of the posterior fossa at the level of the middle cerebellar peduncle for all patients in the series: **A,** represents group A patients and **B,** represents group B. The tumors are shown in ascending order according to their maximum diameter.

TABLE 1. Patient Demographics and Clinical Characteristics

Case no	Gender	Age (years)	Clinical course (months)	Signs and symptoms ^a	Tumor size (cm) ⁺	HC [⊗]	Tumor removal	Karnofsky pre/post
Group A								
1	F	22	8	Neuralgia	2.6	No	Total	90/100
2	F	47	7	Headache, hypoesthesia, hypoacusis	2.8	No	Total	100/100
3	F	39	11	Diplopia (VI), incoordination	3	No	Total	80/100
4	F	64	11	Hypoacusis, paresthesia	3.2	No	Total	90/90
5	F	66	6	Headache, hypoesthesia, hypoacusis	3.3	No	Total	90/90
6	F	38	6	Headache, incoordination, hypoacusis, diplopia (VI)	3.3	No	Total	80/100
7	M	65	8	Hypoesthesia, headache, diplopia (IV)	3.4	No	Total	80/100
8	M	56	8	Hypoesthesia, headache	3.4	No	Total	90/100
9	F	39	6	Hypoacusis, hypoesthesia, incoordination	3.5	No	Total	90/90
10	F	52	9	Hypoacusis, paresthesia	3.5	No	Total	80/80
11	M	42	9	Hypoacusis, hypoesthesia, incoordination, facial weakness	4	No	Total	90/90
12	F	67	14	Headache, hypoesthesia, incoordination, diplopia (IV), vertigo, dysphagia	4.1	No	Total	80/90
13	M	50	20	Neuralgia, hypoacusis, incoordination, diplopia (VI), headache, vertigo, dysphagia, dysphonia	4.5	Yes	No-total	70/90
14	F	53	14	Headache, diplopia (VI), hypoacusis, incoordination, hemiparesis	4.7	Yes	No-total	70/80
15	M	59	24	Headache, hypoesthesia, diplopia (VI), hypoacusis, hemiparesis, vertigo, dysphagia	5.1	No	No-total	80/80
Group B								
16	M	43	22	Headache, hypoesthesia, hemiparesis, deafness	4.6	Yes	Total	70/80
17	F	59	24	Headache, quadriplegia, diplopia (VI), deafness, hypoesthesia, dysphagia	4.8	Yes	No-total	60/70
18	F	52	26	Headache, hemiparesis, diplopia (VI), deafness, hypoesthesia, dysphonia, dysphagia	5.2	No	No-total	70/70
19	F	52	25	Headache, quadriplegia, diplopia (VI), dysphonia, dysphagia	5.3	Yes	No-total	60/70
20	M	56	19	Headache, deafness, hypoesthesia, hemiparesis, facial weakness	5.5	No	No-total	70/80

^aSigns and symptoms in order of appearance. Neuralgia = trigeminal; hypoesthesia = facial; hearing loss = on the tumor side; diplopia (VI) = involvement of the abducens nerve; diplopia IV = involvement of the trochlear nerve; paresthesia = facial; deafness = on the tumor side. +, maximum tumor diameter, ⊗, hydrocephalus.

QoL. By contrast, patients in group A had fewer postoperative neurological deficits and all of them were able to return to their normal daily activities. Finally, no deaths occurred during the study period, and there was no evidence of tumor recurrence or regrowth on imaging performed at the end of the follow-up period.

DISCUSSION

Meningioma has an incidence of 2 to 15/100 000 and represents approximately 20% of all primary intracranial tumors. Typically, 9% to 15% of these tumors occur in the posterior fossa and only 3% to 10% are PCM.¹⁷ Considering

TABLE 2. Statistical Analysis of Between-Group Differences in Patient Demographics and Clinical Characteristics

Feature	Group A	Group B	P value
Patients (n)	15	5	
Age (y, mean \pm s.d.)	50.6 \pm 12.9	52.4 \pm 6.0	.866
Gender			
M (n, [%])	5 [33.3]	2 [40.0]	
F (n, [%])	10 [66.7]	3 [60.0]	
M/F ratio	0.50	0.7	.778
Tumor size			
Max diameter (cm, mean \pm s.d.)	3.6 \pm 0.71	5.1 \pm 0.37	.001
Volume (cc, mean \pm s.d.)	29.9 \pm 16.4	101.0 \pm 33.6	.002
Clinical data			
Duration (m, mean \pm s.d.)	10.7 \pm 5.3	23.2 \pm 2.8	.001
No signs/symptoms (mean \pm s.d.)	3.5 \pm 1.6	5.0 \pm 1.0	.046
Headache (n, [%])	9 [60.0]	5 [100]	.260
Hydrocephalus (n, [%])	2 [13.3]	3 [60.0]	.073
Motor deficit (n, [%])	2 [13.3]	5 [100]	.001
Incoordination (n, [%])	7 [46.7]	0 [00.0]	.114
IV (n, [%])	2 [13.3]	0 [00.0]	.269
V (n, [%])	12 [80.0]	4 [80.0]	1.0
VI (n, [%])	5 [33.3]	3 [60.0]	.347
VII (n, [%])	1 [6.66]	1 [20.0]	.447
VIII (n, [%])	11 [73.3]	4 [80.0]	.762
IX, X, XI (n, [%])	3 [20.0]	3 [60.0]	.131
Tumor removal			
GTR (n, [%])	12 [80.0]	1 [20.0]	.031
NTR (n, [%])	3 [20.0]	4 [80.0]	
Postoperative clinical deficit			
Motor (n, [%])	0 [0.00]	3 [60.0]	.009
IV (n, [%])	2 [13.3]	2 [40.0]	.249
V (n, [%])	1 [6.66]	2 [40.0]	.14
VI (n, [%])	2 [13.3]	3 [60.0]	.073
VII (n, [%])	1 [6.66]	2 [40.0]	.140
VIII (n, [%])	2 [13.3]	4 [80.0]	.014
IX, X, XI (n, [%])	0	0	–
Incoordination (n, [%])	0	0	–
Karnofsky performance status			
Initial (mean \pm s.d.)	84.0 \pm 8.3	66.0 \pm 5.5	.001
Final (mean \pm s.d.)	92.0 \pm 7.7	74.0 \pm 5.5	.001
Difference (mean \pm s.d.)	8.0 \pm 8.6	8.0 \pm 4.5	.866
Reincorporation to activity (n, [%])	15 [100]	2 [40.0]	.009

F, female; GTR, gross total removal; M, male; NTR, nontotal removal.

this low frequency, most studies include series of less than 100 cases.

For a meningioma to be strictly petroclival, the fifth cranial nerve needs to be located laterally to the tumor.² In many patients with PCM, the exact location of the cisternal portion of the fifth cranial nerve is difficult to detect on imaging studies,^{18,19} even when diffusion tensor imaging or FIESTA (fast imaging employing steady-state acquisition) sequences²⁰ are used and can only be detected intraoperatively by the surgeon.

The overall clinical scenario in our series is very similar to that reported by other authors.²¹⁻²⁵ Ichiumura et al²⁶ make a more detailed analysis of the clinical manifestations of PCM, based on a series of 91 cases, and considering the possible origin of the

tumors. We wanted to simplify the tumor categorization by only dividing our series into 2 groups. We found that in group A, the clinical manifestations related were earlier. By contrast, patients in group B had a longer disease duration and more marked neurological deficits at the first visit.

A route other than the RSA, such as a posterior¹³ or anterior^{26,27} transpetrosal approach, is usually needed when a PCM extends into the upper surface of the cerebellar tentorium. However, there has been a description of a suprameatal transtentorial approach that can be used to remove this tumor component during an RSA.^{28,29} In our series, we did not find a single tumor with implants located at the upper surface of the tentorium and so, it was not a decisive factor when determining the approach. However, this may be related to the small number of cases included here.

The RSA is the simplest of the approaches that can be used to remove PCM and is widely used.^{1,3,4,8,9,11,12,23} Nevertheless, as indicated by other authors, transpetrosal approaches are more suitable in some cases.^{2,14,15,22,25,26,27} Zhao et al¹⁶ made a very careful analysis in a series of 168 patients, to define the criteria for selection of the approach. It is noteworthy that the most used surgical access was the RSA, even considering that they divided their series of tumors into 4 groups.

Our results suggest that it is possible to identify tumors amenable to an RSA, only by evaluating the degree of displacement of the peduncular line. We did not find any other studies that included this feature in the decision-making process. This proposal is based on 2 facts: (1) the posterior portion of the MCP is its most bulky section and (2) the anterior end of the MCP is closest to the tumor and, therefore, is displaced by it in almost all cases. The midpoint of the peduncular line was taken as a reference for tumor exposure purposes because it is very easy to reach this point in any RSA just by relaxing the cisterns and gently retracting the cerebellum. The rationale for considering more than two-thirds of the tumor line as reference to define the degree of tumor exposure was based on previous experience of the main surgeon in similar cases, where it was possible to observe that when two-thirds of the lesion had been removed, the decompression typically achieved by this maneuver allowed the last fragment to move and be clearly visible in the surgical field at the final steps of the procedure.

Gross tumor removal was achieved in 13 (65%) of the 20 patients in this series. Similar studies have reported complete PCM excision rates between 14% and 79%.^{30,31} According to other series,^{1,10,16,22,23,31,32} the most important determinant of the degree of complexity of a PCM after location is its size. In contrast to our initial assumptions, we observed that the smallest tumors caused the most displacement of the peduncular line. Thus, the location of the tumor was more critical than its size in terms of displacement. Other studies^{30,33,34} have emphasized the consistency and the degree of invasion of the meningioma into the neurovascular structures of the posterior fossa rather than tumor size when determining the feasibility of resection. It is clear that all criteria are very important and should be considered in order to perform a judicious tumor resection.^{25,35,36}

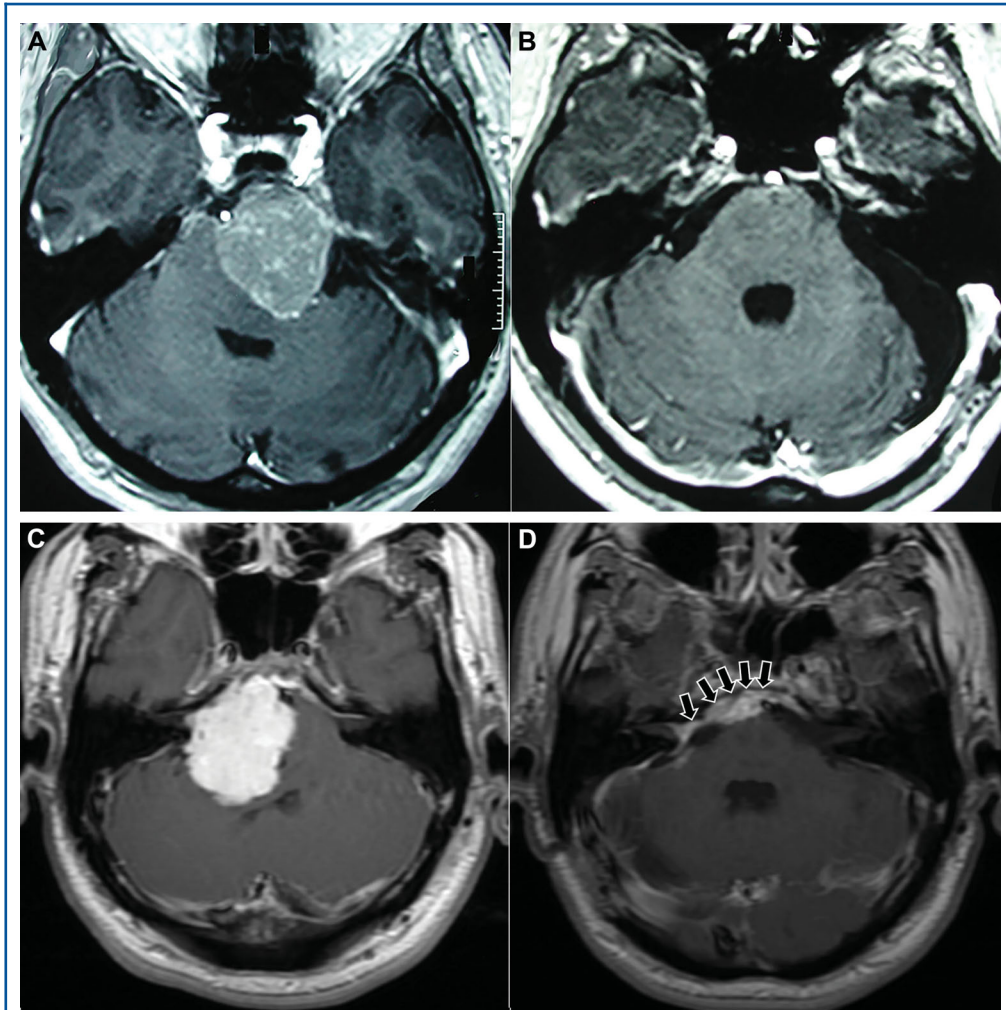


FIGURE 6. A, B, Representative axial T1-weighted contrast magnetic resonance imaging, showing complete macroscopic resection of a tumor in group A. A, Before surgery. B, After surgery. C, D, Representative image showing nontotal removal of a tumor in group A. C, Before surgery. D, After surgery. In this case, the tumor remained at the clivus and was attached to cranial nerves VI, VII, and VIII and to the basilar artery (arrows).

In total, 12 (60%) of the 20 patients had improvement in their QoL postoperatively. However, in 8 (66.6%) of these 12 patients, this improvement consisted of increasing their functional level by only 10 points on the Karnofsky Performance Scale, which was not statistically significant and is consistent with other studies.^{12,22,24,30}

Limitations

It is important to clarify that our study has some limitations. It is a short series, coming from a single center, where all tumors were operated on by the same surgical group. This creates a very important bias when analyzing the results. It is clear that it is necessary to include more cases in a multicenter study, to assess whether our conclusions are reliable. However, considering the

low frequency of these tumors, this would require several years to gather a sufficient number of cases. Serve then this work as an initial report to be considered in the decision-making process for the surgical treatment of these difficult tumors.

CONCLUSION

We cannot conclude that measurement of displacement of the MCP is the only factor in defining the indication for an RSA in PCM but believe that can be used as a guide. The design of this study was never with the intention to compare the effectiveness of the 2 approaches used, since the precise location of the tumors were different. The only intention was just to define the applicability of RSA in these tumors. However, by

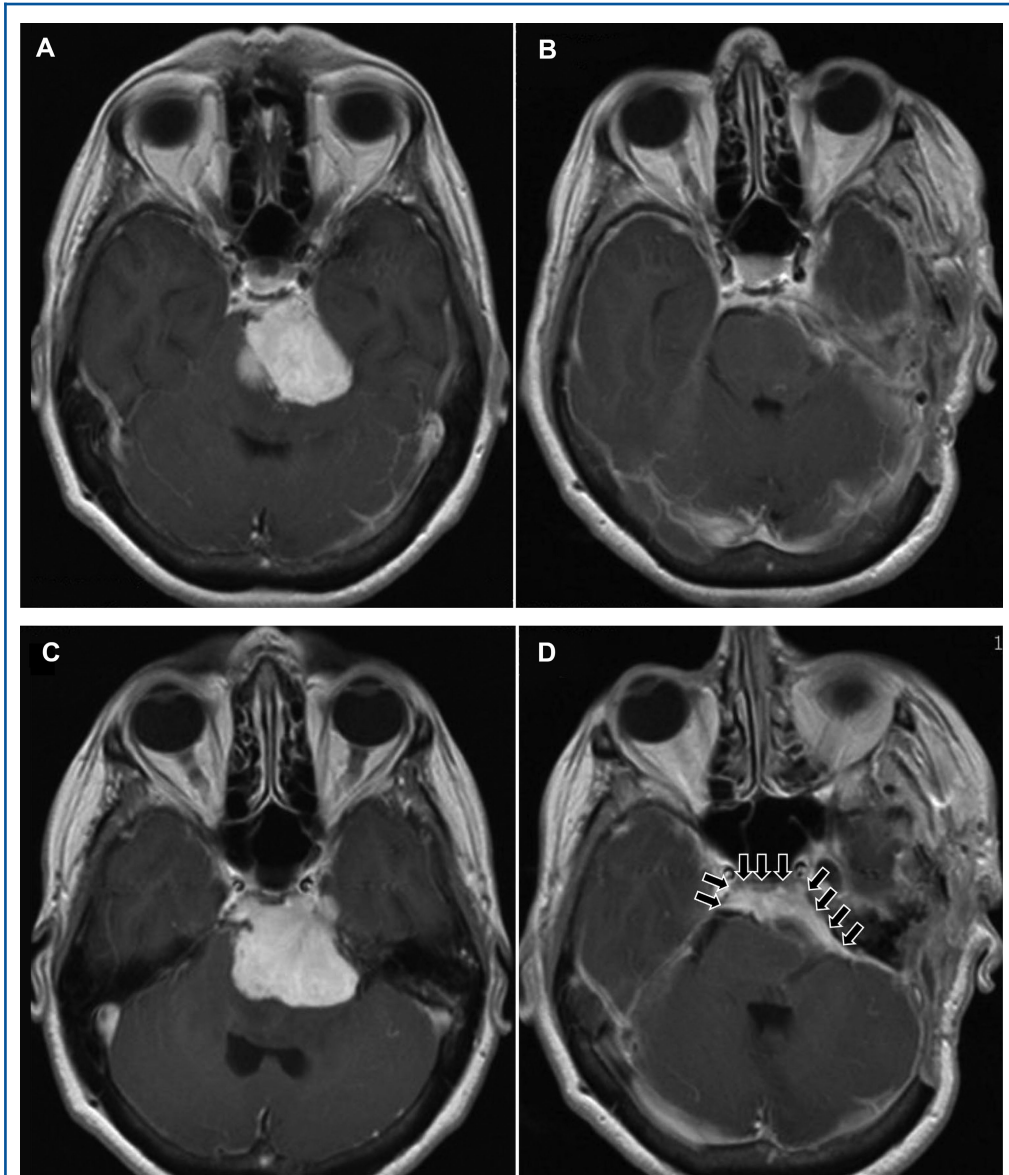


FIGURE 7. A, B, Representative axial T1-weighted contrast magnetic resonance imaging of the posterior fossa showing an example of gross total removal of a tumor in group B. A, Before surgery. B, After surgery. C, D, Representative image of nontotal tumor removal in group B. C, Before surgery. D, After surgery. The residual tumor was found at the clivus and was attached to cranial nerves VI, VII, and VIII and to the basilar artery (arrows).

doing this, it was possible to observe a clear differentiation between the 2 groups created by this measurement. Our findings suggest the possible existence of 2 types of PCMs but considering only their posterior fossa component. The first type (group A) includes smaller tumors located slightly laterally that cause early but mild symptoms and may be excised via a simple RSA. We suggest that they be named *petroclival* tumors to convey the idea that their lateral (petro) portion is more important than

their medial (clival) one. The second type (group B) includes tumors located near the midline that reach larger sizes, cause late but more severe symptoms, and are likely to require a more complex approach when removing them. They may be called *clivopetrosal* tumors because their relevant component is near the midline (clivo) instead of near the petrous (petrosal) portion of the temporal bone. Although it is not intended to modify the universally accepted terminology for PCMs because of our reduced

number of cases, we propose this simple nomenclature as a convenient way of summarizing the clinical manifestations, tumor features, most suitable surgical approach, degree of complexity expected during surgery, and the prognostic implications for each group.

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REFERENCES

1. Beniwal M, Bhat DI, Rao N, Bhagavatula ID, Somanna S. Surgical management of petroclival meningiomas: factors affecting early post-operative outcome. *Br J Neurosurg*. 2015;29(4):559-564.
2. Al-Mefty R, Dunn IF, Pravdenkova S, Abolfotoh M, Al-Mefty O. True petroclival meningiomas: results of surgical management. *J Neurosurg*. 2014;120(1):40-51.
3. Bambakidis NC, Kakarla UK, Kim LJ, et al. Evolution of surgical approaches in the treatment of petroclival meningiomas: a retrospective review. *Neurosurgery*. 2008;62(6):1182-1191.
4. Couldwell WT, Fukushima T, Giannotta SL, Weiss MH. Petroclival meningiomas: surgical experience in 109 cases. *J Neurosurg*. 1996;84(1):20-28.
5. Roberti F, Sekhar LN, Kalavakonda C, Wright DC. Posterior fossa meningiomas: surgical experience in 161 cases. *Surg Neurol*. 2001;56(1):8-20.
6. Al-Mefty O, Fox JL, Smith RR. Petrosal approach for petroclival meningiomas. *Neurosurgery*. 1988;22(3):510-517.
7. Cass SP, Sekhar LN, Pomeranz S, Hirsch BE, Synderman CH. Excision of petroclival tumors by a total petrosectomy approach. *Am J Otol*. 1994;15(4):474-484.
8. Chen LF, Yu XG, Bu B, Xu B, Zhou DB. The retrosigmoid approach to petroclival meningioma surgery. *J Clin Neurosci*. 2011;18(12):1656-1661.
9. Goel A, Muzumdar D. Conventional posterior fossa approach for surgery on petroclival meningiomas: a report on an experience with 28 cases. *Surg Neurol*. 2004;62(4):332-338.
10. Isolan GR, Wayhs SY, Lepski GA, Dini L, Lavinsky J. Petroclival meningiomas: factors determining the choice of approach. *J Neurol Surg B Skull Base*. 2018;79(4):367-378.
11. Samii M, Tatagiba M, Carvalho GA. Resection of large petroclival meningiomas by the simple retrosigmoid route. *J Clin Neurosci*. 1999;6(1):27-30.
12. Xu F, Karampelas I, Megerian CA, Selman WR, Bambakidis NC. Petroclival meningiomas: an update on surgical approaches, decision making, and treatment results. *Neurosurg Focus*. 2013;35(6):E11.
13. Abdel Aziz KM, Sanan A, van Loveren HR, Tew JM Jr, Keller JT, Pensak ML. Petroclival meningiomas: predictive parameters for transpetrosal approaches. *Neurosurgery*. 2000;47(1):139-152.
14. Erkmen K, Pravdenkova S, Al-Mefty O. Surgical management of petroclival meningiomas: factors determining the choice of approach. *Neurosurg Focus*. 2005;19(2):1-12.
15. Tao J, Wang Y, Qiu B, Ou S, Wang Y, Wu P. Selection of surgical approaches based on semi-quantifying the skull-base invasion by petroclival meningiomas: a review of 66 cases. *Acta Neurochir (Wien)*. 2014;156(6):1085-1097.
16. Zhao Z, Yuan X, Yuan J, et al. Treatment strategy for petroclival meningiomas based on a proposed classification in a study of 168 cases. *Sci Rep*. 2020;10(1):4655.
17. Ware ML, Pravdenkova S, Erkmen K, Al-Mefty O. Petroclival and upper clival meningiomas: an overview of surgical approaches. In: Lee JH, ed. *Meningiomas*. London: Springer Verlag; 2009:403-414.
18. Hunter JB, Yawn RJ, Wang R, et al. The natural history of petroclival meningiomas: a volumetric study. *Otol Neurotol*. 2017;38(1):123-128.
19. Pirayesh A, Petrakakis I, Raab P, Polemikos M, Krauss JK, Nakamura M. Petroclival meningiomas: magnetic resonance imaging factors predict tumor resectability and clinical outcome. *Clin Neurol Neurosurg*. 2016;147(2016):90-97.
20. Ma J, Su S, Yue S, et al. Preoperative visualization of cranial nerves in skull base tumor surgery using diffusion tensor imaging technology. *Turk Neurosurg*. 2016;26(6):805-812.
21. Cherington M, Schneck SA. Clivus meningiomas. *Neurology*. 1966;16(1):86-86.
22. Li D, Hao SY, Wang L, et al. Surgical management and outcomes of petroclival meningiomas: a single-center case series of 259 patients. *Acta Neurochir (Wien)*. 2013;155(8):1367-1383.
23. Seifert V. Clinical management of petroclival meningiomas and the eternal quest for preservation of quality of life: personal experiences over a period of 20 years. *Acta Neurochir (Wien)*. 2010;152(7):1099-1116.
24. Qiao L, Yu C, Zhang H, et al. Clinical outcomes and survival analysis for petroclival meningioma patients receiving surgical resection: an analysis of 176 cases. *Cancer Manag Res*. 2019;11(July):5949-5959.
25. Natarajan SK, Sekhar LN, Schessel D, Morita A. Petroclival meningiomas: multimodality treatment and outcomes at long-term follow-up. *Neurosurgery*. 2007;60(6):965-981.
26. Ichimura S, Kawase T, Onozuka S, Yoshida K, Ohira T. Four types of petroclival meningiomas: differences in symptoms and operative findings using the anterior transpetrosal approach. *Acta Neurochir (Wien)*. 2008;50(7):637-645.
27. Kawase T, Shiobara R, Toya S. Middle fossa transpetrosal-transtentorial approaches for petroclival meningiomas. Selective pyramid resection and radicality. *Acta Neurochir (Wien)*. 1994;129(3-4):113-120.
28. Seoane E, Rhoton AL Jr. Suprameatal extension of the retrosigmoid approach: microsurgical anatomy. *Neurosurgery*. 1999;44(3):553-560.
29. Samii M, Tatagiba M, Carvalho GA. Retrosigmoid intradural suprameatal approach to Meckel's cave and the middle fossa: surgical technique and outcome. *J Neurosurg*. 2000;92(2):235-241.
30. Bricolo AP, Turazzi S, Talacchi A, Cristofori L. Microsurgical removal of petroclival meningiomas: a report of 33 patients. *Neurosurgery*. 1992;31(5):813-828.
31. Kim JW, Jung HW, Kim YH, et al. Petroclival meningiomas: long-term outcomes of multimodal treatments and management strategies based on 30 years of experience at single institution. *J Neurosurg*. 2019;132(6):1675-1682.
32. Adachi K, Kawase T, Yoshida K, Yazaki T, Onozuka S. ABC Surgical Risk Scale for skull base meningioma: a new scoring system for predicting the extent of tumor removal and neurological outcome. Clinical article. *J Neurosurg*. 2009;111(5):1053-1061.
33. Li PL, Mao Y, Zhu W, Zhao NQ, Zhao Y, Chen L. Surgical strategies for petroclival meningioma in 57 patients. *Chin Med J (Engl)*. 2010;123(20):2865-2873.
34. Little KM, Friedman AH, Sampson JH, Wanibuchi M, Fukushima T. Surgical management of petroclival meningiomas: defining resection goals based on risk of neurological morbidity and tumor recurrence rates in 137 patients. *Neurosurgery*. 2005;56(3):546-559.
35. Bernard F, Troude L, Isnard S, et al. Long term surgical results of 154 petroclival meningiomas: a retrospective multicenter study. *Neurochirurgie*. 2019;65(2-3):55-62.
36. Park CK, Jung HW, Kim JE, Paek SH, Kim DG. The selection of the optimal therapeutic strategy for petroclival meningiomas. *Surg Neurol*. 2006;66(2):160-165.