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REVIEW ARTICLE

Different microsurgical approaches to meningiomas of the anterior cranial base

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Abstract
Introduction Meningiomas of the anterior skull base show specific characteristics, which render them difficult to handle. These tumors include olfactory groove, supra- and parasellar, anterior sphenoid ridge, cavernous sinus, and spheno-orbital meningiomas. Tumor localization and size, encasement of important structures as well as the extent of dural attachment may influence the decision for an adequate approach.
Discussion Various approaches to the anterior cranial fossa exist, each with corresponding advantages and disadvantages. Recently, endoscopic approaches have increasingly been used. In this review, the different approaches to meningiomas of the anterior cranial fossa in respect of anatomical issues, indications, and associated risks are discussed.

Keywords Meningiomas · Anterior cranial base · Microsurgical · Endoscopic

Introduction

Approximately 25% of intracranial tumors are meningiomas, of which 12% to 20% are located in the anterior cranial fossa [62, 83, 90]. This anatomical area is limited posteriorly by the small sphenoid wing and the anterior margin of the chiasmatic groove, while its floor is formed by the orbital planes of the frontal bone, cribriform lamina of the ethmoid bone as well as the small wing of the sphenoid bone and frontal part of the sphenoid body.

Meningiomas in this area may arise from the cribriform plate, orbital roof, planum sphenoidale, anterior clinoid process, tuberculum sellae, cavernous sinus, or sphenoid wing [83]. Extensions of these meningiomas may involve the orbit, the paranasal sinuses, and the infratemporal fossa [25]. As meningiomas commonly are rather slow growing tumors, they can reach very large volumes before causing clinical symptoms, in spite of massive displacement of intracranial contents. On the other hand, when delicate structures (e.g., optic nerve) are present, even small tumors may cause early clinical signs.

According to their origin and extension, meningiomas of the anterior cranial fossa are classified as follows:

Olfactory groove meningiomas They arise from the midline of the anterior fossa at the cribriform plate and the frontosphenoid suture. Extension into the ethmoid sinus has been reported to occur in up to 15% of patients [41], and further extension into the nasal cavity and/or orbit is seen in some cases. Blood supply of these lesions most commonly derives from the anterior and posterior ethmoidal arteries, anterior branches of the middle meningeal artery, and the meningeal branches of the ophthalmic artery. The olfactory nerves may be displaced laterally on the surface of smaller tumors; however, in larger tumors, the olfactory nerve can be bruised and be tightly adherent to or spread out on the tumor capsule, so that preservation may be hard or impossible. The optic nerves and chiasm are usually located inferolaterally to olfactory groove meningiomas, ranging from mild displacement to severe distortion and compression [26, 27, 41, 59, 60].

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Tuberculum sellae meningiomas They arise from the limbus sphenoidale, chiasmatic sulcus, and tuberculum sellae [13, 99]. These tumors characteristically lie in a suprasellar subchiasmal midline position, displacing the optic chiasm posteriorly and slightly superiorly, and the optic nerves laterally [13, 77]. A frontal extension of the tumor may expand into one or both optic canals. The carotid arteries are usually displaced laterally, but to a lesser degree than the optic nerves, and are occasionally circularly encased. Blood is usually supplied by the posterior ethmoidal arteries, and further contributions may also come from tiny branches of the anterior cerebral and the anterior communicating complex [26].

Sphenoid ridge meningiomas These tumors are further classified into three groups, based primarily on a typical tumor-induced clinical presentation: (1) deep, medial, inner (or clinoidal); (2) alar or middle; and (3) pterional or outer type [3, 15, 93]. Among these three groups, clinoidal meningiomas are most challenging to resect completely and safely when the tumor encircles and/or compresses the optic nerve, internal carotid artery, and/or their branches as well as the oculomotor nerve [93].

Cavernous sinus meningiomas Tumors involving the cavernous sinus may have their origin outside the cavernous sinus and invade it secondarily, or alternatively start within the cavernous sinus and spread outside [9, 43, 87]. Apart from compromising structures within the cavernous sinus (internal carotid artery, the ocular motor nerves, the maxillary and ophthalmic nerve), extensions of the tumor may also affect the optic nerve and chiasm and the pituitary gland [43].

Spheno-orbital meningiomas They are defined by predominantly intraosseous tumor growth, which leads to significant hyperostosis and a thin, yet widespread, carpet-like, soft tissue growth upon the dura. Bony tumor growth usually involves the lesser sphenoid wing, the orbital roof, and the lateral orbital wall [78]. Bony proliferation may include the anterior clinoid process, the superior orbital fissure, the optic canal, and the sphenoid or ethmoidal sinuses. Soft tissue growth can spread into the orbita [78, 85].

Treatment goals

For meningiomas, achieving complete removal with low morbidity rate is desirable as complete removal in meningiomas provides long-term cure [9, 25, 26, 46, 96]. However, due to the adjacency and encircling of intracranial nerve and vessel structures, radical surgery implies the risk of damaging these structures with subsequent neurological deficits. Tumor removal may further be complicated by tumor size, strong vascularization, consistency, and dural attachment [83]. A treatment plan should therefore also consider adjuvant treatment modalities (such as radiosurgery). Therefore, in surgical planning, the choice of adequate surgical approach has to be based on tumor localization, extension, goal of surgery (biopsy, partial resection, or complete resection), necessity of reconstruction, and experience of the surgeon [88].

An adequate approach has to provide exposure of important anatomical structures, minimal working distance, and brain retraction as well as early access to tumor blood supply [26]. Additionally, surgical approaches should combine good access and surgical aesthetic procedures [8, 96, 98]. For minimal risk of intracranial infection by postoperative cerebrospinal fluid leakage, reliable methods for skull base reconstruction are indispensable.

Microsurgical approaches

Since Cushing's publication in 1938, describing the removal of meningiomas located in the anterior cranial fossa, some techniques have evolved a lot [91]. Several approaches to the anterior cranial fossa exist with individual pros and cons. In recent years, endoscopic approaches have gained growing importance.

A significant role for the decision on the best approach is played by adequate preoperative imaging with magnetic resonance imaging (MRI) and computed tomography (CT). MRI imaging reveals in detail the anatomical relationship with adjacent vital structures and the location or encasement of major vessels. Perifocal edema can be displayed. CT imaging is important to show intratumoral calcification or hyperostosis. Angiography has contributed significantly to the understanding of vascular supply of the meningioma, although its diagnostic role has been largely supplanted by MRI and CT. Angiography may in selected cases be of benefit as an adjunct to surgery through preoperative embolization [28].

Pterional approach

The pterional or fronto-temporo-sphenoid approach was first used in 1918 by Heuer to gain access to suprasellar lesions. It was later modified by Dandy and Yasargil and is one of the most commonly used neurosurgical approaches [39, 40, 84].

The pterional approach consists of opening the skull and accessing the brain through its lateral aspect by removing the frontal bone, the squamous part of the temporal bone, and the greater wing of the sphenoid (Fig. 1). The pterional

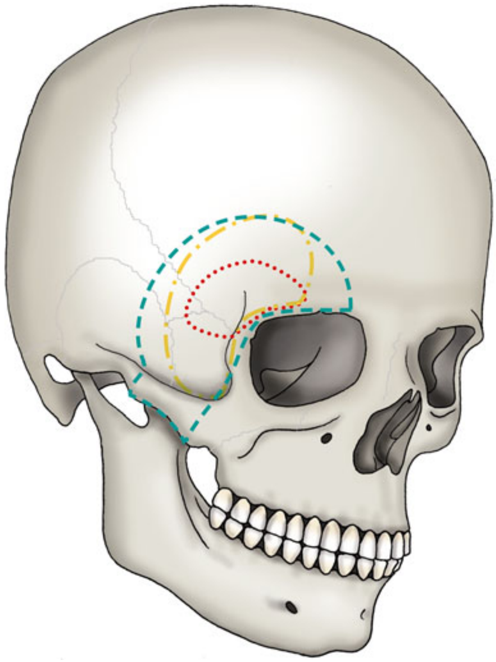

Fig. 1 The frontolateral (*red*, *dotted*), pterional (*yellow*, *dashed-dotted*), and orbitozygomatic approaches are sketched in

approach can be modified into frontolateral or fronto-orbitozygomatic craniotomies [89].

The main direction of preparation leads along the lesser sphenoid wing. Extradural resections of the sphenoid wing and the dissection of the Sylvian fissure are synergistic effects to gain wider access between the frontal and the temporal lobes. The pterional approach provides the shortest route to the internal carotid artery and to its branches, but also to deep-seated areas of the retroclival and retrochiasmatic, supra- and parasellar space [88, 95].

This approach offers several advantages. It allows early cerebrospinal fluid release by opening cisterns before dissecting the tumor. After wide opening of the Sylvian fissure, visualization of all critical neurovascular structures is enabled with protection of these. The frontal veins are not compressed as the frontal lobes are not strongly elevated; thus, venous drainage remains intact throughout the entire surgical procedure [39, 40]. Intradural and extradural removal of hyperostotic bone of the sphenoid wing including the anterior clinoid process can be performed safely. The risk of postoperative rhinorrhea is low as opening of the frontal sinus can usually be avoided [84]. No cerebrospinal fluid (CSF) rhinorrhea is reported in all studies mentioned above dealing with the pterional approach.

The major disadvantage of the pterional approach is the narrow working angle. In high riding olfactory groove meningiomas, the upper part of the tumor cannot be seen. Also, the working distance to the contralateral side of the tumor may be long [91].

Indications of the pterional approach are meningiomas of the sphenoid ridge or clinoidal meningiomas [3, 6, 54, 69, 72, 79, 93], optic sheet meningiomas [24, 86], meningiomas involving the cavernous sinus [16, 22, 57, 66], suprasellar meningiomas [30, 37, 44, 68, 71, 92, 101], olfactory groove meningiomas [1, 7, 26, 39, 40, 70, 91, 95], and orbital meningiomas [78, 81, 82, 85, 86].

Frontolateral approach

The frontolateral or supraorbital approach is a more medially placed modification of the pterional craniotomy (Fig. 1). It is combining the advantages of the pterional approach with larger exposure of the frontobasal area [91]. The first supraorbital, subfrontal approach was published by Fedor Krause [75, 76]. Perneczky used this approach in a minimally invasive concept. It can be performed by a semicoronar skin incision or a supraciliary incision [29]. The semicoronar incision allows maximum pericranial flap to obtain tissue for skull base sealing.

The suprasellar anatomic structures are accessible for surgical dissection from an anterior view as the anterior part of the temporal lobe does not obscure access to deep-seated areas. After CSF drainage, brain retraction is minimized or can even be dispensed. With thorough dissection of arachnoid adhesions, also contralateral structures can be adequately visualized. Access to the optical cisterns from the lateral side may be equivalent to a frontal approach.

A possible complication is CSF rhinorrhea due to the opening of the frontal sinus. The risk of postoperative CSF rhinorrhea is quoted from 2.9% to 16.7% [29, 50, 65, 91].

Indications for this approach may be clinoidal meningiomas [3, 42, 64, 97], olfactory groove meningiomas [1, 29, 65, 67, 80, 91], meningiomas of the cavernous sinus [42], and suprasellar meningiomas [42, 97]. El-Bahy advocates a limitation of this approach in olfactory groove meningiomas larger than 4 cm [29].

Fronto-orbitozygomatic approach

The fronto-orbitozygomatic or supraorbital–pterional approach was popularized by Jane for the exposure of tumors of the lateral anterior cranial fossa and those in the orbit and retroorbital regions without retraction of the brain and meticulous dissection [45, 89, 91]. Thus, this approach can be used when a more basal approach is needed.

Osteotomy includes the supraorbital rim, part of the roof, and lateral wall of the orbit as well as a portion of the zygoma (Fig. 1). Thus, exposure of the supraorbital nerve is necessary [100]. The orbitozygomatic and pterional bone flaps have to be replaced and fixed in position with miniplates and screws.

This approach allows good exposure to the cavernous sinus and offers more comfortable access to interpeduncular regions [2]. The danger of injuring the frontal branch of the facial nerve may be reduced by extending the scalp incision across the midline and dissecting the temporal fascia in the deep subfascial plane. Some studies describe severe orbital swelling that required temporary tarsorrhaphy and postoperative cerebrospinal fluid fistulas due to the wide opening of the frontal sinus [55, 91, 100].

Indications may be olfactory groove meningiomas [48], clinoidal meningiomas [2, 48], and suprasellar meningiomas [48, 100], spheno-orbital meningiomas [2] as well as meningiomas of the cavernous sinus [100].

Bifrontal approach

The bifrontal approach has been recommended as standard approach for large tumors of the anterior cranial fossa. It was first described by Horsley and Cushing and was later also proposed by Tönnies, who preserved the frontal brain tissue by a subfrontal approach [39, 40, 84].

It is performed with a coronar skin incision from zygoma to zygoma. Boreholes are carried out at the end of the anterior temporal line on both sides. Craniotomy is made anteriorly just above the supraorbital ridge of either side and posteriorly along the convexity of the cranium (Fig. 2). The frontal sinuses are usually opened and the mucous membranes are completely removed. Dura opening involves ligation of the superior sagittal sinus, cut together with the falx, compromising venous drainage from the frontal lobes, and thus possibly contributing to brain edema [69].

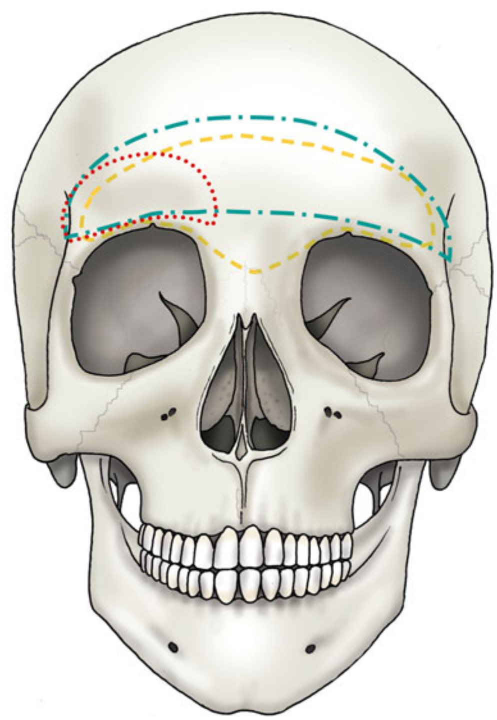

Fig. 2 Three different approaches to the frontal cranial base. Unilateral (*red*, *dotted line*) and bilateral subfrontal (*green*, *dashed-dotted line*) as well as transbasal/subcranial (*yellow*, *dashed*) are plotted

The approach is connected with the least amount of retraction on the frontal lobes and gives direct access to almost all sides of the tumor. It allows early devascularization of meningiomas and also adequate exposure for cranial base reconstruction. It provides opportunity for radical tumor resection, drilling of hyperostosis in the cribriform plate area, and unroofing of both optic nerves.

Disadvantages are late visualization of the most important structures—the optic nerves, internal carotid arteries, and the anterior cerebral complex. Due to the wide opening of the sinus, there is a high risk of developing CSF fistulas. Risk in the literature is quoted from 5% to14.2% [7, 83, 91].

Indications for this approach are olfactory groove meningiomas [1, 7, 41, 65, 69, 83, 91, 94] and parasellar meningiomas [33, 36, 83].

Extended bifrontal/subcranial/transbasal approach

The subcranial approach is an extension of the bifrontal craniotomy first described by Raveh [73, 74]. The goal of that extension was to minimize brain retraction. As for bifrontal craniotomy, a coronar skin incision is made. The craniotomy includes an osteotomy of the entire fronto-naso-orbital segment in one bloc including nasal pyramid and orbital rims (Fig. 2). In order to avoid injury, it is necessary to expose the supraorbital nerve. Opening of the frontal sinus is unavoidable, and therefore, it is mandatory to cranialize it [73, 74].

The subcranial craniotomy greatly reduces the extent of frontal lobe retraction [13, 91]. Chi and McDermott showed in their series a reduction of the incidence of new or worsened edema after surgery [13]. It also allows early control of basal vessels such as ethmoidal arteries especially for tumors inserted on the anterior part of the skull [13, 91].

The disadvantage is the technical difficulty including complex and time-consuming reconstruction [91]. Despite this, Chi and McDermott reported only a postoperative CSF leakage rate of 4.4% [13], while the series of Spektor et al. showed a high risk of CSF fistulas of 25%. Therefore, they advocate a spinal drain to avoid permanent CSF leak [91]. Further disadvantage of this approach is the fact that both olfactory tracts are handled with a possible risk to damage them.

The subcranial approach allows a large field of vision to the anterior cranial base compartment in continuity with neighboring structures including the frontal, sphenoid, and ethmoidal sinuses, the orbits, and the nasal cavity. Therefore, the indications for this approach are large olfactory groove meningiomas [13, 35, 67, 91, 96] and large parasellar meningiomas [13, 91] with paranasal extension.

Unilateral, subfrontal approach

The subfrontal approach is also a prototype approach to resect meningiomas of the anterior skull base. This approach spares the superior sagittal sinus and the contralateral frontal lobe. Starting with a semicoronar skin incision which ends near the midline on the contralateral side, the craniotomy begins at the keyhole and runs along the orbital roof. Thus, a 4-cm-long and 2–3-cm-high bone flap has to be removed (Fig. 2).

It provides symmetrical and wide exposure and direct access to both internal carotid arteries. Important structures, like the internal carotid artery and the optic nerve, are detected and dissected early during the procedure. In contrast to the bifrontal craniotomy, the contralateral olfactory tract is spared [36].

Advantages of this approach as compared to bifrontal craniotomy are a lower risk of opening the frontal sinus, avoidance of manipulation of both frontal lobes as well as preservation of the superior sagittal sinus. However, the risk of CSF leakage is still indicated from 5% to 20% [67, 91, 101].

To avoid this risk, Mayfrank et al. reported a variant of the approach for olfactory groove meningiomas. They presented a frontal interhemispheric approach. They performed a bone flap of about 5×5 cm between the upper limit of the frontal sinus and the coronal suture. Two burr holes are placed over the sagittal sinus and the bone flap is cut with a craniotome. This affords ipsilateral exposure of 4 cm and contralateral of 1 cm. The goal of this approach is to prevent opening of the sagittal sinus and hence decreasing the risk of CSF leakage and infection [59].

Indications for this approach are olfactory groove meningiomas [4, 7, 9, 67, 90, 91] and parasellar meningiomas [13, 25, 26, 36, 90, 101].

Endoscopic approaches

In neurosurgery, endoscopic techniques have been used since the first decades of the twentieth century. In order to avoid surgical trauma to viable cerebral tissue, endoscopes were tried to approach deep-seated lesions. The first endoscopes in the 1920s did not allow sophisticated techniques in the target area due to their technical construction, and thus, did not offer advantages in comparison to the wide exposures by craniotomy [5].

Development of better endoscopes with improved illumination, a wider field of view, and angled views made endoscopy worth further considerations. The advantage of this technique was seen in the potential minimization of surgical trauma in general and especially to healthy cerebral tissue along the route to deep-seated lesions [5]. A further advantage of endoscopy is the small skin incision required and avoidance of brain retraction. Studies advocating endoscopic approaches report shorter duration of postoperative pain and a shorter stay in hospital [11].

Expanded endonasal approach

The transsphenoidal approach to the anterior cranial base was first proposed more than a century ago and reintroduced by Guiot and Hardy in 1963. In recent years, the technique has extended to regions beyond the sella turcica to include a variety of lesions involving the anterior cranial base from the anterior crista galli posteriorly to the clivus (Fig. 3). The increasing popularity of this technique is attributed in part to the less invasive nature and reduced complications and furthermore to limitations of traditional transcranial approaches like the difficult assessment of intra- and infrasellar components [23].

Many skull base meningiomas often originate along the ventral skull base and have a tendency to grow and displace neurovascular structures laterally, which makes an anteromedial transnasal approach an attractive natural corridor. It allows early disruption of tumor blood supply.

However, if neurovascular structures are ventral or basal to the meningioma, the transsphenoidal approach should

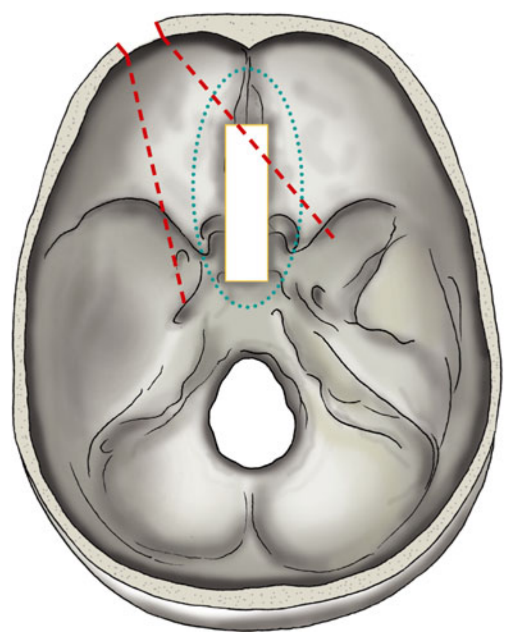

Fig. 3 The two common directions for endoscopic access to the frontal base are illustrated. *Red lines* (*dotted*) show lateral approach with the achievable field of view. Medial, transnasal approach is indicated by the *yellow square* showing the gained area of access outlined in *green* (*dashed*)

not be preferred. As a consequence, meningiomas lateral to the optic nerve should be operated transcranially. Limitations of this approach are in the sagittal plane from the anterior wall of the frontal sinus to the brainstem and in the coronal plane the mid-superior orbit and the optic nerves [50, 51].

Schwartz et al. presented a classification of expanded endonasal approaches and their indications. Their classification included the transnasal, transsphenoidal, transethmoidal, and transmaxillary approach. The transnasal approach does not pass any sinus. It may be followed superiorly to approach the cribriform plate, olfactory groove, and anterior cranial fossa for resection of olfactory groove meningiomas. The transethmoidal corridor provides a superior approach lateral to the nasal approach. A total anterior and posterior ethmoidectomy provides a wide exposure to the frontal skull base with the anatomical borders: fovea ethmoidalis and frontal fossa superiorly, lamina papyracea and orbital apex laterally, sphenoid sinus posteriorly, and frontal sinus anteriorly. This approach in combination with other corridors may be used for meningiomas involving the cavernous sinus, orbital apex, and the anterior fossa.

The transsphenoidal approach is the most commonly used, as the sphenoid sinus provides the most versatile endoscopic corridor to the cranial base. After enlargement of the sphenoid ostia bilaterally, a wide opening of the anterior wall of the sinus is performed, and septations are removed as needed. From the sphenoid sinus, the sella can be opened posteriorly and superiorly, the tuberculum sellae and planum sphenoidale may be accessed superiorly, and the cavernous sinus laterally. Indications for this approach are meningiomas involving the medial cavernous sinus and meningiomas of the region of the suprasellar cistern.

In the literature, there are several case reports and mixed case series discussing this approach, while only a few studies deal with an endonasal approach for meningiomas alone. Studies reported the endoscopic endonasal resection of suprasellar meningiomas [10, 12, 14, 17–21, 23, 31, 34, 49, 53] and olfactory groove meningiomas [20, 32, 34, 50]. Liu et al. in their series presented an endoscopic biopsy of two meningiomas of the cavernous sinus [56].

de Divitiis et al. reported contraindications to this approach: (1) tumor with size exceeding 2 to 2.5 cm and an eccentric shape, (2) extension of the tumor inside the optic canal, (3) encasement of one or both internal carotid arteries with or without extension on the optocarotid triangle, and (4) the encasement of anterior communicating artery complex [17].

Similar advantages of the endonasal approach are pointed out by all studies: (1) avoidance of brain retraction, (2) early tumor vascularization, (3) direct tumor access, and (4) avoidance of manipulation of an ischemic, compressed optic apparatus [34]. Additionally, the involved bone and dura are removed as part of the approach (facilitating Simpson grade I resection) [32, 34] and there is no facial skin incision [11].

The major disadvantage of this approach is a high rate of CSF leakage resulting in a higher rate of infections. Gardner reported a risk of CSF leakage of 40% [34], although better methods of reconstruction reduced the overall CSF leak rate to 5.4% [38, 52].

A less discussed but nevertheless important issue is the difficulty or inability to control major bleedings, as reported by Casler et al. This point limits the use of the endoscopic approach for meningiomas with a significant degree of carotid involvement [11].

Supraorbital approach

In the early 1990s, Perneczky and others introduced less invasive techniques where minimal skin incisions provided maximal exposure of the operative field and hence visualization of the in situ pathology and its immediate surrounding [61].

The supraorbital approach, through an eyebrow incision, involves a small craniotomy flap flush to the orbital roof. The skin incision is placed within the hair of the eyebrow a few millimeters above the orbital rim. It begins medially, lateral to the supraorbital notch, and ends laterally before the lateral end of the eyebrow at an imaginary line perpendicular to the lateral end of the superior orbital wall. Thereafter, a 1.5-cm craniotomy is performed. The endoscope is introduced through the keyhole and advanced between the frontal lobe and the floor of the anterior skull base all the way to the meningioma (Fig. 3). To get better basal view, the posterior frontal bone, the sphenoid ridge, or the superior orbital roof could be drilled away. This allows an overview of the ipsilateral and parts of the contralateral anterior fossa [47, 48, 75, 76].

Kabil et al. used this approach for meningiomas of the olfactory groove, suprasellar meningioma, and a sphenoid wing meningioma [47]. With this approach, no unnecessary brain retraction is needed, and the greater part of the brain remains protected with dura and bone. More than 90% of patients could be discharged from hospital within 48 h [47].

Disadvantages of this approach are the risk of scalp anesthesia caused by section or stretch of the supraorbital and supratrochlear nerves and CSF fistulas through an occult frontal sinus opening [47].

Microsurgical approach, endoscopically assisted

Lespinasse and Dandy reported their early experiences utilizing endoscopic methods as a means of diagnosing intracranial pathology [58]. The development of fine endoscopes with different angles and strikingly clear optics is leading to interesting possibilities in their use as adjuncts to procedures utilizing the microscope. Matula et al. showed in their study that structures that are routinely observed, but hardly noticed through the microscopic view, gain new importance endoscopically [58]. For this reason, more and more neurosurgeons use the endoscope intraoperatively as a tool to get additional views in the surrounding of the meningioma. Thus, they combine the advantages of the transcranial approach with the better illumination and field of view of the endoscope [58]. Fatemi et al. described the use of endoscopic assistance in a supraorbital approach as helpful in a better view of the area directly under the ipsilateral optic nerve and carotid artery. Thereby, residual tumor not seen with the microscope can be revealed [31]. Others use the endoscope after transcranial resection of meningiomas involving the anterior skull base to perform an endonasal approach to rule out CSF leakage, and if necessary, repair it [63].

Conclusion

In spite of several technical inventions and progress in neurosurgical techniques, removal of meningiomas of the anterior cranial base still remains a challenge due to complex anatomical relations and important neurovascular structures with their associated risks.

Traditional approaches, which have been modified as well as the implementation of endoscopic tools, have increased the possibilities to access these tumors in a safe manner and to remove them with minimal risk for the patient. Nevertheless, a treatment plan has to include various issues, both patient- and neurosurgeon-based. Thus, the choice of a surgical approach remains an important individual process, guided by the neurosurgeon's experience and ability as well as tumor characteristics.

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