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TOPIC REVIEW

Microsurgical resection of skull base meningioma—expanding the operative corridor

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Abstract A better understanding of surgical anatomy, marked improvement in illumination devices, provision of improved hemostatic agents, greater availability of more precise surgical instruments, and better modalities for skull base reconstruction have led to an inevitable evolution of skull base neurosurgery. For the past few decades, many skull base neurosurgeons have worked relentlessly to improve the surgical approach and trajectory for the expansion of operative corridor. With the advent of newer techniques and their rapid adaptation, it is foundational, especially for young neurosurgeons, to understand the basics and nuances of modifications of traditional neurosurgical approaches. The goal of this topic review is to discuss the evolution of, concepts in, and technical nuances regarding the operative corridor expansion in the field of skull base surgery for intracranial meningioma as they pertain to achieving optimal functional outcome.

Keywords Skull base · Meningioma · Operative corridor · Technical nuances

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Introduction

With the advent of skull base microneurosurgery, it has become apparent that minimal use of brain retraction is optimal for better patient outcome. A key principle of skull base surgery is the removal of bone to reduce the need for brain retraction. Recent studies have provided evidence of the potential advantages of retractor-less surgery using dynamic retraction over static retraction, especially during prolonged skull base surgery, because the risk of retraction-related tissue edema and injury is reduced [1]. A wide and properly selected operative corridor, appropriate use of hand-held suction devices, adequate dissection of arachnoid planes for release of cerebrospinal fluid (CSF), endoscopic visualization in appropriate cases, optimal patient positioning for adequate gravity-assisted retraction, and refinement of microneurosurgical instrumentation all serve to reduce the need for fixed retraction in skull base surgery [1]. This review addresses the evolution of, concepts in, and technical nuances associated with operative corridor expansion in the surgical management of intracranial meningioma. For the purpose of this topic review, we have divided surgical modifications of conventional craniotomy into five broad categories, which are the workhorses for most skull base microneurosurgeons. Elaborating on the same idea, we have provided three operative videos (Videos 1–3) to help understand the concept of operative corridor expansion in skull base neurosurgery.

Approaches

Frontotemporal craniotomy with orbitozygomatic osteotomy

Pterional or frontotemporal craniotomy has long been a mainstay of skull base surgery for meningiomas involving the parasellar region. It had a long evolution [2] but was popularized by Prof. M.G. Yasargil in the 1960s, and was primarily used at that time for parasellar tumors and aneurysms involving the circle of Willis. An augmentative procedure like the cranio-orbitozygomatic approach has further evolved to address the significant limitations of pterional craniotomy in excising some parasellar lesions, especially those with large superior or posterior extensions into third ventricle [3]. This orbitozygomatic technique, which again emphasizes the tenet of bone removal to reduce brain retraction, was popularized by the efforts of Pellerin et al. [4], Hakuba et al. [5], and Zabramski et al. [6]. Further modifications of the two-stage cranio-orbitozygomatic to a single-stage cranio-orbitozygomatic approach have been recently described to allow for better cosmesis [7]. The addition of an orbital (Video 1) or zygomatic osteotomy to the conventional craniotomy augments the surgical corridor for more extensive middle skull base lesions via a flatter, shorter, and more inferior operative trajectory, thereby reducing undue retraction of brain. This technique is often used to resect more extensive meningiomas arising from the cavernous sinus or the spheno-orbital dura mater. Wide opening of the Sylvian fissure, drilling of the clinoid process (either intra- or extradurally), and optic canal de-roofing can assist in achieving a safe and more aggressive tumor resection. However, the cranio-orbitozygomatic approach is often associated with extensive soft tissue dissections and bone work that can culminate in suboptimal cosmetic outcome at times [3]. To circumvent such complications, other modifications of pterional craniotomy-like zygomatic reshaping have been described recently, providing optimal balance of surgical exposure and cosmesis [3].

Bifrontal craniotomy with bilateral orbitotomy (transbasal approach)

Tessier et al. [8] and Derome et al. [9] popularized the transbasal technique for midline anterior and middle skull base lesions, including lesions extending to the orbit, nasal cavity, paranasal sinuses, pterygopalatine fossa, pituitary fossa, and clivus [10]. The optic nerves, intracavernous carotid arteries, and hypoglossal canal usually limit the lateral exposure [10, 11]. Similar to cranio-orbitozygomatic approach, this approach provides a very wide, short, and inferior trajectory to midline skull base lesions, with minimal brain retraction and midline anatomical orientation. Feiz-Erfan et al. [10] proposed classifying transbasal approaches into one of three levels depending on the extent of bony removal and the degree of freedom in horizontal and vertical dimensions. The transbasal approach is currently applied for extensive olfactory groove, planum sphenoidale, clinoidal, suprasellar, and upper clival meningiomas. It may also be used to access tumors with paranasal extension. The accessibility of such tumors may be determined by preoperative coronal computed tomography (CT) or magnetic resonance (MR) imaging as described by Liu and Couldwell [12]. Extradural drilling of the anterior cranial fossa including crista galli and division of the anterior third of the superior sagittal sinus adds to the width of the operative corridor for such lesions; however, this technique is limited by a higher incidence of CSF leakage and associated risk for infection, despite newer skull base reconstructive techniques [11]. Removal of the supraorbital bar enables a more inferior-to-superior trajectory and reduces the need for frontal lobe retraction.

Many of the tumors of the midline anterior skull base traditionally approached by a transbasal approach may be appropriate for transnasal endoscopic removal from below [12, 13].

Temporal craniotomy with anterior petrosectomy (Kawase's approach)

In 1991, Kawase et al. [14] described this approach for petroclival meningiomas extending into the parasellar region. It was initially utilized to approach posterior circulation aneurysms. It augments the subtemporal approach by additional extradural removal of the petrous apex and provides an excellent view from the cavernous sinus to the mid-clivus, without causing undue retraction of the temporal lobe. Supplementation of the zygomatic osteotomy and division of the superior petrosal sinus and tentorial-free margin posterior to the trochlear nerve add to the working corridor in the central skull base region [14]. This technique can also be complemented with posterior petrosectomy in case of more inferior extension of tumor in the posterior fossa, below the internal auditory meatus [15]. The Dolenc–Kawase approach [16] is a recent modification of Kawase's approach that includes additional transcavernous exploration and medial mobilization of the cisternal segment of the trigeminal nerve, thereby providing larger fenestration of the petrous apex and consequent greater surgical freedom at Dorello's canal, the gasserian ganglion, and the prepontine area. These approaches are commonly employed for sphenopetroclival meningioma with posterior cavernous extension (Video 2). Common complications include transient trigeminal nerve and facial nerve paresis attributable to retraction, in addition to the risk for CSF leak, retraction hematoma of the temporal lobe, seizures, or infection [14, 15]. The Kawase approach may be utilized for petroclival meningiomas with extension as far inferior as the internal auditory meatus.

Retrosigmoid suboccipital craniotomy with occipital condyle and posterior C1-arch removal (far-lateral and extreme lateral transcondylar approach)

Heros [17] and Bertalanffy and Seeger [18] initially described the far lateral approach, which was an effort to see lateral and anterior to the brain stem to reach aneurysms and tumors, respectively. Sen et al. [19] and George et al. [20] also pioneered these surgical modifications of the retrosigmoid suboccipital craniotomy to achieve a wider and more anterior trajectory to skull base lesions located at the lower clivus, craniovertebral junction (CVJ), and upper cervical spine to avoid undue retraction on the neuraxis. The approaches include removal of the foramen magnum rim, occipital condyle (<50 % in far lateral and >50 % in extreme lateral transcondylar), and posterior C1 arch and transposition of the vertebral artery to gain access to lesions located anterolateral to the cervicomedullary region [19, 21] (Video 3). Further augmentation of the operative corridor can be gained by drilling the jugular tubercle. The extreme lateral transcondylar approach gives a wider and more anterior exposure than the far lateral approach to access the lesions extending across the midline, though at the cost of destabilizing the CVJ [19, 21]. These approaches are reserved for extensive ventral foramen magnum and lower clival meningiomas. Procedural complications include CSF leakage, pseudomeningocele, meningitis, motor deficits, lower cranial nerve paresis, and vertebral artery injury requiring repair [22]. In addition, radical removal of occipital condyle can render the CVJ unstable, necessitating fixation and fusion procedures.

Extended endonasal skull base surgery

Endonasal skull base surgery owes its origin to the innovative efforts of Schloffer, Hirsch, and Cushing in the early 1900s [23, 24]; however, the transsphenoidal approach was repopularized by Dott, Guiot, and Hardy later [23]. Various modifications of transsphenoidal approaches, including extended and parasellar transsphenoidal approaches, have aimed at achieving additional bone removal. Recent innovations have provided a more versatile and direct operative corridor to complex skull base lesions extending to the anterior skull base, clivus, cavernous sinus, and parasellar regions [25, 26]. Depending on the location and extent of lesion, accessibility through different paranasal sinuses (transethmoidal and transmaxillary) has broadened the scope of endonasal skull base neurosurgery [27–29]. These approaches can be performed either microscopically, endoscopically, or both [30]. The primary advantage of these approaches is to avoid craniotomy and prolonged brain retraction [25]. In addition, because of its minimally invasive nature, endonasal surgery offers the potential advantages of reduced blood loss, lack of visible scar, early devascularization of dural-based lesions, minimal manipulation of neurovascular structures, and shorter hospitalization period [25]. However, use of these operative corridors is beneficial primarily for midline skull base lesions (from the cribriform plate to the craniovertebral junction) with limited lateral extension, although combination with a transmaxillary approach enables additional lateral access to the pterygopalatine fossa and medial aspect of infratemporal fossa [25]. The advent of endoscopic instruments with improved illumination, the availability of better high-speed diamond drills and more effective hemostatic agents, innovation of frameless stereotactic neuronavigation, and standardization of extensive skull base reconstructive techniques have led to the tremendous increase in the use of endonasal skull base surgery [31].

Transposition of the pituitary gland and mobilization of the cavernous internal carotid artery (ICA) provide additional surgical access to complex skull base lesions. Such an approach was initially limited by the large dural defect, difficult reconstruction of skull base, and high incidence of CSF leak and associated complications [32], but these complications have been minimized by the use of the nasoseptal flap for skull base reconstruction rather than free fat reconstruction. This innovation reduced the risk of CSF leak from about 16 to 6 % on average [32, 33]. Other complications of the endonasal approach include nasal stuffiness, nasoseptal crusting, epistaxis from sphenopalatine artery, delayed development of ICA pseudoaneurysm, and potential life-threatening bleeding [32].

Discussion

Principles of skull base microsurgery

Patient positioning that helps gravity-assisted retraction, extensive dissection of arachnoid planes, refinement of microsurgical techniques, appropriate selection of operative corridor, intraoperative neuromonitoring, and use of neuronavigation help to improve patient outcome and decrease procedure-related morbidity for skull base surgery. Early devascularization of the tumor by drilling involved bones and coagulating dural blood supply is a basic principle of skull base meningioma resection. The aggressiveness of resection must be tailored according to realistic goals for each patient, taking into account the tumor biology and aggressiveness and the patient's age, life expectancy, functional status, and functional expectations.

Surgical approach

An appropriate surgical corridor is chosen based on the location of the epicenter of the tumor, its pattern of spread, and surgeon preference. While conceptualizing the appropriate trajectory, it is important to consider the shortest distance to the target, the tumor's relationship to vital neurovascular structures, an estimation of potential intraoperative complications and means to avoid them, alternative preparation for possible cerebral revascularization, and appropriate ways for skull base reconstruction. The decision to operate transcranially rather than endonasally in certain skull base lesions is made because of the size, lateral extent, location, and nature of the lesion; the surgeon's preference and expertise; the relationship of the tumor with vital neurovascular structures; the presence/absence of a protective cortical cuff between tumor and vessels; and the presence/absence of pial invasion [34, 35].

The rationale for choosing an operative corridor expansion in each of these mentioned approaches is essentially individualized based on the patient-specific and tumor-related anatomical considerations, surgeon's preference, and patient's willingness. Adequately explaining the risks and benefits of each available surgical procedure and different surgical corridors available to approach a given tumor is paramount to have an appropriate patient-tailored selection of safe and effective operative strategy.

Expansion of operative corridor

Skull base microneurosurgery owes its origin to the tenacity of neurosurgeons who were devoted to preventing undue retraction of the brain surface. The key goal in skull base neurosurgery is to be maximally aggressive in bone removal to achieve an optimal surgical corridor while being minimally invasive on manipulations of the brain to allow better functional outcome. For the past few decades, most of the innovations in the field of skull base neurosurgery have focused on understanding the surgical anatomy, optimization of surgical trajectory, ease of access, better cosmetic outcome, reduction of surgical morbidity and mortality, use of minimally invasive techniques like endoscopy, and better skull base reconstruction. Rapid adaptation of newer surgical approaches and modifications of existing techniques have led to an inevitable evolution of safe neurosurgical practices in the realm of skull base surgery, with acceptable cosmesis and morbidity profile. It is especially pivotal for young neurosurgeons to understand the concepts and technical nuances of operative corridor expansion in the field of skull base neurosurgery, which hallmarks the optimal patient outcome.

Conclusions

Appropriate knowledge of surgical anatomy, use of appropriate surgical trajectory, wide operative corridor, minimal use of fixed retraction, adequate release of CSF via arachnoid dissection, and use of optimal microsurgical instrumentation are the key concepts in safe skull base practice. Understanding the basics and suitable application in a clinical scenario are essential for optimal patient outcome. Modifications of surgical approaches to expand the operative corridor like orbitozygomatic osteotomy, petrosectomy, transbasal approach, extended endonasal approach, and drilling of the occipital condyle, clinoid process, and jugular tubercle have proved invaluable in evolution of modern skull base neurosurgery.

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Compliance with ethical standards

Conflict of interest The authors report no conflicts of interest.

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