Meningiomas of the anterior cranial fossa represent 12%-20% of all intracranial meningiomas. The large size of these lesions at the time of diagnosis, as well as their close relation with important neurovascular structures (Fig. 1), often makes their resection challenging. This group of tumors represents an exemplar of the evolution of craniotomy for surgical approaches to the skull base. The first surgical procedures to treat these tumors were performed in the late 19th century and were carried out by prominent and pioneering neurosurgeons. Subsequent technical advances have allowed better surgical outcomes, and presently these tumors can be treated safely using a plethora of surgical approaches. Furthermore, adjuvant therapies not available at the outset of surgical treatment of anterior fossa meningiomas, such as stereotactic radiation and intensity modulated radiation therapies, have provided options for treating surgeons. In this review, we trace the evolution of neurosurgery for anterior cranial fossa meningiomas.

Classification

According to the site of attachment, the most common meningiomas of the anterior cranial fossa are classified into olfactory groove, planum sphenoidale, and tuberculum sellae meningiomas. Each of these tumors has a few distinct clinical features. However, in practice, this group of tumors often represents a continuum. Their original site of attachment may differ, but given the high compliance of the brain at this location, they can attain large sizes and at the time of diagnosis the more anterior types (olfactory groove and planum sphenoidale group) occupy a significant portion of the anterior cranial fossa.

Clinical Presentation

At a time when imaging modalities were not widely available, the diagnosis of diseases relied upon accurate observations of clinicians. The identification of intracranial lesions was particularly difficult because the functional division of the brain was not completely understood. Dr. Robert Foster Kennedy made a significant contribution, recognizing a common clinical presentation of space-occupying lesions located in the frontal lobe. These observations, which led him to describe what is now called “Foster Kennedy syndrome,” came from the time he spent at the National Hospital in Queen’s Square in London, working with prominent figures such as Sir William Gowers and Sir Victor Horsley. Foster Kennedy defined the syndrome in 1911 and described it further in later publications.

One syndrome when present is diagnostically decisive: a speedy reduction in ipsilateral acuity of vision due to ipsilateral compression neuritis of the optic nerve lying below the frontal lobe, coincident with papilledema and normal vision of the
opposite eye. From compression of the olfactory tract there is usually under these circumstances anosmia on the same side on which retrobulbar neuritis and the primary optic atrophy have occurred.

He also described some changes in mental function that could be caused by these tumors: "First, is seen a lessening in power of attention; irrelevant replies are made. There develops a trivial and meaningless jocosity. Short periods of excitement occur, with foolish, inept and causeless laughter."

With modern imaging and earlier diagnosis, the Foster Kennedy syndrome is only seen in a minority of patients and in some series it has been found in approximately 5% of cases. A change in mental function (such as loss of inhibition, memory deterioration, and personality changes) is reported as the primary symptom in 20%–70% of patients harboring olfactory groove meningiomas. These symptoms, which are often attributed to aging and depression, are occasionally overlooked by the patients and are mainly noticed by family members.

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Visual impairment is among the primary symptoms of patients with meningiomas of the anterior cranial fossa, especially those located in the tuberculum sellae (Fig. 2). In patients harboring olfactory groove meningiomas, the incidence of preoperative visual deficits ranges between 15% and 60%. Compression of the ipsilateral optic apparatus in a posteroinferior direction results in painless visual blurring and defects in the inferior visual field. When the tumor arises from the tuberculum sellae, bitemporal visual field deficits are common. In 1879, Sir William Macewen evaluated a 14-year-old girl with a swelling at the upper and inner portion of the left orbital cavity; she complained of occasional frontal headache and was found to have a miotic left pupil with no response to light. Macewen suspected an intracranial lesion and admitted her for observation. During this period she developed seizures, initially localized to the right side of her body but later generalized and associated with loss of consciousness. The presence of seizures and their prolonged duration prompted Macewen to proceed with resection. He described the surgical procedure in an article published in 1881.

A trephine having a disc an inch in diameter was chosen and a portion of bone was elevated. The skull was thicker than normal, and attached to the undersurface of the disc was a tumour of a gummatous aspect. A portion of the tumour adhered to the disc which was removed. The remainder was attached to the dura mater and spread over that membrane in a downward direction towards the base of the frontal lobes... The tumor was removed from the dura mater as far down as the orbital portion of the frontal bone.

However, this is not a typical case in presentation and demographics and the exact pathology is not known. More celebrated and definitely typical in presentation is the case described by Francesco Durante in 1887, but operated on in 1884. Durante’s patient on inspection showed no abnormality, except as to her left eye, which appeared somewhat low and drawn outwardly, otherwise the movements as well as the functions of the globe were normal. For a year or more, however, she had entirely lost her sense of smell; her memory had become impaired, particularly as to remembering names... From her husband I learnt that she had
somewhat changed in disposition; that from being generally happy and bright, she had become sad, melancholic, and taciturn, although she did not seem to brood over the state of her health.

Finally he concluded:

The course of the disease, the loss of memory and of the sense of smell, and the objective and subjective state of the patient led me to believe in the presence of a tumour within the cranium, the pressure of which affected the anterior lobes of the brain and paralysed or destroyed the olfactory nerve. Moreover, the displacement of the globe of the left eye led me to believe also that the tumour had penetrated the superior arch of the orbital cavity.

Durante reported that: “Such being my diagnosis, I now proposed to the patient an operation that would remove the offending object, explaining to her the gravity of the operation without reserve. She was brave, and she consented.”

The tumor was approached through a left frontal craniectomy: “It occupied the anterior fossa at the base of the left cranium, extending to the right and upon the cribiform lamina, which it destroyed. Posteriorly it extended to the glenoid tubercles before the sella turcica. The left anterior cerebral lobe was greatly atrophied; the orbital arch was much depressed, but not perforated by the tumor as I had anticipated.”

Chloroform was used for anesthesia and surprisingly, the entire procedure lasted only an hour; the patient was discharged home on the 15th day and Durante concluded, “My diagnosis and the operation, apparently so hazardous at the time, are therefore justified by the result.”

Dr. Durante presented the patient 3 months after the surgery at a local meeting in Perugia, where she narrated her experience. The case was later published in the Lancet and presented in the International Medical Congress held in Washington, D.C., in 1887. The patient is known to have suffered a recurrence and underwent another operation in 1896 with good results; she was last known to be in good condition in 1905, more than 20 years after the first surgery.

Contributions by Harvey Cushing

Although the tumors described by Macewen and Durante were most likely meningiomas, the term “meningioma” to describe this type of neoplasms was later introduced by Harvey Cushing. In 1927, he dedicated the Macewen Memorial Lecture to illustrate two cases of olfactory groove meningiomas. In the lecture, titled “Meningiomas arising from the olfactory groove and their removal by the aid of electro-surgery,” Cushing demonstrated the utility of the recently introduced electrocautery, comparing the treatment of two tumors before and after this tool was available. Cushing stated: “…with Dr. Bovie’s co-operation, during the past few months I have gained sufficient familiarity with the instrument to realize that it holds out untold possibilities for the future of neurosurgery” (Fig. 5).

The first patient was a 62-year-old woman who pre-
sented with impaired vision for 1 year, frontal headaches, loss of sense of smell, and mental deterioration. Skull radiographs revealed an enlarged sella and erosion of the left wing of the sphenoid. A left frontal tumor was diagnosed and she underwent surgical treatment. However, the resection was not simple; in fact, 3 different operations were required to remove the entire tumor due to difficulty achieving hemostasis.4 Cushing described:4

...the intra-capsular method of enucleation, long put in use in the surgical treatment of acoustic tumors, was called upon to get us out of difficulties. Accordingly, with a sharp spoon, cup-shaped fragments were scooped out of the anterior pole of the tumor until a large cavity was produced. This was a tedious procedure since it was necessary, after the removal of each fragment, to delay until bleeding from the raw surface could be checked.

The second case, in contrast, involved a relatively straightforward treatment. A 45-year-old man presenting with progressive loss of vision and altered personality was found to have complete loss of smell and bilateral optic atrophy on examination. Radiographs showed a small area of calcification lying above the left olfactory groove. The tumor was approached by a frontal craniotomy, and in Cushing’s words:4

...to make a long story short, it was finally possible so far to excavate the chief mass of the tumor lying to the left of the falk that the outer border of the growth could be drawn forward and freed from its dense site of attachment along the deepened and widened olfactory groove underlying the ethmoidal plate. Only in this area was any troublesome bleeding encountered, and it was easily controlled by using a desiccating current which charred the dura and, at the same time, it is to be expected, destroyed any remaining nests of tumor cells which remained adherent to it.

Cushing finally concludes: “As can be appreciated, this was not a procedure to be done hurriedly, nor could it possibly have been carried through in a single session by any other method I can conceive of... from the time when the scalp was novocainized to the final closure and dressing, seven hours were consumed.” The postoperative course of this patient was unremarkable and there was immediate improvement in both visual and mental symptoms.3

These cases were later included in his renowned book Meningiomas, Their Classification, Regional Behavior, Life History and Surgical End Results, which was published in 1938 and summarized data on patients with intracranial meningiomas in different locations.5 Among the 313 cases presented in this publication, 28 were suprasellar and 29 olfactory groove meningiomas. Cushing provided details about the clinical history and diagnostic approach as well as the surgical procedures to treat these tumors. In most cases, the tumor was approached via a unilateral frontal craniotomy with resection of part of the frontal lobe (Fig. 6).5 However, he considered some meningiomas to be inoperable due to their size, and in those cases a subtemporal decompression was performed.5 He provided follow-up data of the surviving patients up to 10 years and demonstrated good functional outcomes.

Evolution of Modern Approaches to Anterior Cranial Fossa Meningiomas

Since the initial experience of these pioneering neurosurgeons, multiple advances have taken place allowing a safer and more effective treatment of this group of tumors. The unilateral frontal craniotomy used by Cushing evolved to a bifrontal craniotomy and a transbasal approach described by Dandy, but a continued necessity of frontal lobe resection. Subsequently, Tonnis reported his successful experience with the bifrontal approach preserving the brain tissue, which was followed by multiple surgeons. The introduction of the operating microscope in the 1970s and the refinement of surgical instruments improved the ability of neurosurgeons to carefully dissect these neoplasms.20,26 The unilateral and bifrontal craniotomies have been further modified and currently some craniofacial approaches are used to treat tumors invading the nasal cavity and/or paranasal sinuses. The endoscope, which has been available for a long time for the treatment of other neurosurgical entities, was introduced recently in the treatment of anterior cranial fossa meningiomas and is acquiring more advocates as supporting evidence becomes available.

The ideal surgical approach should provide enough exposure of the tumor and the surrounding structures, including its dural attachment, to interrupt its blood supply early in the procedure. In addition, brain retraction and manipulation of critical neurovascular structures should be minimized as much as possible to avoid procedure-related morbidity. Sufficient access to the skull base is also desirable in cases in which bone resection and subsequent cranial base reconstruction are necessary. The selection of the most appropriate approach depends on multiple factors, including surgeon’s preference and experience, tumor size and location, extent of dural attachment, and relation with the surrounding neurovascular structures.

Subfrontal Approaches

Anterior cranial fossa meningiomas can be approached by a subfrontal route using either bifrontal or...
unilateral craniotomies. Bifrontal craniotomy is frequently used for large tumors and offers advantages such as wide symmetrical exposure that is useful when cranial base reconstruction has to be performed. However, this strategy requires ligation of part of the superior sagittal sinus and exposes both frontal lobes to the risk of postoperative edema from retraction.\textsuperscript{16,21,28} Other disadvantages include the opening of the frontal sinuses and, more importantly, late visualization of important structures such as the optic apparatus, the internal carotid arteries (ICAs), and the anterior cerebral–anterior communicating artery complex.

Compared with the bifrontal approach, a unilateral frontal craniotomy allows sparing of the superior sagittal sinus and minimizes manipulation of the contralateral frontal lobe. The optic chiasm and ipsilateral carotid artery can be identified early during the surgical procedure and the more lateral view of the tumor/optic nerve and tumor/neurovascular complex favors precise microsurgical dissection. However, the view is limited, which can be problematic when treating large tumors and dealing with their superior portion. Nevertheless, high rates of complete resection have been reported even for large tumors (> 6 cm) with minimal morbidity and no mortality.\textsuperscript{23,24} Nakamura et al. directly compared the bifrontal and frontolateral approaches in a series of patients with olfactory groove meningiomas and found comparable rates of complete tumor removal but higher morbidity in the group treated with the bifrontal approach as there was a greater incidence of cerebral edema in this group.\textsuperscript{16}

To provide a wider exposure and to avoid excessive brain retraction, some modifications to these approaches have been proposed.\textsuperscript{2,19} Persing and colleagues described an approach through the frontal sinus that provides adequate exposure of the anterior cranial base and is especially useful to resect tumors with extension to the facial region.\textsuperscript{19} This approach can be extended by using a larger frontal craniotomy or including orbital osteotomies. More recently, Chi et al. reported their successful experience treating midline anterior fossa meningiomas with an extended bifrontal approach that included orbital osteotomies.\textsuperscript{2} Simpson Grade 1 or 2 resection was achieved in 80% of patients, and postoperative cerebral edema was observed in only 7% of patients. Disadvan-

**Fig. 6.** Preferred approach by Cushing for lesions of the anterior cranial fossa. Reproduced from Cushing H: Meningiomas, Their Classification, Regional Behavior, Life History and Surgical End Results, Charles C. Thomas, 1938.
vantages of approaches combining craniotomy with orbital osteotomies include a higher risk of CSF fistula caused by wide opening of the frontal sinus and their complex and time-consuming nature. Furthermore, infection of this large free bone flap is difficult to reconstruct if needed.

The Pterional Approach and its Variations

The use of the pterional approach was popularized by Yasargil and first described specifically for the resection of anterior skull base meningiomas by Hassler and Zentner. This approach constitutes a short route to the parasellar region and allows early visualization of important structures such as the optic apparatus and the ICA and its branches. The patient’s nondominant side is usually approached, unless the tumor extends predominantly to the left side with significant encasement of the left ICA. The basal cisterns are opened early to allow CSF release and brain relaxation and thus an adequate exposure is possible before the tumor is dissected. The main disadvantage of this approach is the difficulty in removing tumor located underneath the ipsilateral optic nerve without considerable manipulation. Tomasello and colleagues described the pterional route to treat giant olfactory groove meningiomas with high rates of complete macroscopic removal, minimal morbidity, and a low recurrence rate at long-term follow-up.

There are multiple variations of the pterional approach; for instance, the frontoorbitozygomatic approach that involves a more extensive craniotomy and includes osteotomies of the roof and lateral wall of the orbit as well as a part of the zygoma and supraorbital rim. This variant combines the advantages of the subfrontal approaches allowing a more basal exposure, and the pterional approach providing early neurovascular control and a better inferior to superior view than other anterolateral approaches.

Supraorbital Approach

Modern neuroimaging techniques allow proper characterization of brain tumors and their relation to surrounding structures. This characterization is helpful in presurgical planning and in the intraoperative setting and makes it possible to approach deep-seated lesions through very small openings. Perneczky and colleagues introduced the concept of a supraorbital “keyhole” craniotomy to approach a variety of skull base lesions, including meningiomas of the anterior cranial fossa. This approach represents the frontobasal portion of the pterional approach with the advantage of greatly reducing the size of the skin incision (made typically within the eyebrow or palpebral fissure) and the craniotomy. With adequate patient positioning and brain relaxation there is minimal need of brain retraction to obtain adequate visualization. In the series of 1125 lesions treated by Reisch and Perneczky during a 10-year period using this approach, 93 represented anterior cranial base meningiomas. The majority of tumors (80.2%) were completely resected in a piecemeal fashion regardless of their size.

Extended Endonasal Transsphenoidal Approach

Most tumors arising in the midline of the anterior cranial base expand, displacing the critical neurovascular structures superiorly and laterally. This anatomical relation makes a ventral approach appropriate for small “midline” tumors without significant lateral extension. In relation to endoscopic approaches, lateral extension is defined as lateral to the supracliodal carotid, or lateral to the midportion of the superior orbit. The transsphenoidal approach, initially used to treat intrasellar lesions, was modified to gain access to lesions located beyond the boundaries of the sella turcica. For instance, this approach may be extended anteriorly to reach tumors of the anterior cranial base by removing the anterior part of the sella turcica, and part of the planum sphenoidale. In circumstances in which olfactory groove meningiomas are approached in this manner, anterior extension to the posterior table of the frontal sinus can be managed with this technique.

Couldwell et al. pioneered the extended endonasal transsphenoidal approach and emphasized its utility to treat lesions such as tuberculum sellae and planum sphenoidale meningiomas. The advantages of this approach include the avoidance of brain exposure and retraction, early devascularization of the tumor at its base, and removal of the tumor beneath the chiasm and optic nerves with minimal manipulation of these delicate structures. Thus, this ventral approach constitutes a valid alternative to transcranial approaches and is particularly useful in elderly patients or properly selected patients.

Endoscopic Approaches

The introduction of the endoscope to the realm of neurosurgery led to successful treatment of deep-seated lesions with minimal brain retraction. To gain access to the anterior skull base, the endoscope can be used mainly through two of the previously described approaches: via a ventral, midline approach through the skull base, such as the extended endonasal approach, or using a small supraorbital craniotomy. The endoscopic endonasal approach for the treatment of anterior cranial fossa meningiomas is relatively new and has been increasingly reported during the last decade, with significant contributions from different study groups.

The advantages of the endoscopic endonasal removal include its minimally invasive nature and the early mediol optic canal decompression, when necessary. However, an important disadvantage of this approach is the high incidence of postoperative CSF leakage, which has been reported in as many as 40% of cases. A recent systematic review compared transcranial approaches with the endonasal endoscopic approach for the treatment of olfactory groove, tuberculum sellae, and planum sphenoidale meningiomas with more favorable results in the transcranial approaches. The endonasal endoscopic approach was found to be associated with a lower percentage of gross-total resection and a higher rate of postoperative CSF leakage. Increased experience, better instrumentation, and the use of multilayer closure and nasoseptal flaps may minimize and reduce the risk of this complication.

Conclusions

Diagnosis and surgical treatment of anterior cranial meningiomas is an evolving field. The use of microsurgical techniques and the introduction of endoscopic endonasal approaches have allowed the safe removal of tumors located in the cranial base, with minimal morbidity and a low recurrence rate. The choice of approach depends on the location and characteristics of the tumor, as well as the experience of the surgeon. Further research is needed to determine the optimal surgical technique for each case, and to compare outcomes across different methods of treatment.
base meningiomas has paralleled the dramatic advances in neurosurgery over the past century. Pioneering neurosurgeons such as Sir William McEwen, Francesco Durante, and Harvey Cushing made significant contributions to this area. Since then, approaches to these tumors have evolved, and the recent explosion of interest for minimally invasive techniques has opened a new chapter in the treatment of these formidable lesions.

Disclosure

Dr. Lanzino serves as a consultant to Covidien/ev3, Edge Therapeutics, and Codman/Johnson and Johnson.

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