1 ТОМ 27 Vol. 27 2025
НЕЙРОХИРУРГИЯ
Russian Journal of Neurosurgery
Original report

DOI: https://doi.org/10.24412/2587-7569-2025-1-10-21


# Surgical treatment of patients with giant petroclival meningiomas

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**Background.** Surgical treatment of petroclival meningiomas (PCM), especially of giant PCM, remains one of the most difficult problems in neurosurgery and is associated with high risks of postoperative morbidity and mortality.
**Aim.** to determinate frequency and reversibility of post-operative neurological deficit after giant PCMs resection as well as identify risk factors of this surgery and the resection quality of these tumors.
**Materials and methods.** The results of surgical treatment of 18 patients underwent 22 operations to resect giant PCMs were retrospectively studied. The neurological status and Karnofsky Performance Scale (KPS) of patients were assessed before surgery, immediately after and 6 months later, as well as neuroimaging characteristics of tumors before and after surgery were studied. We analyzed the influence of various factors on neurological outcomes and the resection quality.
**Results.** The average PCM volume before surgery was 46.3 ± 25.4 cm3, the average resection volume was 81 ± 16.8 %. The incidence of neurological deficit in the early postoperative period was 63.6 %, mortality was 0 %. The most common complication was injury of cranial nerves (63.6 %). The scores according to Karnofsky Performance Scale (KPS) before surgery (median 80 %) improved 6 months after surgery (median 90 %). The PCMIS after 6 months was on average equal to the preoperative level (8.1 ± 6.3 and 7.5 ± 5.3, respectively). Low Karnofsky Performance Scale status before surgery (<70 %) did not affect the occurrence of postoperative deficit ($p = 0.465$)
**Conclusion.** Surgery of giant PCMs is a difficult problem. Subcompensated patients with these tumors are often rejected in surgical treatment, however, our results demonstrate that this surgery leads in most cases to an improvement in the patients' neurological condition in 6 months after surgery, while using the surgical treatment principles described by us.

**Keywords:** petroclival meningioma, sphenopetroclival meningioma, brainstem compression

**For citation:** Alekseev I.M., Turabekov N.N., Dimertsev A.V., Zuev A.A. Surgical treatment of patients with giant petroclival meningiomas. Neyrokhirurgiya = Russian Journal of Neurosurgery 2025;27(1):10–21. (In Russ.).
DOI: https://doi.org/10.24412/2587-7569-2025-1-10-21

## INTRODUCTION

Petroclival meningiomas (PCM) account for 2 % of all intracranial meningiomas [1]. Surgical removal of these tumors, especially if they are giant in size, is associated with a high risk of postoperative complications and mortality, which is due to the deep location of PCM and their interaction with the main intracranial vessels, their branches, the brainstem (BS), cranial nerves (CN), etc. [2–3].

Traditionally, meningiomas with a matrix in the area of the petroclival junction in the upper 2/3 of the clivus and the apex of the petrous temporal bone, medial to the 5th cranial nerve and the internal auditory canal are classified as PCMs [3]. However, in the case of giant PCMs (>4.5 cm in size), the localization of the matrix cannot always be accurately identified, especially at the preoperative stage [4]. Due to the complexity of the anatomy and the peculiarities of the distribution of PCMs, many of their classifications have been designed resulting in some ambiguity and uncertainty into the issues of their diagnosis and treatment [4–5].

Petroclival meningiomas are characterized by slow growth and a long asymptomatic course, often manifesting clinically only when they reach giant sizes. At the same time, after the first clinical manifestations, symptoms can progress quite quickly. Neurologically, PCMs can be represented by general cerebral, brainstem, cerebellar, hydrocephalic symptoms, dysfunction of various cranial nerves [5]. A feature of the clinical picture in patients with giant PCMs is the damage of various cranial nerves, as well as an initially lower status according to the Karnofsky Performance Scale (KPS), which often leads to refusal in surgical treatment.

Despite the relevance of the problem, there remain a number of unresolved and controversial issues of PCM surgery: 1) what the criteria are for patients' selection for surgery; 2) what degree of PCM resection can be considered

satisfactory and what influences on the radicality of PCM removal; 3) what prognostic factors are for an unfavorable outcome; 4) preference of two-stage resection in the case of giant PCMs, taking into account the severity of the patient's condition and the volume of the upcoming operation.

We analyzed and systematized our experience in surgical treatment of patients with giant PCM in this paper.

**Aim** – to determine the nature and frequency of postoperative deficit development in surgery of giant PCM, to identify prognostic factors influencing on neurological outcomes and the degree of removal radicality of these tumors.

## MATERIALS AND METHODS

**Patients' selection**. A retrospective study of surgical treatment outcomes in patients with giant PCMs was conducted. The work included patients' data treated in the neurosurgical department of the N.I. Pirogov National Medical and Surgical Center from 2014 to 2022.

**Inclusion criteria:** 1) surgical removal of petroclival junction meningeoma with a confirmed histological diagnosis; 2) tumor size in maximum dimension >4.5 cm according to magnetic resonance imaging (MRI); 3) age – from 18 years old.

**Exclusion criteria:** 1) follow-up <6 months; 2) absence of postoperative MRI data; 3) surgical anamnesis – previous tumor resection stages performed in other centers; 4) the presence of concomitant diseases causing decrease in functional status.

**Neurological examination and neuroimaging.** All patients underwent a standard neurological examination, as well as an assessment of the general somatic status according to the Karnofsky Performance Scale (KPS) before surgery, in the early postoperative period, and 6 months after surgery. Additionally, the neurological status was assessed using the Petroclival Meningioma Impairment Scale (PCMIS) [6].

All patients underwent high-field thin-slice MRI twice in T1 sequences before and after contrast administration, T2 and FLAIR – 24 h before surgery and within 48 h after it. PCMs were considered giant if the largest diameter was >4.5 cm based on the Sekhar classification (Fig. 1) [7].

All patients with PCM were assessed for the presence of brainstem edema in the FLAIR mode and signs of good

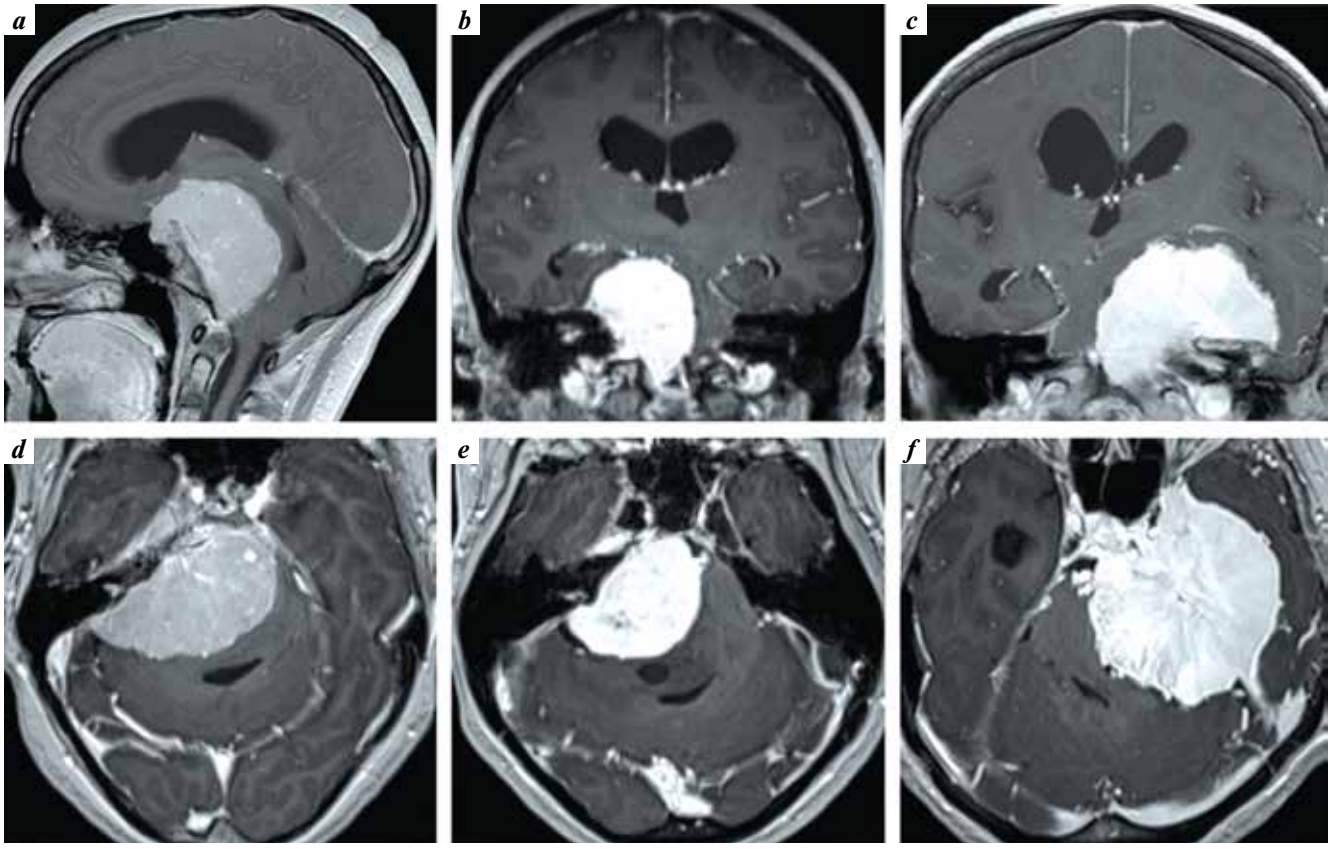


**Fig. 1.** *Examples of brain magnetic resonance images (contrast-enhanced T1-weighted) of patients with giant petroclival meningiomas (a–f): a, d – female patient, 31 years, Karnofsky performance scale (KPS) 80 %, admitted with complaints of headache, unsteady gait, hyperesthesia in the left half of the face, exotropia, difficulty swallowing solid food; b, e – female patient, 50 years, KPS 80 %, admitted with complaints of unsteady gait, exotropia, impaired hearing on the right, and weakness in the right half of the face (House–Brackmann score 2); c, f – female patient, 64 years, KPS 70 %, admitted with complaints of unsteady gait, weakness in all limbs (4 points) and in the left half of the face (House–Brackmann score 3), absence of hearing on the left, and pain in the right half of the face*

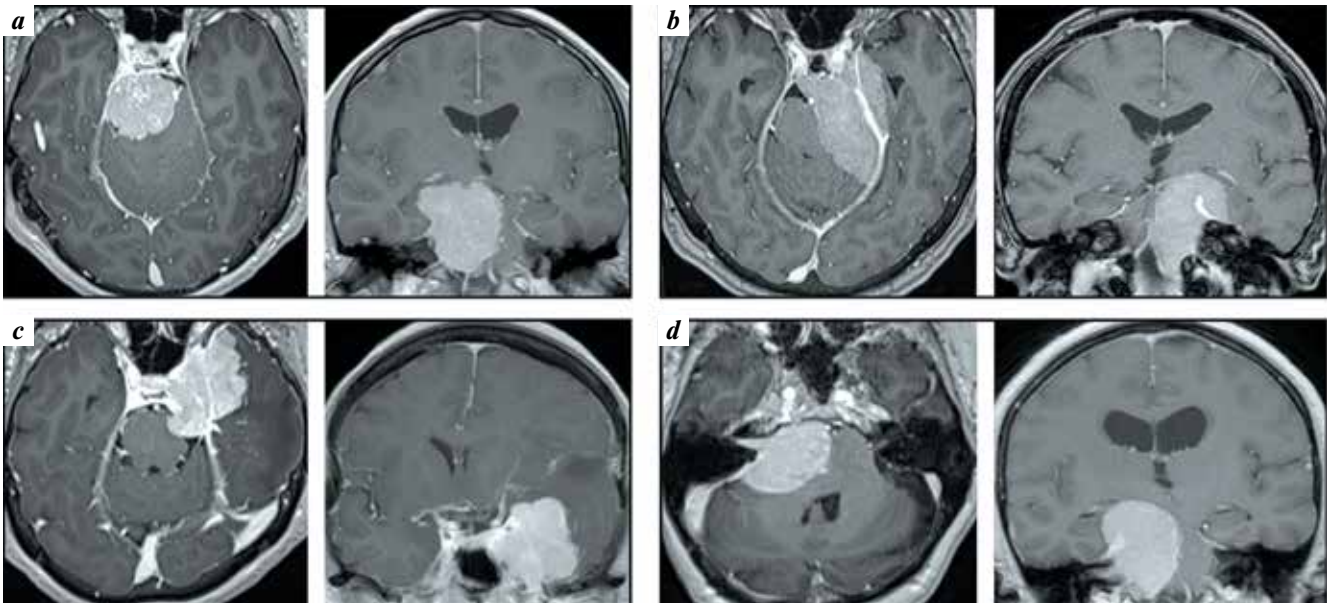


**Fig. 2.** *Classification of petroclival meningiomas by Ichimura–Kawase: a – meningioma of the upper clivus (UC type), lateral shift of the trigeminal nerve; b – meningioma of the tentorium (TE type), downward and lateral shift of the trigeminal nerve; c – meningioma of the cavernous sinus (CS type); d – meningioma of the petrous apex (PA type), upward and medial shift of the trigeminal nerve*

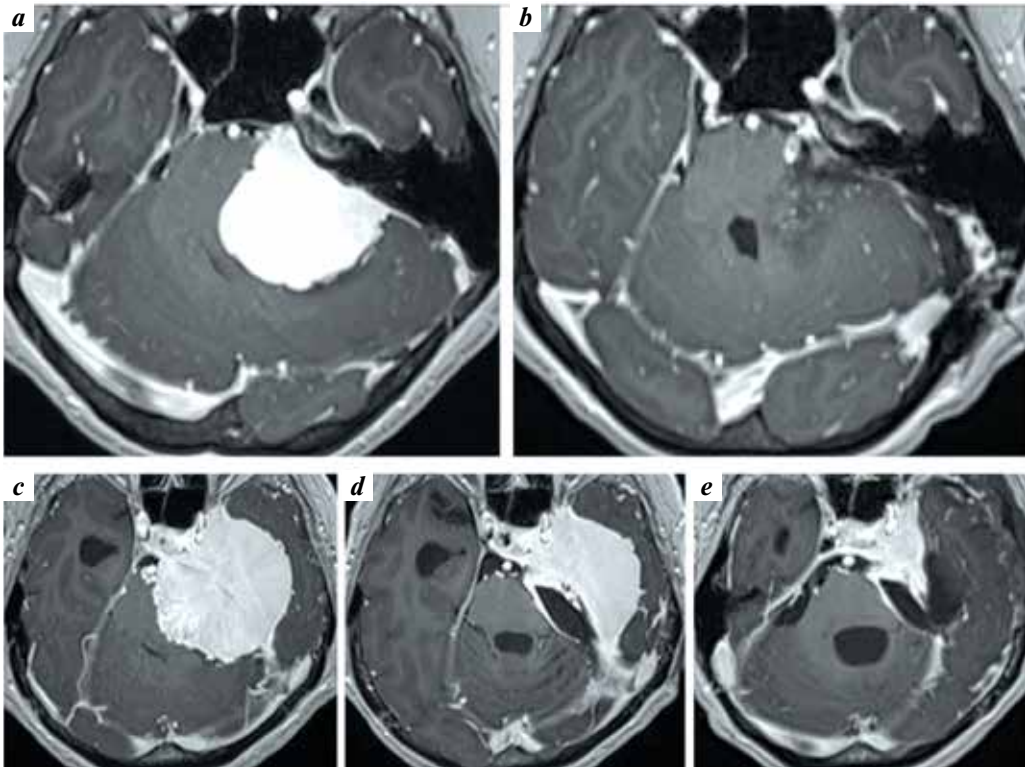


**Fig. 3.** *Cases of retrosigmoid approach usage in surgery of petroclival meningiomas: a, b – single-step microsurgical resection of the tumor from left-sided retrosigmoid approach (magnetic resonance images prior to surgery (a) and after surgery (b)); c–e – microsurgical resection of the tumor from left-sided retrosigmoid approach as the 1st step with subsequent 2nd step through infratemporal access (magnetic resonance images prior to surgery (c), after the 1st and 2nd steps (d, e))*

demarcation of tumor from brainstem represented in the form of liquor layer between the tumor and the brainstem in the T2 mode. In addition, the presence of brainstem compression by the tumor was assessed based on the Pirayesh classification [8]. According to preoperative MRI data, all PCMs were additionally divided into 4 subtypes (according to Ichimura–Kawase): meningiomas of the upper part of the clivus (UC type), cavernous sinus (CS

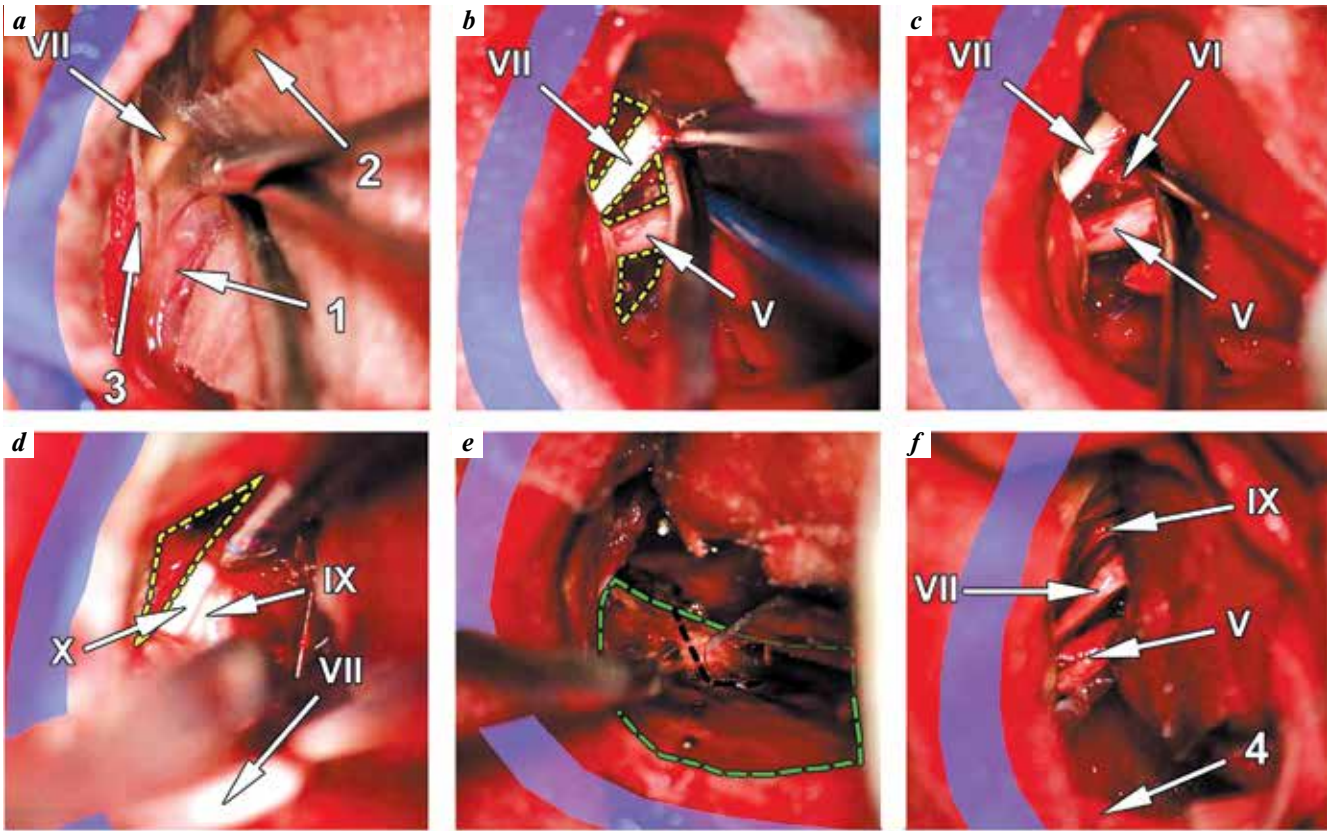


**Fig. 4.** *Steps of microsurgical resection of petroclival meningiomas through right-sided retrosigmoid approach. Projections of the sigmoid and transverse sinuses are shown in light blue, cranial nerves (CNs) are denoted by roman numerals (1 – tumor, 2 – right cerebellar hemisphere, 3 – petrous part of the temporal bone, 4 – tentorium): a – dissection of the subarachnoid cistern of the cerebellopontine angle; b – selection of the CNs VII and V. Surgical corridors between the CNs through which tumor resection was performed are shown by yellow dashed lines; c – identification of CN VI; d – mobilization of the lower pole of the tumor, visualization of the caudal group of the cranial nerves. Surgical corridors between the caudal CNs and condyle are shown by yellow dashed lines; e – dissection of the tentorium to remove the supratentorial fragment of petroclival meningioma. Tentorium is shown by green dashed lines, the line of tentorium dissection is shown in black; f – final view of the right cerebellopontine angle after tumor resection*

type), tentorium cerebelli (TE type), and apex of the petrous temporal bone (PA type) (Fig. 2) [4].

**Surgical treatment.** We used 4 surgical approaches: retrosigmoid, infratemporal with resection of the petrous apex, lateral suboccipital and pterional. In some cases, when it was impossible to remove the PCM through one approach, a two-stage treatment was performed. In most cases (72.2 %), a retrosigmoid approach with a diameter of 3–3.5 cm was used to remove the PCM or perform the 1st ("posterior") stage of surgical treatment (Fig. 3).

Tumor removal was performed under the control of computer neuronavigation (Fig. 4). After opening the dura mater and dynamically retracting the cerebellar hemisphere (retractors were not used in any case), cerebrospinal fluid was removed from any accessible basal cisterns (see Fig. 4, *a*) [9]. After relaxation of the brain, cranial nerves were identified on the posterior surface of the tumor using direct electrical stimulation (see Fig. 4, *b*). Then, V, VII–VIII, IX–XI cranial nerves were mobilized, if possible, to expand the space between them.

The tumor was separated from its matrix through the formed "windows" as well as and partially devascularized in the direction from the posterior surface of the temporal bone pyramid to the clivus with simultaneous reducing the tumor volume by morcellation and using an ultrasonic aspirator. When the PCM grew into the internal auditory canal, we sawed its posterior wall and removed the tumor, preserving the VII–VIII cranial nerves and the labyrinthine artery passing through it. After reducing the volume of the PCM, it became possible to safely separate the tumor from the cranial nerves (see Fig. 4, *c*). The special attention was paid to identifying the IV and VI cranial nerves in the medial sections. The microsurgical dissection and accurate separation of these nerves from the tumor were performed (see Fig. 4, *d*).

The most difficult task was to detach the sixth cranial nerve in the area of its entry into the Dorello canal, since the highly vascularized matrix of PCM was often located here. Then the tumor was separated from the brainstem, the basilar artery and its branches. In the case of dense fusion of PCM with the arachnoid membrane of brainstem, vessels or cranial nerves, the small tumor fragments were left on these structures, since the priority of treatment was maximum but safe resection, decompression of the

brainstem and creation of conditions for subsequent radiation therapy.

After tumor removal in the petroclival area, the space was freed for manipulations at the apex of the clivus and the posterior surface of the sella turcica. Here the tumor was detached from the third cranial nerve and tumor's accessible fragments were removed. If the tumor invaded the tentorium, it was dissected along the perimeter of the neoplasm to the notch with the detachment of the fourth cranial nerve while tumor fragments accessible for visualization were removed (see Fig. 4, *e*). In the case of a soft consistency of the PCM and its spreading to the cavernous sinus, access to the sinus was performed along the fifth cranial nerve to remove accessible tumor fragments. At this point, the "posterior" stage of treatment was completed; its average time was 485.9 ± 147.1 min (see Fig. 4, *f*).

After the surgery, the radicality of tumor removal was assessed based on the control MRI data. In the case of small fragments of the PCM in the cavernous sinus area and in the base of the anterior and middle cranial fossae accessible for subsequent radiation therapy, the 2nd stage of surgery was not offered to patients. In the case of residual tumor elements >3 cm in size, the "anterior" step of treatment was performed in 2–3 months after the 1st step using the pterional or infratemporal approaches, its average time was 408 ± 74.7 min.

Intraoperative neurophysiological monitoring was performed in all cases. Direct bipolar stimulation with a concentric electrode (0.05–0.2 mA, 1 Hz) was used to verify and evaluate the function of the cranial nerves (III–VII, IX–XII), which allowed us to verify the course of the nerves and remove the PCM with maximal radicality. The muscles tested for the cranial nerves were the following: *m. rect. med., m. levat. palp.* (III); *m. oblq. sup.* (IV); *m. rect. lat.* (VI); *m. masseter, m. digastricus, m. temporalis* (V); *m. mentalis, m. orbic. oculi, m. orbic. oris* (VII); *m. styloph.* (IX); *m. lev. vel. pal., m. cricothyr* (X); *m. trapezius* (XI); *m. transv. ling.* (XII).

During manipulations near the cranial nerves, the method of recording motor evoked potentials in the spontaneous electromyography mode (free run) was used, which allowed to change the plane of dissection, the degree of impact on the tumor or instrument depending on the esponses intensity. In all cases, due to compression of the brainstem, transcranial stimulation was also used to assess the motor evoked potentials (a series of 3 pulses up to 210 mV).

Two patients in the study group had previously undergone ventriculoperitoneal shunting in another medical institution, with subsequent development of shunt system dysfunction in both cases. We did not additionally perform cerebrospinal fluid shunting surgery in any of the patients because the brain relaxation was achieved by removing the cerebrospinal fluid after opening the arachnoid cisterns.

The radicality of tumor resection was assessed using the Simpson scale. Additionally, the volume of PCM resection was measured without taking into account the removal or coagulation of the matrix: 100 % of the volume without taking into account the matrix was considered total removal, 95–99 % – close to total, 85–94 % – subtotal, <85 % – partial.

**Statistical data analysis.** Statistical processing was performed using the SPSS Statistics program (IBM, USA). The level of statistical significance was set at $p < 0.05$. To compare independent samples by quantitative parameters, Student's t-test and the Mann–Whitney test were used, and by nominal parameters, $\chi^2$ and Fisher's exact test were used. When comparing quantitative characteristics in ≥3 independent groups, one-way ANOVA and the Kruskal–Wallis test were used.

## RESULTS

**Patients' characteristics.** The study group included 18 patients, 4 of whom underwent two-stage surgery (a total number of 22 surgeries were performed). The female to male ratio was 2.6:1, the average age at the time of surgery was 54.6 ± 11.8 years (range, 31–70 years). The median duration of the disease from the onset of the first symptoms to surgery was 15 (6–41.5) months. Tumor location was on the left in 11 (61.1 %) and on the right in 7 (38.9 %) patients. The average tumor volume before surgery was 46.3 ± 25.4 $cm^3$. Histological examination results were the following: grade 1 meningothelial meningiomas were verified in 15 (83.2 %) patients; meningiomas of mixed type of structure grade 1, atypical grade 2 and chordoid grade 2 – on 1 case (5.6 %), respectively.

**Clinical signs before surgery.** The most common preoperative symptoms were general cerebral (88.9 %) and cerebellar (66.7 %) syndromes, as well as symptoms of cranial nerve damage (83.3 %), with 80 % of patients having symptoms of damage to 2 or more cranial nerves. The initial status of patients according to the KPS varied from 50 to 90 % (median 80 %). Three patients (16.7 %) underwent preventive tracheostomy before surgery, as they had already pronounced bulbar symptoms, which allowed the conduction of patients' rehabilitation in the early postoperative period.

**Radicality of removal.** Taking into account the total volume of resection during two-stage operations, 1 (5.6 %) PCM was removed radically (100 % of the volume) (radicality corresponded to grade III according to the Simpson classification), close to total removal (95–99 %) was performed in 1 (5.6 %) patient, subtotal (85–94 %) – in 8 (44.4 %), partial (<85 %) – also in 8 (44.4 %) patients (Fig. 5). On average, the resection volume was 81 ± 16.8 % from the initial tumor volume.

**Neurological outcomes of surgical treatment.** In the early postoperative period, 63.6 % of patients experienced worsening of symptoms, 13.6 % experienced neurological improvement, and 22.8 % had no significant changes. Motor deficit developed/increased in 9.1 % of cases, cerebellar symptoms in 13.6 %, bulbar syndrome in 18.2 %, and cranial nerve deficit in 63.6 %. The patients' condition

assessment according to the KPS was higher before surgery (median 80 %) than after (median 70 %); the average PCMIS score before surgery was 7.5 ± 5.3 points, while after it was 11 ± 6.4 points; on average, the difference between the post- and preoperative condition assessment according to this scale was 3.6 ± 5.4 points. The most common complication was deterioration of cranial nerve function (63.6 %), especially VI (31.8 %) and VII (36.4 %).

In 2 patients (9.1 %), posthemorrhagic anemia developed after surgery (intraoperative blood loss of 600 and 1500 ml, respectively), which required blood transfusion; in 2 other patients (9.1 %), nosocomial polysegmental pneumonia, developed against the preventive tracheostomy, which required antibacterial therapy.

In 6 months after surgery, the median of the KPS assessment was 90 %, and the neurological status according to the PCMIS scale was on average 8.1 ± 6.3 points (Fig. 6, Table 1). There was no statistically significant difference in PCMIS scores before surgery and in 6 months after it ($p = 0.593$). Oculomotor disorders were detected in 6 months after surgery in 9 patients, and all of them were associated with insufficiency of the sixth cranial nerve.

**Comparison of meningioma groups according to Ichimura–Kawase**. The distribution of meningiomas according to Ichimura–Kawase was as follows: PCM of the petrous apex – 8 (44.4 %) cases, upper part of the clivus – 5 (27.8 %), cavernous sinus – 3 (16.7 %), tentorium cerebelli – 2 (11.1 %). We investigated the relationship between the type of PCM and various symptoms before surgery – a significant difference between these PCM groups was found only in the degree of brainstem compression, which was higher in the group of petrous apex PCM and upper part of the clivus ($p = 0.006$).

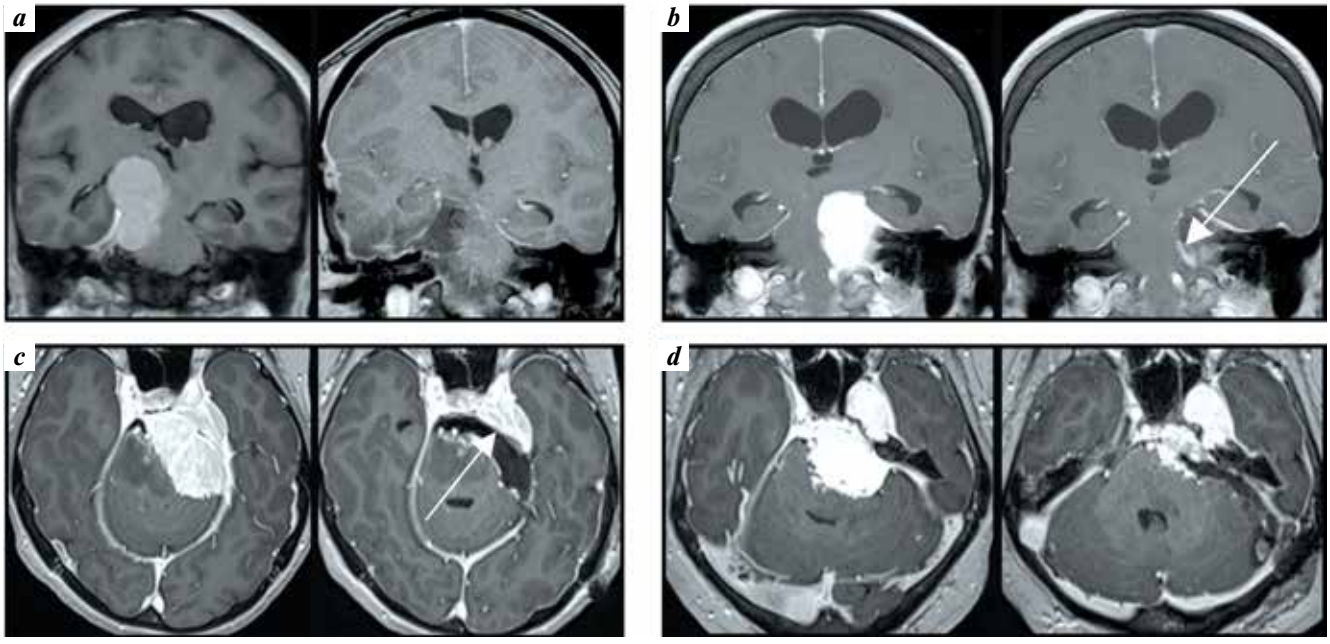


**Fig. 5.** *Cases of resection radicality of petroclival meningiomas (magnetic resonance images): a – complete resection (100 %) (Simpson III); b – close to complete resection (97.8 %). Arrow shows a fragment of tumor capsule which was tightly attached to the brainstem; c – subtotal resection (88 %). Arrow shows a fragment of the tumor in the cavernous sinus and tentorium; d – partial resection (64 %). A part of the tumor is left in the cavernous sinus and tumor fragment tightly attached to the brainstem*

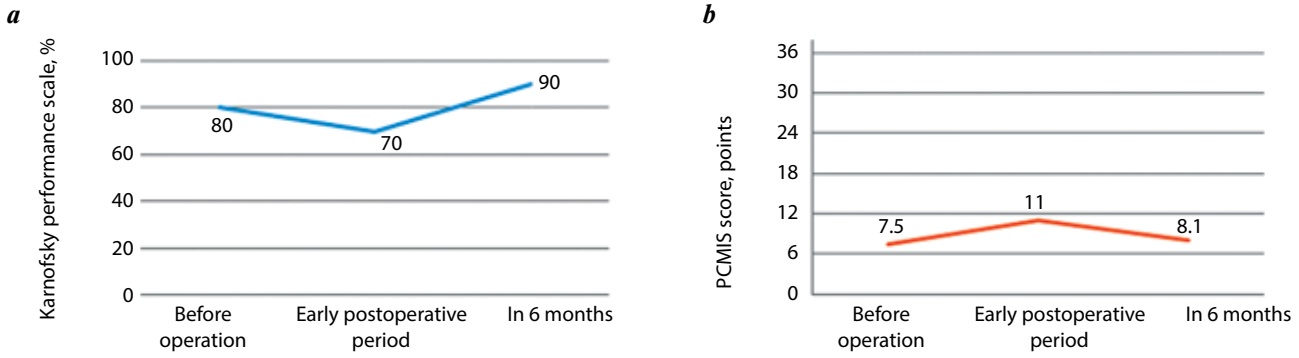


**Fig. 6.** *Dynamics of the patients' condition and neurologic status: a – the Karnofsky Performance scale; b – the PCMIS (Petroclival Meningioma Impairment Scale)*

**Table 1.** *Dynamics of the patients' neurological condition*

| Parameter | Before surgery | Early postoperative period | In 6 months |
|---|---|---|---|
| Karnofsky Performance Scale (median), % | 80 | 70 | 90 |
| PCMIS score, points | 7.5 ± 5.3 | 11 ± 6.4 | 8.1 ± 6.3 |
| Involvement of the cranial nerves III, IV, VI, *n* (%) | 9 (41) | 17 (77.3) | 9 (40.9) |
| Involvement of the trigeminal nerve, *n* (%) | 13 (59.1) | 16 (72.7) | 8 (36.4) |
| Involvement of the cochlear and facial nerves, *n* (%) | 14 (63.6) | 17 (77.3) | 12 (54.5) |
| Involvement of the bulbar nerves, *n* (%) | 8 (36.4) | 7 (31.8) | 4 (18.2) |

***Note.*** *PCMIS – Petroclival Meningioma Impairment Scale.*

**Table 2.** *Influence of various factors on the development of postoperative neurologic deficit*

| Factor | CN deficit | | | Motor deficit | | | Bulbar symptoms | | |
|---|---|---|---|---|---|---|---|---|---|
| | + | – | *p* | + | – | *p* | + | – | *p* |
| Age, years | 49.8 ± 11.2 | 64 ± 5.7 | 0.001* | 36.5 ±7.8 | 5.8 ±10.2 | 0.037* | 45.5 ±13.4 | 57.1 ± 10.3 | 0.148 |
| PCM volume prior to surgery, $cm^3$ | 51 ± 28.8 | 36.9 ± 14.4 | 0.275 | 54.4 ± 27.6 | 45.3 ± 26 | 0.424 | 62.7 ± 13.7 | 41.6 ± 26.3 | 0.014* |
| Duration of the disease, months | 14.5 {6–35.2} | 18 {7.2–3.5} | 0.639 | 45.5 | 11.5 {6–35.2} | 0.205 | 33.5 {21.2–78.7} | 9.5 {6–39.2} | 0.110 |
| KPS <70 %, *n* (%) | 2 (14.3) | 2 (25.5) | 0.465 | 0 | 4 (20) | 0.662 | 1 (25) | 3 (16.7) | 0.582 |
| PCMIS prior to surgery, points | 6.1 ± 3.7 | 5.5 ± 5.2 | 0.758 | 9.5 ± 3.5 | 5.4 ± 4.1 | 0.422 | 7.8 ± 3 | 5.4 ± 4.4 | 0.550 |
| Brainstem compression, grade (median) | 3 | 1–2 | 0.129 | 2–3 | 2 | 0.864 | 3 | 2 | 0.118 |
| Brainstem edema, *n* (%) | 8 (57.1) | 3 (37.5) | 0.330 | 2 (100) | 9 (45) | 0.238 | 3 (75) | 8 (44.4) | 0.293 |
| Cerebrospinal fluid layer between tumor and brainstem, *n* (%) | 9 (64.3) | 7 (87.5) | 0.255 | 1 (50) | 15 (75) | 0.481 | 3 (75) | 13 (72.2) | 0.708 |
| Growth in the cavernous sinus, *n* (%) | 11 (78.6) | 7 (87.5) | 0.535 | 1 (50) | 17 (85) | 0.338 | 4 (100) | 14 (77.8) | 0.418 |
| Growth into the IAC, *n* (%) | 9 (64.3) | 4 (50) | 0.416 | 1 (50) | 12 (60) | 0.662 | 4 (100) | 9 (50) | 0.098 |
| Resection volume, cm3 | 79.8 ± 15.3 | 70.3 ± 25 | 0.375 | 85.1 ± 21.1 | 75.6 ± 19.1 | 0.424 | 70.7 ± 16.2 | 78.4 ± 19.8 | 0.496 |
| Bulbar syndrome prior to surgery, *n* (%) | 6 (42.9) | 2 (25) | 0.358 | 2 (100) | 6 (30) | 0.121 | 3 (75) | 5 (27.8) | 0.117 |

**Statistically significant results.*
***Note.*** *CN – cranial nerves; PCM – petroclival meningioma; KPS – Karnofsky performance scale; PCMIS – Petroclival Meningioma Impairment Scale; IAC – internal auditory canal.*

**Prognostic factors for unfavorable outcome.** The study of parameters influencing the development of neurological deficit (ND) revealed the following data. The patient's age influenced both the development of motor disorders ($p = 0.001$) and symptoms of cranial nerve damage ($p = 0.037$), with younger age being associated with a higher incidence of new postoperative ND. Thus, in individuals <60 years of age, new ND developed in 90.9 % of cases, while in individuals >60 years of age it developed in 36.4 % of cases; these patient groups did not differ in tumor volume ($p = 0.438$) and resection volume ($p = 0.243$). At the same time, only the tumor volume before surgery ($p = 0.014$) significantly affected the development/worsening of bulbar symptoms in the postoperative period (Table 2).

**Prognostic factors for the radicality of PCM removal.** The influence of various factors on the volume of tumor

**Table 3.** *Influence of various factors on tumor resection volume*

| Factor | Resection volume, mm³ | *p* |
|---|---|---|
| Grade of brainstem compression:<br>I<br>II<br>III | <br>79.5 ± 7<br>68.4 ± 26.9<br>81.2 ± 14.7 | 0.701 |
| Cerebrospinal fluid layer between tumor and brainstem:<br>present<br>absent | <br>71.8 ± 19.7<br>89.4 ± 8 | 0.089 |
| Tumor type per Ichimura–Kawase:<br>UC<br><br>CS<br>TE<br>PA | <br>85.9 (51.2–95.8)<br>77.7<br>69.5<br>84.7 (73.2–89.9) | 0.780 |
| Growth into the cavernous sinus:<br>yes<br><br>no | <br>77.9 (59.2–86)<br>94.4 (87.6–99.5) | 0.005* |

**Statistically significant result.*
***Note.*** *UC – meningioma of the upper clivus; TE – meningioma of the tentorium; CS – meningioma of the cavernous sinus; PA – meningioma of the petrous apex.*

resection was analyzed (Table 3). Only the spread of PCM into the cavernous sinus had a statistically significant effect on the tumor resection volume ($p = 0.005$).

## DISCUSSION

Surgical treatment of PCM remains one of the most complex problems of modern neurosurgery [5]. Tumors of this localization are quite rare (2 % of all intracranial meningiomas), and the frequency of detection of giant PCM is even lower, but it is the giant size of these neoplasms that often leads to difficulties in choosing the optimal treatment strategy.

For maximum radicality of PCM removal, different centers use different surgical approaches; in our study, we most frequently used the retrosigmoid approach (59.1 %). Many surgeons prefer the retrosigmoid approach thanks to its simplicity, the advantage of brainstem decompression and the absence of the need for petrosectomy, but its disadvantage is the need to remove the tumor through the spaces between the cranial nerves, displaced by the PCM laterally and posteriorly [10].

The presigmoid approach with petrosectomy is often positioned as the safest, providing the greatest freedom and minimizing cranial nerve traction, but at the same time it is more traumatic and time-consuming [10]. In general, most experts recommend to give the preference for those approaches that are more convenient for the surgeon [10–11].

According to the literature data, the mortality rate after surgery of PCM reaches 5.39 %, and the incidence of worsening ND is 47.7–82.1 % [2, 5, 10, 12]. The incidence of new ND in our group in the early postoperative period was 63.6 %, mortality was 0 %. Six months after surgery, the patients' status according to the KPS improved in most cases compared to the preoperative level (median 80 % before surgery and 90 % in 6 months), and the integrative status according to PCMIS almost returned to the initial values (7.5 ± 5.3 points before surgery, 11 ± 6.4 points immediately after, 8.1 ± 6.3 points after 6 months).

The most frequent complication was the damage of the cranial nerves (63.6 %). Dysfunction of the sixth cranial nerve developed after 31.8 % of operations and was the most resistant to recovery in 6 months after operation, which is explained by the frequent location of the tumor matrix of giant PCMs in the area of the Dorello canal, in which it can be difficult to identify the nerve against the matrix bleeding.

Cerebellar edema, impaired blood circulation of the brainstem, and intracranial hematomas are considered to be the serious complications leading to severe disability or death [5, 13]. We did not observe these complications in any of our patients, probably one of the reasons for this was the rejection of any type of retractors and the use of the principles of dynamic retraction with an aspirator or other instrument [9].

In the light of the operation duration and the need for significant displacement of the cerebellar hemisphere, the retractor can cause ischemic changes in the cerebellum with subsequent edema, hemorrhages, etc. The small size of the trepanation allows avoiding the brain tissue herniation between the bone and the instruments, without interfering the visualization of the tumor poles and critical brain structures.

While the main goal in surgery of small and medium-sized PCMs is their maximally radical removal, the giant and large size of these tumors limits the radicality of resection [5]. According to different authors, the average volume of PCM resection varies significantly from 6.7 to 33 % [10, 12–13].

Radical (100 %) or close to it (95–99 %) resection of the PCM was performed by us only in 11.2 % of cases, which is associated with the inclusion in the study group of only patients with giant PCM (average volume before surgery – 46.3 ± 25.4 cm³, average resection volume – 81 ± 16.8 % of the original). Thus, the obtained results should be considered taking into account the significant volumes of resection.

According to the literature data, a low KPS status in the preoperative period is a predictor of unfavorable outcomes [12]. In our work, we showed that a low KPS status before surgery (<70 %) did not affect the development of a new postoperative ND ($p = 0.465$): out of 4 patients with a KPS score of <70 % before surgery, none had an additional deterioration in status. This pattern is also relevant for patients with initial bulbar disorders ($p = 0.358$).

Elderly and senile age is also considered as unfavorable predictor [12]. In our study, there were no patients over

70 years old, but when comparing elderly (>60 years) and younger patients, we showed that in the latter, new postoperative ND developed more often (90.9 % of cases) than in the elderly (36.4 % of cases) ($p = 0.012$), while the groups were homogeneous in tumor volume and resection volume.

This result may be due to both objective reasons (easier and safer traction of nerve structures due to the larger volume of cerebrospinal fluid spaces in elderly patients) and insufficient sample size. However, this pattern emphasizes the possibility of surgical care for patients of the older age group.

We showed that the development/worsening of bulbar symptoms is associated with the tumor size ($p = 0.014$). It was previously demonstrated that a favorable predictor of the radicality of tumor removal is the presence of a cerebrospinal fluid layer between the PCM and the brainstem, and a predictor of an unfavorable neurological outcome is brainstem edema according to preoperative MRI data [8].

However, in our study, these factors did not show their significance. The radicality of resection was influenced only by the fact of tumor spread into the cavernous sinus ($p = 0.005$). Also, in our study, it was not possible to prove the practical significance of the PCM classification according to Ichimura–Kawase (besides the association of PCM of the clivus upper part and the petrous apex PCM with more significant compression of the brainstem, $p = 0.006$) [4].

## CONCLUSION

Petroclival meningiomas are a complex problem of modern neurosurgery. Subcompensated patients with the giant PCMs have often been rejected surgical treatment, leaving only the possibility of symptomatic therapy.

The presented small series of clinical cases demonstrates that surgery of large-sized PCM remains quite complex, but it allows achieving the improvement of the patients' condition in 6 months after surgery in most cases when using the abovementioned principles of surgical treatment. Taking into account the frequent spread of the tumor into the cavernous sinus, the radicality of removal in our series of observations was slightly higher than 80 %, however, this created favorable conditions for further radiation therapy.

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**Authors' contribution**
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N.N. Turabekov: collection and processing of the material;
A.V. Dimertsev: editing of the article;
A.A. Zuev: development of the concept and design of the study, writing and editing of the article.

НЕЙРОХИРУРГИЯ
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**Conflict of interest.** The authors declare no conflict of interest.

**Funding.** The study was performed without external funding.

**Compliance with patient rights and principles of bioethics**
The study was approved by the Bioethics Committee of the I.I. Pirogov National Medical Surgical Center. All patients gave written informed consent to participate in the study.

**Article submitted:** 24.11.2023. **Accepted for publication:** 19.11.2024. **Published online:** 15.04.2025.

НЕЙРОХИРУРГИЯ
Russian Journal of Neurosurgery
1 ТОМ 27 Vol. 27 2025