Chapter

Surgery of Meningiomas of the Anterior Clinoid Process

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Abstract

Sphenoid wing meningiomas account for 11%-20% of all intracranial meningiomas, whereas meningiomas of the anterior clinoid process comprise about 34.0–43.9%. Assignment of these cranio-basal tumors to a separate group is due to the parasellar location and challenges in their surgical removal, mainly because of its anatomical syntopy: compression of the optic nerve, carotid artery inclusion, and invasion to the cavernous sinus. This chapter consists of the combination of current knowledge and our experience in understanding, diagnosis, surgical strategy, and complication avoidance with these tumors.

Keywords: sphenoid wing meningioma, classification, anterior clinoid process, clinoidectomy, parasellar syntopy, pterional approach, fronto-lateral approach, skull base

1. Introduction

Meningiomas are the most common primary intracranial tumors accounting for 20% of all intracranial neoplasms. Sphenoid wing meningiomas (SWM) account for 11%-20% of all intracranial meningiomas. Meningiomas of the anterior clinoid process (MAC) comprise about 34.0–43.9% of all sphenoid wing meningiomas. There is female prevalence among patients [1–3].

The challenges start with the definition of MAC. From the early beginning, H. Cushing and Eisenhardt in 1938 were the first to divide SWM into globoid tumors with a nodular shape and en plaque tumors, which are flat and spread along the sphenoid wing [2]. The globoid tumors were then categorized into lateral, middle, and medial. The last group could be classified as MAC. In accordance with Al-Mefti, MAC was classified into 3 groups according to the side of their origin on the surface of the clinoid process. First group meningiomas arise from the subclinoidal dura at the most proximal point of intradural entry of the internal carotid artery, before the carotid enters into the arachnoidal cisternal space. The second group clinoidal meningiomas originates from the superolateral aspect of the anterior clinoid process. The third group originates from the region of the optic foramen and extends into the optic canal [1, 4]. Many authors consider this classification hard to apply in daily practice. Russell & Benjamin took into account the invasion of the tumor into the lesser sphenoid wing and spread into the cavernous sinus [3]. Both parameters have great practical significance in surgical approach planning [5].

The exclusion method is also useful to identify the MAC. All paraoptic meningiomas such as tuberculum sella, diaphragm, cavernous sinus, planum sphenoidale, as well as spheno-orbital are recognizable with their specific findings [6, 7, 9]. We

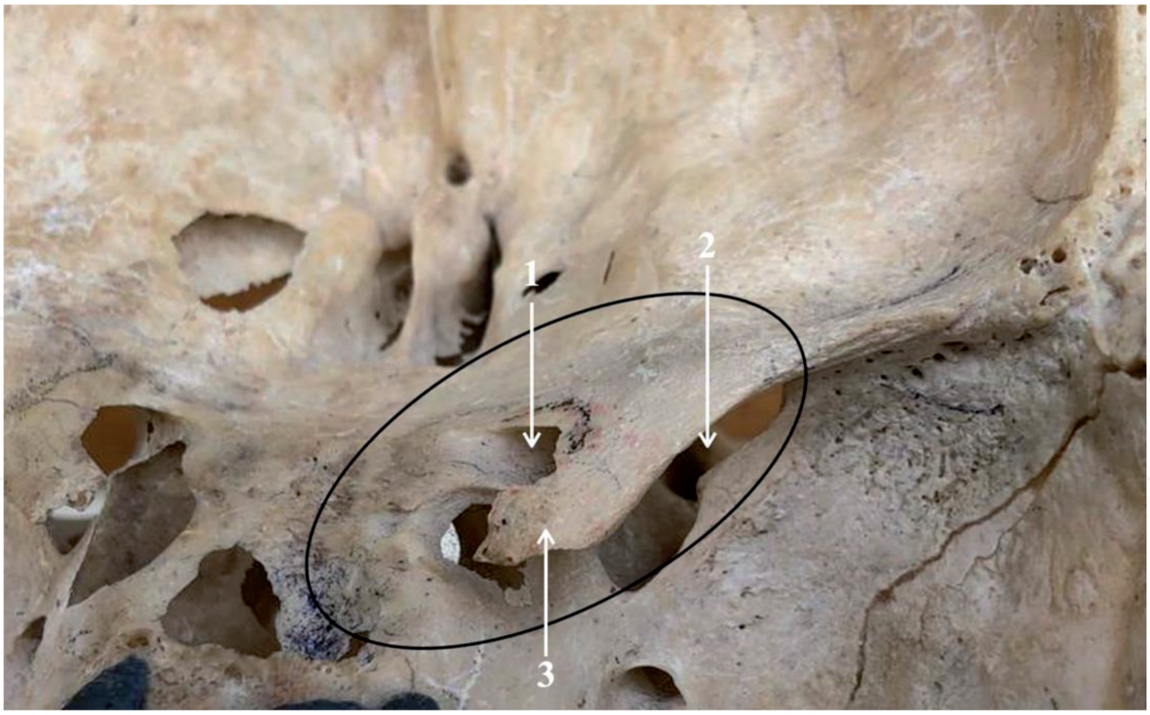

Figure 1.
Anterior clinoid bone anatomy, right side. 1 – Optic canal; 2 – Superior orbital fissure; 3 – Anterior clinoid process.

consider the presence of the anterior clinoid process in the center of the tumor bone attachment to be the main feature of clinoidal meningiomas (**Figure 1**). The second apparent peculiarity is the paramedian location of the tumor and consequently the displaced ipsilateral optic nerve, III nerve, and the ICA toward the midline [8–10].

2. Anatomical aspects

Anterior clinoid process (ACP) is tetrahedron in shape with the apex projected medio-posteriorly. Medially, it forms a superolateral wall of the optic canal. The optic strut is the posterior root of the ACP. Anteriorly it continues with the medial aspect of the sphenoid ridge.

As a rule, the process comprises the bony cortex. However, its pneumatization and bony connections could be variable and attention should be paid before the planned removal.

The removal of the process reveals the 2-6 cm long clinoid space [10]. The dural layer between this space and ACP is the deep extension from the roof of the cavernous sinus and covers the inferior surface of the clinoid process. Medially, this layer extends to surround the ICA as the proximal dural ring and turns upward along the clinoid segment of the ICA to fuse with the distal dural ring. The dural connection between the 3rd nerve and the lateral aspect of the distal dural ring is called the carotico-oculomotor membrane. From the inferolateral aspect of the ACP, the neural bundle consisting of 3rd, 4th, 6th and three branches of the ophthalmic nerve are running. Thus, manipulation in the inferior direction exposes these structures to danger and should be avoided [11, 12]. Meningiomas usually invade the outer (temporal) dural leaf and rarely spread to dura propria (DP), so the separation of dural leaves during surgery provides an increased removal rate as well as better visualization of anatomical structures [13, 14].

C2 and C3 segments of ICA (Bouthillier nomenclature) are traversing the horizontal and vertical portion of the carotid canal in the petrous bone. The cavernous

C4 segment is forming a carotid siphon, surrounded by venous plexus. This portion ends with the dural entrance through the proximal dural ring. The number of veins surrounding the clinoid meningioma is not constant. The superficial middle cerebral vein (SMCV) drains the lateral part of the cerebral hemisphere into the cavernous sinus (CS) directly by penetrating its lateral wall and indirectly through the sphenoparietal sinus or through the latero-cavernous sinus. Sphenoparietal sinus runs medially just below the lesser sphenoid wing to empty into the anterior part of the CS [15, 16].

3. Syntopy

Understanding of ACP syntopy with surrounding anatomical structures is extremely important for surgical dissection and anterior clinoidectomy during surgery. The base of the process forms the lateral and lower walls of the optic canal, the medial surface forms the ICA canal, and the lateral surface and optic strut are the parts of the upper medial wall of the upper orbit (**Figure 1**). Thus, ACP is located between the canal of the optic nerve, upper orbital fissure, and ICA canal. Extradural resection of the process provides the access to these bony channels and their content. The clinoidal process also separates two leaves of the dura: dura temporalis (DT) and DP. DP represents the lateral wall of the cavernous sinus and extends from the outer to the inner dural rings, where the ICA penetrates the cavernous sinus. Also, it touches the free edge of the tentorium in posterior divisions, which is fixed to the apex of the ACP [17]. Anteriorly it continues to the layers of the upper orbit. It should be remembered that ACP meningiomas usually invade the outer leaf of the dura and very rarely are spread to the DP. Thus, the separation of the dural leaves during surgery allows exposure of the lateral surface of the ACP and provides consequent visualization of the important anatomical structures of the skull base [17, 18].

After performing extradural clinoidectomy, the optic nerve in the dural sheath could be visualized [19, 20]. The lateral wall of the cavernous sinus and the intracavernous part of the ICA that is passing behind are seen as well. The 3rd nerve is located immediately below the projection of the lower clinoidal edge. The 1st branch of the V nerve passes lower.

Variable pathological anatomy of this area due to tumor growth has to be taken into account. Most clinoid meningiomas invade ACP causing its hyperostotic enlargement [21, 22]. Thus, anterior clinoidectomy is considered the key to the radicality of surgery.

However, there is a group of meningiomas that grows from the superior or superolateral surface of the clinoid without invasion into the ACP and hyperostosis does not exist [23–25]. Complete clinoidectomy is not necessary for this type of MAC.

Intradural syntopy in presence of MAC is much more complex and variable in comparison with extradural peculiarities. Primarily, it is due to the nature of meningioma spread, that has two patterns: expansive and invasive. The first type has a small fixation area and the tumor "wraps" around vessels and nerves. Invasive type spreads along the dura and longitudinally ingrowth into the anatomical structures [26]. In practice, a combination of both types with some predominance is usually seen.

The important tip is to follow the olfactory nerve that always leads to the optic nerve if the last is markedly displaced by the tumor.

A1 segment of ACA and all anterior semicircle of Willis are shifted medially and located on the dorsomedial surface of meningioma. M1 segment of MCA "rolls over" through the dome of the tumor on its upper lateral surface. Special attention to perforating and small branches of the anterior circle of Willis should be paid because of their tight inclusion in the tumor [27]. Sharp dissection is the only possible method to separate them from the tumor.

The oculomotor nerve is displaced dorso-medially and could be encased by neoplasm.

The pituitary stalk itself is not commonly involved in MAC, located on the postero-medial portion of meningioma, and could be separated without difficulties. Although, the superior hypophyseal artery has a variable way and has to be saved to prevent postoperative diabetes insipidus.

4. Diagnosis

Despite the fact that advanced imaging techniques are more accessible and have advantages in certain scenarios, the computed tomography and MRI routine scans remain the standard investigations for patients with MAC [28]. Hyperostosis, bone structures, and anatomical syntopy could be assessed with standard protocols. CT is informative in assessing the bony structures of the skull base, especially anterior clinoid hyperostosis, as well as to determine the presence of petrifications in the tumor. This examination is routinely performed the next day after surgery to control the extent of the tumor removal and exclude the hematoma.

Some features are associated with more aggressive meningiomas and include increased signals on both T1- and T2-weighted MRI, irregular contour, extensive edema, lack of calcifications, central necrosis, and low apparent diffusion coefficient [29]. However, if normal anatomy is variable, the more challenging pathological anatomy influenced by the tumor makes the strategy individual.

Attention should be paid to the tumoral entrapment of the supraclinoid part of the ICA. The ICA is "enveloped" and can *potentially* be dissected from the tumor if the tumor does not invade the bone, CS, and grows expansively in the intracranial direction. Circular encasement of the ICA by the tumor that spreads from the CS along the artery makes its surgical separation almost impossible [30].

Thus, we tend to divide MAC into two main types. The first includes tumors that do not invade the anterior clinoid process and grow expansively into the cranial cavity. Type II meningiomas involve the ACP, spread into the CS, and concentrically entrap the supraclinoid segment of the ICA. There is a sense to separate the second subgroup of tumors: with the penetration to the CS and without it. Anatomical criteria for distribution are demonstrated in **Table 1** and **Figures 2**–**4**.

	Type I	**Type IIA**	**Type IIB**
Anterior clinoid process hyperostosis	—	+	+
Cavernous sinus invasion	—	—	+
Internal carotid artery entrapment	Shifting / Wrapping	Wrapping / Adhesion	Concentric encasement
Needed clinoidectomy	Partial	Total	Total
Surgical approach	Fronto-lateral* intradural	Pterional extradural	Pterional extradural

**In absence of peritumoral edema.*

Table 1.
Criteria for distribution of sphenoid meningiomas.

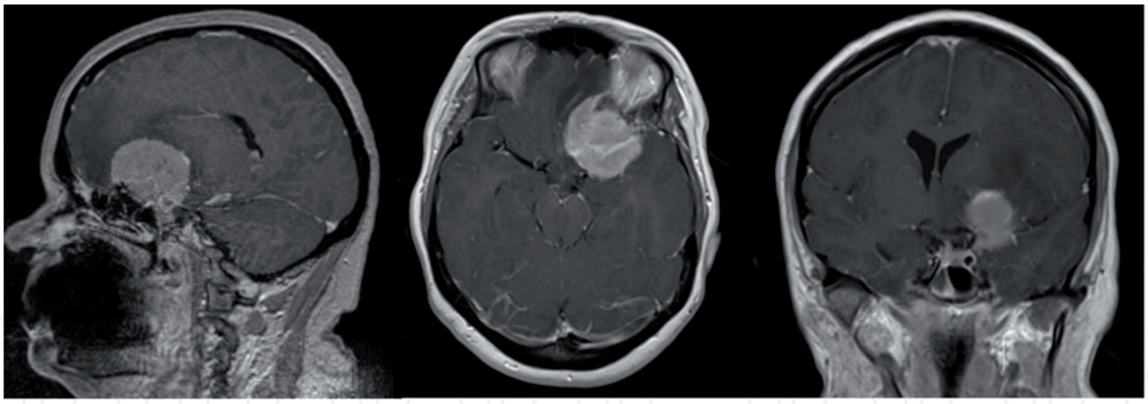

Figure 2.
Type I sphenoid meningioma.

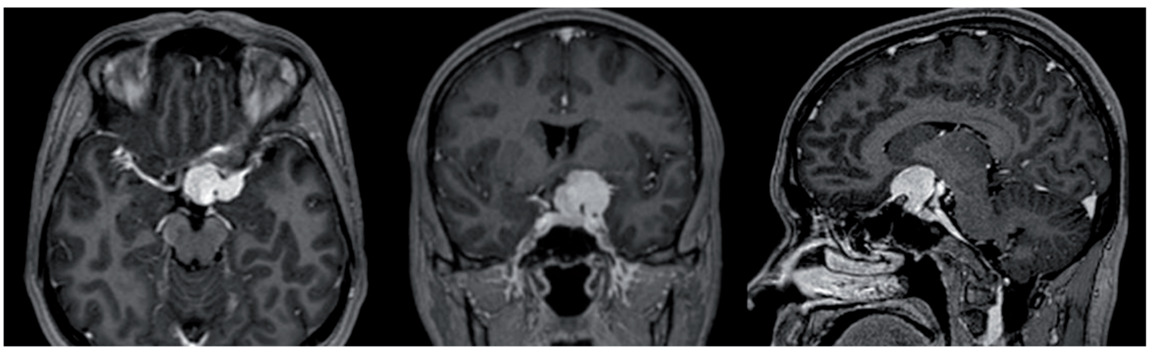

Figure 3.
Type IIA sphenoid meningioma.

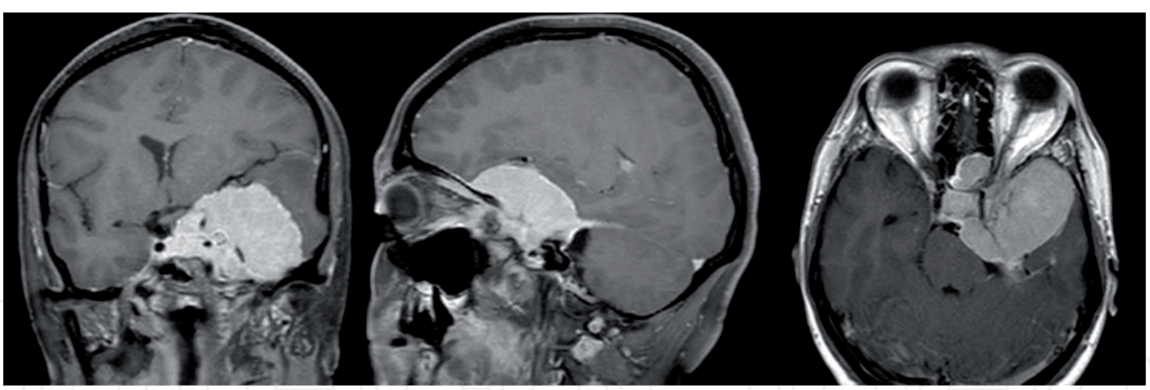

Figure 4.
Type IIB sphenoid meningioma.

Many surgeons recommend performing angiography before surgery to determine the tumor's blood supply and venous features. We totally agree with the expediency of this study, however, we would not insist on the absolute need to conduct it to all patients with this pathology.

5. Surgical approaches

According to the literature, several surgical approaches are used to remove sphenoid meningiomas: subfrontal, fronto-lateral, fronto-temporal intradural, pterional, fronto-temporo-orbito-zygomatic [14, 31, 32]. Eyebrow incision supraorbital keyhole approach (essential modification of the standard frontal-lateral/supraorbital) could be used as well [33]. Recently, several authors have reported their experience using this approach in the management of tumorous lesions around the sellar region [34, 35].

We are using two surgical approaches in our practice: fronto-lateral supraorbital and pterional. The advantages and disadvantages of both approaches are presented in **Table 2**.

In general, the patient's body should be strictly fixated despite the chosen approach to allow the operative field position and angles change. A rigid fixation of the head in the Mayfield or Sugita skull clamp should be used. We have abandoned the use of lumbar drainage to relax the brain during surgery. All surgeries are performed under general anesthesia with artificial lung ventilation.

5.1 Pterional approach

The head is turned away from the side of the craniotomy and the neck should be extended so that malar eminence is at the highest point of the operative field to allow gravity to facilitate brain retraction. The neck should be positioned to avoid excessive compression of jugular veins and the endotracheal tube. Elevation of the head of the bed and ipsilateral shoulder elevation with a pad is used to ensure adequate jugular venous return. The hair is shaved, extending for 3 cm behind the hairline. Skin is incised in a curvilinear fashion from 1 cm anterior to the tragus to the midline. Temporalis muscle is divided by electrocautery and the myocutaneous flap is reflected anteriorly and inferiorly by the subperiosteal dissection with the periosteal elevator and minimal electrocautery, until the root of the zygoma, keyhole, and supraorbital ridge are identified. Posteriorly, the temporalis muscle is retracted for additional temporal exposure.

Adjacent to the Sylvian fissure parts of the frontal and temporal lobes should be widely exposed during the trepanation window formation. The extradural stage includes pterion and lateral orbit drilling. The meningo-orbital band is cut. Dura propria and temporalis are separated from each other. The removal of hyperostotic ACP is impossible without this maneuver. MAC usually involves only temporal dura, thus DP serves as a great orientation layer covering cavernous sinus and protecting its structures during dissection. Intraoperative ultrasound investigation and neuromonitoring should be used during this stage to ensure the ICA and adjacent III and V1 nerves location. Before the intradural stage, it is necessary to visualize the optic nerve in the dural sheath, ICA, and the lateral wall of the cavernous sinus. Arcuate dural incision along the tumoral border allows to use the proximal undamaged dura as brain protection. Incision prolongs to the dura that rostrally covers the optic nerve and then along the upper edge of the cavernous sinus caudally. The edges are connected along the upper part of the cavernous sinus. Mobilized shred is removed together with the adjacent tumor (**Figure 5**).

	Fronto-lateral	Pterional
Surgical corridor	Intradural	Extradural
Clinoidectomy	Intradural partial	Extradural
Exposure of optic nerve and internal carotid artery	Intradural after dissection and debulking of tumor	Extradural before the tumor dissection
Meningioma devascularization	During the removal	Mainly before the removal
Need for Sylvian fissure dissection	+	—
Need for cerebral traction	Frontal lobe	Minimal due to protective dura

Table 2.
Advantages and disadvantages of pterional and fronto-lateral approaches.

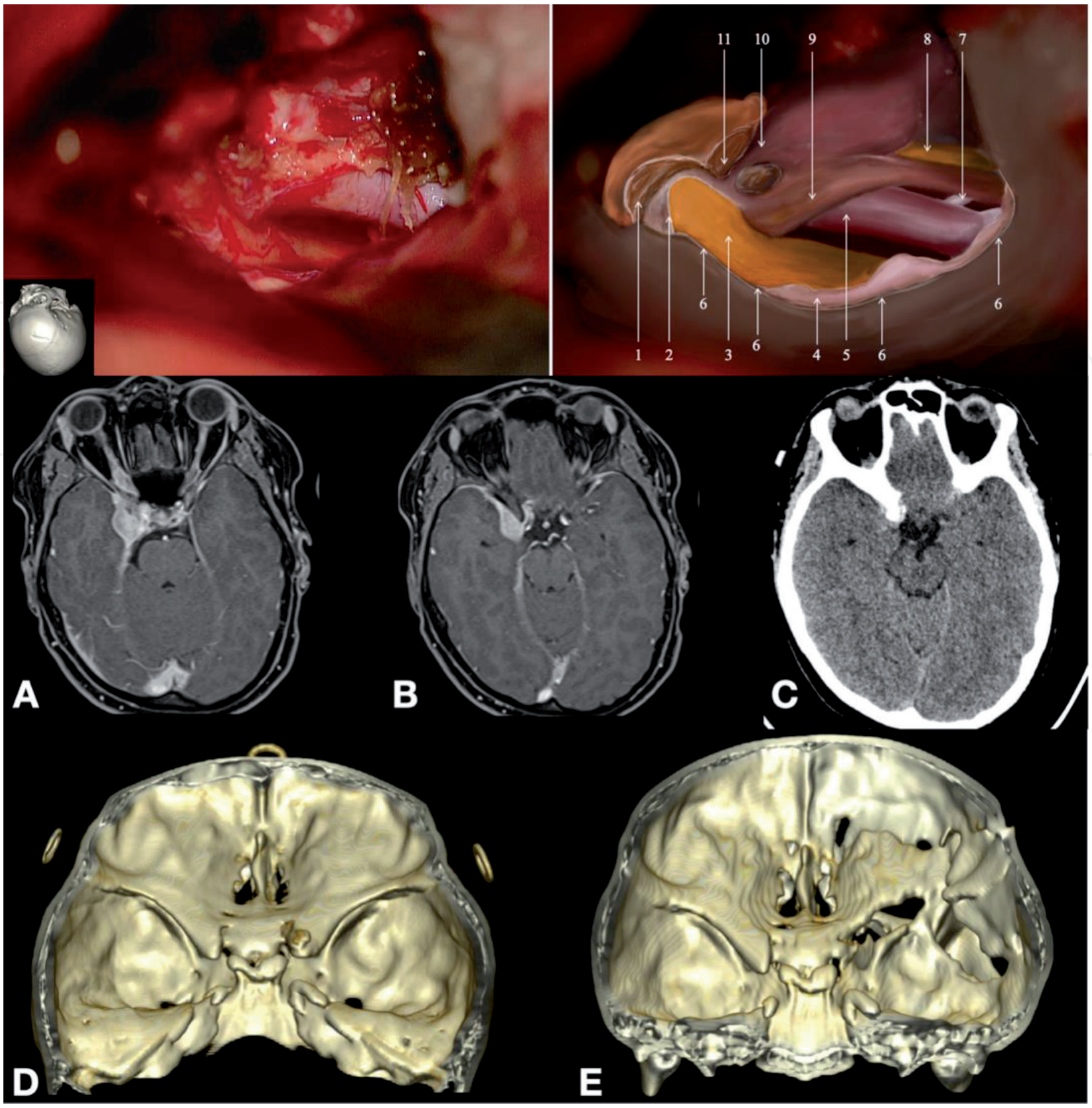

Figure 5.
Final view after tumor removal, right side. 1 – Drilled optic canal 2 – Incised dura around the optic nerve 3 – Optic nerve 4 – Brain tissue 5 – Internal carotid artery 6 – Dural edge 7 – Posterior communicant artery 8 – Oculomotor nerve 9 – Distal dural ring 10 – Superior orbital fissure (connected with optic canal) 11 – Drilled clinoid base; A and B – Preoperative MRI; C – Preoperative CT; D – Preoperative 3D CT bone reconstruction; E – Postoperative 3D CT bone reconstruction.

At this stage, the ON and supraclinoid segment of the ICA could be visualized. Markedly deprived from the blood supply, the tumor is debulked. Incrementally, the tumor is dissected from ON, chiasm, pituitary stalk, 3rd nerve, bran surface, ICA, PCA, ACA, MCA, and their branches in a sharp manner. Wound hermitization could be conducted with fat or vascularized galeo-aponeurotic flap.

5.2 Fronto-lateral supraorbital approach

The position of the patient is on his back. The head is raised and turned by 30° from the approach side. The skin incision is performed along the edge of hair growth. The musculocutaneous flap is directed toward the superciliary arch. Supraorbitally, a bone flap of approximately 5x3 cm is formed. Avoidance of frontal sinus opening is important and the mucous membrane should be dissected from the bone and sutured by atraumatic sutures if opened. Following the arcuate dural incision, CSF aspiration during Sylvian fissure dissection provides the brain's relaxation and wide working space. There is a tendency to avoid using a retractor for the frontal lobe. Even if needed, the use should be as the "brain holder" but not for the forced retraction. Tumor dissection is started from the attachment point and after the ICA, 2nd and 3rd nerves visualization the separation from the basal attachment could be safely ended. Following the main arterial supply deprivation, the tumor usually becomes softer and the volume reduction is effectively conducted. This step allows crucial structures to release. The superior and lateral surface of the anterior clinoid bone as well as the optic nerve roof should be skeletonized by excision of the involved dura. The optic canal is opened necessarily and the anterior clinoid process is drilled within its tumor germination. The procedure is ended with the hermetic dural suturing, fixation of the bone flap, and suturing of the skin.

6. Complication avoidance

Skull base surgery is technically complex and requires special training of the entire neurosurgical team. The procedure should be performed step by step, as each subsequent stage is possible only after the perfect execution of the previous ones. This form of organization as well as applying general principles of craniobasal surgery prevents the majority of surgical complications [36, 37]. Today, mortality after sphenoid wing meningioma surgery does not exceed 1.2% (0.6-1.8%).

In addition to technical aspects, the correct position of the body and head, the presence of neuronavigation and the intraoperative neuromonitoring system accompanied with a well-prepared neurophysiologist are no less important [38, 39]. The confidence with a set of special micro instruments and its appropriate application is crucial. Co-working with anesthesiologists is of great importance in managing the brain edema and consequences of nerves, meninges, and other immediately reactive structures irritation.

The most common complications after the removal of the sphenoid wing meningioma are deterioration of vision, 3rd nerve damage, vascular accidents due to vessels injury, and CSF leakage [36].

6.1 Optic nerve

Visual impairment is usually the first and main symptom and the primary goal of surgery is to preserve and improve the visual function of these patients.

Thus, early extradural visualization following the anterior clinoidectomy and intensive irrigation while drilling to prevent thermal damage is extremely important.

Dissection of the optic nerve sheath, as well as the falciform ligament, allow to explore the nerve in the optic canal, remove the intracanal portion of the tumor, and to ensure the complete ON decompression in the bone canal. Subsequent intracranial dissection from the tumor should be gentle to cause minimal injury of the ON and chiasm.

Early visualization of the ON is challenging in the case of the intradural frontolateral approach as it is covered with a tumor. The fixation point of MAP often extends to the roof of the optic canal. The risk of thermal damage of the optic nerve is high during the attachment site coagulation. We coagulate and separate the meningioma not directly along the basal dura, but retreating a few millimeters into the tumor mass. This maneuver lowers the risk of ON sacrifice. Ophthalmic nerves could serve as a landmark to find the 2nd nerve as I and II nerves as they are always overcrossing.

6.2 Oculomotor nerve

The oculomotor nerve has a low tolerance to any traumatic impact, so the violation of its function is possible even in the absence of direct manipulation with it during surgery. Nevertheless, if the 3rd nerve has not suffered serious traumatic impact intraoperatively, its function will be restored within 1-3 months postoperatively.

In contrast to pterional, the risk of damage to the 3rd nerve is minimal via the fronto-lateral approach. The oculomotor nerve passes directly below the lower edge of the wing, so clinoidectomy and separation of the two dural leaves could be harmful. Attentive dissection of DP and DT along with the plan, adequate irrigation, and coagulation avoidance in this area provide a better chance to pass by troubles.

The intracranial area of the 3rd nerve can be visualized after removal of the germinated basal dura. Sometimes it is appropriate to cut the 3rd nerve meningeal canal, to reach the tumor in the CS.

6.3 Arteries

Detection of the ICA is challenging because it is covered with a tumor. The point is to estimate the character of MAP adhesion to the arterial wall as early as possible. Intimate fusion makes surgical separation impossible because of the risk of arterial wall damage. The so-called "proximal control" proposed by Al-Mefty is not frequently used nowadays. Comparing two approaches in the context of ICA damage risk, the intradural approach is more dangerous because of the need to go through the mass of the tumor to reach the artery wall without having a plan for dissection. In contrast, the extradural approach provides the opportunity to assess the degree of adhesion by early detection of the ICA in CS using intraoperative Doppler and visualize it at the level of the distal dural ring.

The presence of circular ingrowth of the ICA by the tumor cast doubt on attempts to separate them. Consequently, the sharp dissection of all involved vessels of the circle of Willis is preferred.

6.4 Veins

Venous anatomy in this region is extremely variable. They are always full-blooded and are at high risk of being damaged. The CS is a complex of venous channels. Due to the variability of the functional role of each vein, the excision of the tumor should be conducted with maintaining the integrity of the veins. They should be cut only if there is a confidence that the vein drains the tumor. Sylvian veins could be directly drained into the CS [15].

7. Surgical outcomes and prognosis

Sphenoid wing meningiomas are the group of tumors where the advantages of cranial base surgery over conventional transcranial surgery can be clearly demonstrated. The introduction of craniobasal approaches, which evolved from the fronto-temporal to the pterional and the fronto-temporo-orbito-zygomatic, and from the unilateral subfrontal to the fronto-lateral supraorbital, significantly reduces both the mortality and postoperative complications rate. Thus, in the 1970s postoperative mortality was up to 43% in some reports [37]. In contrast, nowadays less than 2% are reported [36]. The complication rate is dependent on involved structures and surgical approach but has markedly fallen over during the recent decades.

Analysis of the factors influencing the postoperative prognosis showed that histopathological characteristic of meningioma is one of the main determinants. Around 70% of meningiomas are benign (WHO grade I), while 28% are atypical (WHO grade II), and 2% are malignant (WHO grade III) [40]. Despite these well-known prognostic groups, meningiomas could have up to 15 different histologic subtypes. These characteristics are marked prognostic predictors and define the treatment strategy.

Anterolateral skull base and convexity meninges are derived from the neural crest, but the rest of the skull base has mesenchymal origin (paraxial mesoderm and dorsal mesoderm) [41]. This correlates with different histological subtypes of tumors and even WHO grades. Interestingly, the recent studies demonstrate the link between topography (meaning mesenchymal or neural crest origin) and the main somatic gene mutations [42].

The radicality of the removal is the next important prognostic factor. However, the introduction of radiosurgical treatment of the residual tumor of the skull base has significantly decreased the recurrence rate in the described group [42, 43].

8. Radiotherapy and radiosurgery

Surgical resection of MAC is the treatment of choice, but in some cases, surgery alone may not be radical due to the tumor invasion to the CS, ICA, and/or ON encasement. Subtotal resection with adjuvant postoperative radiotherapy may be preferable over complete resection.

High-dose fractionated radiotherapy and radiosurgery have been reported to achieve a tumor control rate between 93–97% and 91–98%, respectively [43]. Permanent complications after radiosurgery are rare and have been reported in 0–10.5% of patients. They mainly consist of delayed optic nerve neuropathy, trigeminal nerve dysfunction, cognitive deficits, and seizures [44]. Functional results after radiosurgery for meningiomas involving the CS have proved to be superior to those obtained after microsurgical resection. [45]

The growth pattern in progressive benign meningiomas after failed radiosurgery can be unusually aggressive. In the case of reoperation after radiotherapy, it is associated with a higher complication rate compared to primary procedures [46].

9. Conclusions

Despite the great variety of existing approaches, the pterional extradural is the most common “workhorse” for meningiomas of the anterior clinoidal process excision. If there is no clinoid process hyperostosis and cavernous sinus invasion, the fronto-lateral approach will be an option. Overall, total clinoidectomy is the key procedure for visualization of all important structures during an extradural way to the tumor. All the peculiarities should be taken into account to move safely and prevent the thermal and mechanical injury of neural and vascular structures. Radicality of excision is limited by the ICA encasement rate and character, the cavernous sinus invasion, and an anterior semicircle of Willis ingrowth. Preserving the integrity of perforating arteries and surrounding veins is the main key to preventing complications. Finally, the radicality of surgery will never exceed the value of the functional result of surgery and the patient’s postoperative quality of life.

Conflict of interest

The authors declare no conflict of interest.

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