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The Role of Surgery in Meningiomas

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Abstract

Purpose of review This review presents the most recent evidences and recommendations in the pre-, intra-, and post-surgical management of patients harboring meningiomas. Due to the increasing relevance of multimodal approaches, in order to preserve patients' neurological function and quality of life (QoL), the role of observation and radiation treatments (as either primary or adjuvant therapy) has also been discussed.
Recent findings Multiple advances in neurosurgery, including the use of the microscope and endoscope, improved preoperative neuroimaging, intraoperative image-guided approaches, and intraoperative neurophysiological monitoring, have extended the neurosurgeon's ability to remove lesions that were previously considered only partially resectable or unresectable, while minimizing morbidity. On the other hand, the preservation of patients' neurological integrity and QoL are increasingly important issues, more than complete tumor resection, for both patients and neurosurgeons. In this setting, stereotactic radiosurgery (SRS) and radiotherapy (RT) may be considered safe and effective alternatives for asymptomatic small- to moderate-sized tumors that demonstrate growth on serial imaging, or in combination with planned subtotal resection (STR) for tumors in critical locations. Data supporting the use of pharmacotherapy in meningiomas are, to date, weak, but the strength of the evidence might improve in the next future with the identification of targetable mutations.
Summary Complete microsurgical resection remains the standard of care if it can be

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achieved with minimal or no morbidity. However, many studies have reported SRS/RT as safe and effective treatments, either as primary approach or as complementary to surgery, especially when dealing with critically located meningiomas (e.g., cranial base) or in patients with comorbidity or wishing to avoid invasive treatments. The management of meningiomas is a field of complementary disciplines: neurosurgeon needs to work closely with radiation oncologists while tailoring the optimal treatment for these patients in order to achieve the best results.

Introduction

Meningiomas account for approximately a third of all primary central nervous system tumors. Although most meningiomas are considered as benign lesions (World Health Organization [WHO] grade I), their location may entail serious morbidity and mortality. Prognosis of benign lesions is mostly favorable with an overall recurrence rate of 20% within 20 years. Anaplastic meningiomas (WHO grade III), however, have a poor prognosis with a median overall survival (OS) of only 1.5 years [1••].

The management of patients with meningioma requires a balance between tumor's definitive treatment and avoidance of treatment-related neurologic morbidity. Patient-specific factors (presence or absence of symptoms, age, comorbidity), tumor location in relation to critical neurovascular structures, and histopathologic characteristics (WHO grade) are all important factors in determining the optimal treatment strategy [1••, 2••].

Management

Small, asymptomatic tumors

Due to advances in neuroimaging and increased frequency of clinical and radiological checkups, detection of incidental, asymptomatic meningioma is increasingly common. Initial treatment options include observation with regular imaging follow-up (FU), surgery, and stereotactic radiosurgery (SRS), considering the situation of each individual patient [3•]. In a 2019 meta-analysis including 2130 patients harboring incidental, asymptomatic meningiomas, management at first presentation was active monitoring, SRS, and surgery in 51%, 22%, and 27% respectively [4•].

A "watchful waiting" approach is particularly suitable for very old patients and those with significant comorbidities or poor performance status. In this case, after an initial observation interval of 6 months with clinical and MRI evaluation, if patients do remain asymptomatic and no evidence of tumor growth is detected, they can be monitored with neuroimaging on an annual basis for 3 to 5 years, then every 2 to 3 years for as long as they remain putative candidates for a treatment. However, if the tumor enlarges significantly or becomes symptomatic during FU, proactive treatment is recommended (*Evidence level III, Recommendation level 2C*) [2••, 4•, 5••].

For relatively healthy younger patients, there is a lower threshold for therapeutic intervention because of the expectation that tumor progression will inevitably require active treatment [2••]. Some authors suggest proactive SRS as a wise treatment option for asymptomatic meningioma when there is no significant comorbidity limiting life expectancy [3•, 6•]. MRI FU throughout a patient's lifetime is essential for an untreated lesion because the tumor behavior cannot be accurately predicted. However, it has to be considered that, in clinical practice, a significant number of patients can show low compliance to checkup schedule and might eventually drop out from their lifelong FU. Another possible issue is represented by the risk of misinterpreting a growing tumor as "stable" when volumetric analysis is not performed and the new MRI scan is constantly compared with the most recent one and not with the one acquired at "time zero," which, conversely, should be always used as a reference. These patients may not receive clinical attention until symptomatic progression to a much larger tumor, when only invasive treatments remain feasible; it should be noted that this can represent a much greater issue in those patients initially managed conservatively due to old age or comorbidities. In contrast, omission of FU MRI scans after SRS has much lower risks, since tumor control is reported 90% at a long-term FU in most SRS series [3•]. Therefore, SRS might offer an advantage in terms of fewer clinic visits and MRI scans over the patient's lifetime. Finally, clinicians and patients may be relieved of a psychological burden after noninvasive treatment, whereas untreated patients may always maintain a fear of tumor growth [3•, 7].

Linear diameter growth was observed in 44% of tumors in one of the largest series investigating natural history of meningiomas at a mean FU of 3.8 years, but the rate of enlargement raised to 74% in the same study when volumetric measurement was assessed [8]. In recent papers, the proportion of patients undergoing intervention after initial conservative treatment was reported 25% and 36% at a mean FU of approximately 4 and 5 years respectively, while symptom development was reported 8–21% [3•, 4•]. Tumor size (≥3cm), presence of peritumoral edema, young age (<60 years old), lack of calcifications, and lesion hyperintensity on T2-weighted MRI were found to be significantly related to the risk of symptomatic progression in different studies [4•, 8, 9, 10•].

Maximal safe resection still represents the first option to be considered for a tumor undergoing symptomatic progression (*Evidence level II, Recommendation level B*) [5••]; however, SRS may again be regarded as a secure and effective alternative for asymptomatic small- to moderate-sized tumors that demonstrate growth on serial imaging, particularly in case critical location, comorbidities, or patients wishing to avoid surgery [5••, 6•, 10•, 11, 12]. Besides the invasiveness and potential risk of serious morbidity, it is important to consider the impact surgery entails on patients' private and working life, both in short term (e.g., hospitalization and time needed to recover) and long term, as pointed out in a recent study reporting a rate of 40% cognitive or emotional problems (e.g., anxiety or depressive symptoms) following resection [13].

Large or symptomatic tumors

Symptomatic meningiomas and asymptomatic tumors that are large, expanding, infiltrating, or associated with surrounding edema should undergo maximal safe resection, if feasible (*Evidence level II, Recommendation level 1B*) [2••, 5••]. Complete tumor resection (with its dural attachment) is advisable when meningiomas are in accessible locations, since it can be curative.

Surgery is often combined with SRS or conventional radiotherapy (RT) in the initial management of atypical and malignant meningiomas (WHO grades II and III) because of the high risk of recurrence even after achieving an apparent Simpson grade I resection.

Management of peritumoral edema largely relies on the use of corticosteroids (mainly dexamethasone), but antiangiogenic therapy (e.g., bevacizumab) can be considered in exceptional cases when (long-term) side effects or insufficient efficacy is being faced [1••].

Extent of resection

Gross total resection (GTR), when feasible, is associated with significantly improved local tumor control and progression-free survival (PFS), compared with partial resection, independently from tumor grade and other prognostic factors [2••, 5••, 14–16]. Complete resection should include removal of the tumor dural attachment and any abnormal bone.

Simpson grading system has been used to describe the extent of removal in convexity meningiomas [17]:

- Grade 1, complete resection, including the dural attachment and any abnormal bone
- Grade 2, complete resection, with coagulation of the dural attachment
- Grade 3, complete resection, without resection or coagulation of the dural attachment
- Grade 4, subtotal resection
- Grade 5, tumor biopsy only

Studies demonstrating an OS and PFS advantage from complete resection of benign meningiomas generally antedate the routine use of postoperative MRI and the adjuvant use of SRS/RT with contemporary conformal techniques for patients with residual disease. The use of modern adjuvant SRS/RT techniques to treat residual disease appears to yield results comparable to more aggressive surgery and can minimize treatment-related neurologic deficits [2••].

Intraoperative assessment of the extent of resection should be confirmed by a postoperative MRI performed within 48 h from surgery, or after 3 months, to avoid surgery-related artifacts [5••].

In contemporary practice, the goal of surgery is to achieve as extensive resection as possible while minimizing neurologic deficits (a.k.a. maximal safe resection). The extent of resection varies depending upon the location of the tumor, whether there is evidence of invasion on imaging, and the preoperative status of the patient (e.g., presence of neurologic deficits, comorbidities) [2••]. Complete resection is usually attempted for tumors of the convexity, olfactory groove, anterior third of the sagittal sinus, and some tentorial and posterior fossa tumors. Partial resection may be more appropriate for less accessible tumors, such as those involving the posterior sagittal sinus region and cranial base. Residual tumor, particularly when dealing with atypical or malignant lesions, can be treated postoperatively with SRS/RT. Biopsy alone or treatment without histopathological diagnosis may be needed for inaccessible tumors such as those involving the cavernous sinus. Definitive SRS/RT is the treatment of choice in these cases [2••].

Preoperative embolization

There are no well-conducted prospective studies supporting the use of preoperative embolization and, therefore, it is generally not recommended; however, it can facilitate surgery in selected cases such as giant convexity meningiomas or petroclival meningiomas, in which the presumed feeding arteries are not readily accessible to the surgeon (*Evidence level IV, Recommendation level C*) [2••, 5••]. When indicated, this procedure can be performed the day prior to surgery. In a retrospective series of up to 200 patients, the reported complication rate of preoperative embolization ranged from 3 to 13%, with most complications being minor and transient [18]. Rare major or long-term complications include intratumoral hemorrhage, stroke, and cranial neuropathies.

Surgical morbidity

The reported incidence of postoperative neurologic deficits directly related to surgery ranges from 2 to 30% depending upon tumor location and extent of the resection. Cortical brain injury may occur if arachnoid and pia do tightly adhere to tumor capsule and if disruption of pial vasculature with subsequent cortical microinfarction occurs. Skull base surgery harbors a significant risk of cranial nerve deficits, and intraoperative cranial nerve monitoring should be used for tumors located close to cranial nerves [2••].

The reported overall surgical mortality varies widely, reflecting differences in patient selection criteria as well as changes in surgical care. Factors associated with increased mortality included poor preoperative clinical condition, tumor-related brain compression, advanced age, incomplete tumor removal, and intracranial hematoma requiring evacuation [2••]. Older series indicated that the mortality was higher in older adults. More recent series, using contemporary neurosurgical techniques, have shown that surgery is feasible in carefully selected older adults [2••, 19].

Perioperative medical management

In addition to neurologic deficits that are a direct consequence of surgery, common medical complications include seizures, deep venous thrombosis (DVT) and pulmonary embolism, pneumonia, myocardial infarction, and arrhythmias [2••].

Seizures

Seizures are a frequent presenting symptom of meningiomas, but can also occur in the postoperative period. Prophylactic anticonvulsants are generally not indicated prior to treatment in patients without a history of seizures (*Recommendation grade 1B*). In patients undergoing resection, prophylactic anticonvulsant drugs might be given perioperatively (*Recommendation grade 2C*); they can be gradually tapered postoperatively if patients remain seizure-free. To avoid clinically significant drug-to-drug interactions, the use of non-enzyme-inducing antiseizure drugs, such as levetiracetam, is suggested (*Recommendation grade 2B*). Long-term seizure prophylaxis is not required [2••, 20].

For patients who have experienced one or more meningioma-related seizures, initial treatment with a single-agent antiseizure drug is recommended (*Recommendation grade 1A*). Again, monotherapy with a non-enzyme-inducing antiseizure drug, such as levetiracetam, is suggested (*Recommendation grade 2C*). However, when drug interactions are not a concern, other anticonvulsant drugs, that can be quickly titrated, can also be considered. If patients have incomplete seizure control while on therapy, adequate serum drug levels should be verified before switching drugs or adding a second agent [2••, 20].

Cerebral edema

Glucocorticoids are used preoperatively to reduce brain edema in symptomatic patients. During surgical procedure, options to reduce intracranial pressure, if the tumor is large or if significant brain retraction is expected to be needed, include furosemide, dexamethasone, osmotherapy (e.g., mannitol), and temporary hyperventilation, aiming for arterial pCO_2 of 30 to 35 mmHg. Glucocorticoids should be tapered postoperatively. Taper increments and duration should be individualized according to the extent of edema, the completeness of resection, and preoperative glucocorticoids dose and duration [2••]. Antiangiogenic therapy (e.g., bevacizumab) can be considered in exceptional cases when (long-term) side effects or insufficient efficacy is being faced [1••].

Deep venous thrombosis

DVT is especially problematic because in addition to the increased thromboembolic risk in patients undergoing brain surgery, meningiomas can produce a hypercoagulable state [2••]. The rates of symptomatic and asymptomatic postoperative venous thromboembolism have been reported as 4% and 26%, respectively. On a multivariate analysis, predictors of increased risk included older age (≥65 years) and low postoperative performance status [21].

In patients undergoing surgery for meningioma, it is suggested the use of pneumatic compression stockings combined with postoperative low molecular weight (LMW) heparin or unfractionated heparin beginning 12 to 24 h after surgery and continuing until ambulation is resumed (*Recommendation grade 2B*) [2••].

SRS/RT after partial resection

The use of planned combination therapies consisting of subtotal or partial resection followed by SRS or RT allows complete tumor treatment, while reducing surgery-related risks, especially in cases of tumors located in critical areas such as the cavernous sinus (*Evidence level IV*, *Recommendation level C*) [5••].

When GTR cannot be achieved in WHO grade I meningiomas, SRS is the adjuvant treatment of choice (*Recommendation level C*) [1••]. The dose can be delivered in a single session (typical prescription doses range from 12 to 16 Gy) or through hypofractionated (2–5 sessions) regimens [22, 6•] according to the applied technique, tumor size, and proximity to organ at risks (e.g., optic pathways or brainstem).

When RT is used postoperatively (e.g., large residual tumor, proximity to organ at risks, irregular margins, difficult target definition) to treat residual disease, a dose of 50 to 54 Gy in daily fractions of 1.8 to 2 Gy is generally recommended [12]. In WHO grade II (*Recommendation level C*) and III (*Recommendation level B*) tumors, RT with higher doses (≥54 Gy in 1.8 to 2.0 Gy fractions) is the adjuvant therapy of choice [1••]. Observational studies indicate that RT administered shortly after partial resection of atypical or malignant meningiomas substantially improves PFS, compared with partial resection alone [1••].

Anaplastic meningioma (WHO III)

Adjuvant RT is recommended, regardless of the extent of surgery (*Evidence level III, Recommendation level 1B*) [5••]. FU should be done 3 months after initial therapy, then every 3 or 6 months depending on initial growth kinetics. Pharmacotherapy options remain experimental (*Evidence level IV, Recommendation level C*) and data on efficacy of antineoplastic drugs in WHO grade III meningiomas are, to date, scarce [5••].

Atypical meningioma (WHO II)

For patients who have undergone incomplete resection or biopsy, adjuvant RT rather than observation after surgery is recommended (*Evidence level III, Recommendation level C*) [5••]. In cases of progression, RT should be given, if not already done, following initial surgery, with or without second surgery (*Evidence level III, Recommendation level C*) [5••].

For patients, who have undergone GTR, the potential benefits of RT are more closely balanced with the risks of side effects and delayed toxicity [5••, 23]. For patients who are at low risk for radiation-induced complications, adjuvant RT is suggested rather than observation after surgery (*Grade 2C*). Patients who are particularly concerned about radiation toxicity could reasonably choose not to undergo adjuvant radiation, in favor of surveillance by imaging [24•]. For patients who are at increased risk for complications of radiation (e.g., advanced age, low functional status, large radiation field, and proximity of critical structures), observation is suggested rather than adjuvant RT (*Grade 2C*) [24•]. Patients, who want to maximize the chance of avoiding a recurrence and are willing to accept the risk of treatment-related toxicity, could reasonably choose adjuvant radiation [24•].

Overall, pharmacotherapy should be considered after further progression of WHO grade II meningiomas (*Evidence level IV, Recommendation level C*) [5••].

Benign meningioma (WHO I)

In most single-center observational studies with prolonged FU, the local progression rate after STR was approximately 40–50% at 5 years and approximately 60% at 10 years [12]. Adjuvant SRS/RT for incompletely resected WHO grade I meningiomas has been shown to improve local control, but the correct timing and indication for adjuvant SRS/RT is still controversial. Some authors prefer to avoid the potential, although low, morbidity of immediate SRS/RT since a significant number of patients will not recur or will progress slowly after surgery [2••]. Other authors advocate early adjuvant treatment, addressing the same considerations already cited when discussing proactive treatment for asymptomatic/small meningiomas, in addition to the fact that they are dealing with a tumor that already showed a growth tendency.

Adjuvant SRS/RT is therefore more selectively used after partial resection of WHO grade I meningiomas as compared to higher-grade tumors. Retrospective data do support the role of SRS/RT in patients, who have undergone subtotal resection (STR) for meningiomas in poorly accessible areas such as the skull base or posterior sagittal sinus [2••]. Accurate delineation of residual or recurrent tumor following surgery using contemporary imaging studies is critical for the achievement of optimal results with postoperative SRS/RT.

Nonresectable tumors or older patients

SRS/RT alone can be effective in treating meningiomas that are not amenable to even a STR because of their proximity to critical neurologic structures, providing excellent tumor control and avoiding the risks of surgery [25]. The approach is most commonly used for skull base meningiomas and optic nerve sheath meningiomas. Tumor size is an important factor that cannot be underestimated, when considering SRS/RT alone. Larger tumors with significant mass effect are associated with an increased risk of reactive edema following SRS/RT, which can cause seizures and neurologic deficits, that vary based upon tumor location. STR in advance of SRS/RT is often considered to attempt decreasing the risk for radiation-related complications [2••]. Irradiation of medically nonsurgical patients with large tumors at risk for herniation should be evaluated carefully; symptomatic glucocorticoids and investigational medical therapies may be considered in such cases. Data supporting the use of pharmacotherapy in meningiomas of WHO grade I are weak, but the strength of the evidence might soon improve with the identification of targetable mutations [5••]. A detailed review of advancements in pharmacotherapy is beyond the scope of the present paper.

SRS, particularly when performed with Gamma Knife, has a very low risk of secondary brain radio-induced tumors and long-term cognitive deterioration, especially when compared to conventional RT. [5••, 26, 27] Moreover, SRS is believed to offer some advantages, as an enhanced dose-response, particularly when dealing with late responding tissues (α/β ratio close to normal brain tissue) as meningiomas. Indeed, new radiobiologic mechanisms, such as profound vascular damage, antigen expression, and enhanced immune response, that come in addition to the classic DNA damage, are involved in SRS dose delivery regimens [28–34]. A series of 35 retrospective studies showed a 5-year PFS of 86–100% after primary SRS [12]. SRS appears to be a safe and effective alternative to surgery also in older adults or patients that wish to avoid surgery, particularly for small-/middle-sized tumors in deep or functionally high-risk locations.

If the tumor volume cannot be treated with a single or hypofractionated SRS regimen, RT of 50–54 Gy administered in doses of 1.8–2.0 Gy per fraction can be undertaken (*Evidence level III*, *Recommendation level B*). After RT, control rates of 75–92% are described in various series. The combination of STR with RT is associated with PFS and survival rates similar to those reported for GTR [5••].

Surgical approaches and outcome by tumor location

The results of treatment vary depending upon the location of the meningioma as well as the therapeutic approach. There are no randomized trials comparing different approaches. Optimal therapy needs to be individualized, based upon the anatomic location of the tumor and patient-specific considerations. Evolving research also indicates that the genetic profile of meningiomas varies by tumor location and may also impact prognosis [2••].

Convexity meningiomas

Because of their superficial location and easier control of the feeding arteries, the large majority of WHO grade I convexity meningiomas can be completely resected with an excellent prognosis after surgical resection alone [2••]. Rates of recurrence after Simpson grade I or II resection range from 3 to 10% [2••, 35–38]. Simpson grade III and IV resections are associated with significantly higher recurrence rates (10–25% and 33–50%, respectively) [2••, 35–38]. Elevated MIB-1 index (≥3%) and atypical histologic features are also associated with increased risk of recurrence [2••, 15, 36, 39].

The surgical complication rate is approximately 8–10% [2••]. In a single-center series of 163 patients, new neurologic deficits occurred in 2% of patients postoperatively, all of which represented worsening of motor weakness that was present preoperatively in patients with large (>4 cm) tumors [39].

Skull base meningiomas

Skull base meningiomas represent some of the most challenging lesions encountered by neurosurgeons, on account of their depth, invasion, vascularity, texture/consistency, and their relationship to bony anatomy, cranial nerves, and blood vessels. These tumors generally have an indolent history with only mild symptoms [2••, 40]. At the same time, radical surgery (with removal of the involved dura and hyperostotic bone) is associated with substantial morbidity. Due to these technical issues, there is a higher frequency of local recurrence [2••].

A variety of traditional skull base approaches have evolved. Resection of complex skull base meningiomas often mandates adequate bony removal to achieve sufficient exposure of the tumor and the surrounding region, in order to minimize brain retraction and optimally identify, protect, control, and manipulate sensitive neurovascular structures.

In cases of anterior and middle fossa meningiomas, surgical resectability has reached a sufficient level to maximize functional preservation. In cases of many posterior fossa meningioma, however, surgical resectability remains insufficient even with full use of recent surgical modalities [41].

Meningiomas originating from the posterior surface of the *petrous bone*, especially when behind the internal acoustic meatus, can be sufficiently resected (GTR 78–100%). The reported average rate of facial function and serviceable hearing preservation is 94% and 85%, respectively [41].

Petroclival meningioma remains one of the most challenging tumors. After pioneering efforts in the skull base field, surgical resectability of these lesions started to increase in the 1990s, but the price to pay in morbidity was high at that time (more than 50% of patients in most clinical articles). Among surgical series published in the last two decades, GTR ranged from 20 to 94% (mean 53%), mortality 0–13% (mean 2%), major morbidity 7–66% (mean 30%), and new cranial nerve deficit 8–67% (mean 32%) [42]. STR followed by SRS/RT is preferable to minimize complications [43]. Tumor control has been reported 86–100% in SRS series, with 1–9% major morbidity and 0–8% new cranial nerve deficit rates [44].

In the 1990s, when skull base approaches flourished, many experts tried total resection of *cavernous sinus meningioma*. Surgical outcomes were not satisfactory for functional preservation of cranial nerves passing through the cavernous sinus. STR with stereotactic SRS/RT has since been regarded as an acceptable treatment to preserve cranial nerve functions [41].

Cranio-cervical junction meningiomas, although in a critical location, have been successfully resected in most recent clinical papers. Precise radiological evaluation is recommended to estimate surgical resectability [41].

Clinoid and sphenoidal wing meningiomas were regarded as challenging tumors at the beginning of microsurgery, due to the anatomical proximity to the optic nerve and involvement of the internal carotid artery and its perforating arteries [41]. With advances in skull base techniques, such as clinoidectomy and optic canal unroofing, this type of tumor can be safely and radically resected (GTR reported ranging 59–92.3%; visual deterioration 0–14%) [41]. Most recent clinical articles have emphasized the importance of early optic canal unroofing to obtain preservation of optic function [41].

En plaque meningiomas are characterized by a sheet-like growth pattern along the dura and a pronounced hyperostosis [1••]. They predominantly occur at the sphenoid wing with frequent involvement of the orbit. Their surgical removal is challenging with GTR in 56–83% of cases. As such, aggressive resection might not be advisable and a combined primary approach with adjuvant SRS/RT might be preferred [1••, 45].

In the last decade, *tuberculum sellae meningiomas* (TSMs) and *olfactory groove meningiomas* (OGMs) have been increasingly resected using an endonasal endoscopic transsphenoidal approach (EEA). The EEA uses a natural anatomic corridor, such as the nasal cavity, that allows an early devascularization and debulking of the lesion; it also allows maneuvers of extracapsular dissection without brain retraction, even if it does require proper reconstruction of the osteodural defect to avoid the risk of CSF fistula [46]. Prospective studies directly comparing the efficacy and adverse effect profile of the transcranial approaches (TCA) vs EEA for both tuberculum sellae and planum meningiomas are currently lacking in the literature [47]. Although EEA is generally viewed as less invasive, with some studies suggesting its association with fewer postoperative changes on MRI compared to the TCA, possibly indicating less manipulation, a recent meta-analysis of 64 case series [48•] found that the GTR rate was significantly higher among TCA patients for OGM (88.5% vs. 70.9%), but not significantly higher for TSM (85.8% vs. 83.0%). Despite considerable heterogeneity, visual improvement was higher with EEA than TCA for TSM, but not for OGM. CSF leak was significantly higher among EEA patients for both OGM (25.1% vs. 10.5%) and TSM (19.3% vs. 5.81%). Intraoperative arterial injury was higher among EEA patients (4.89% vs. 1.86%) for TSM, but not for OGM resection. There was no difference in mortality.

The main advantages of the TCA over endoscopy are the possibility of using different surgical corridors. Furthermore, modern anesthetic and microsurgical techniques, thanks to the maneuvers of cistern openings, make it possible to obtain sufficient operating space and to allow the removal of lesions of any size. The TCA also enables early identification of vessels of the anterior circulation and the optic nerves to obtain a good decompression. Finally, TCA has a low risk of CSF fistula [46].

At present, microsurgery is still the gold standard for the removal of the anterior cranial fossa meningiomas of all sizes, while the endoscopic technique remains a feasible option in selected cases with predominantly midline extension, where the need for brain retraction can be avoided [46, 47]. Combined microscopic and endoscopic approaches are increasingly used due to the periscopic visualization of the endoscope to investigate corners of a surgical field difficult to view with conventional microscopy [49].

Most studies suggest that surgery and SRS/RT have complementary roles in the management of cranial base meningiomas: patients do best if all modalities are afforded to them [34]. The results of a combined-modality approach are illustrated by a single surgeon's series of 100 consecutive patients [40]. At a median FU of 5 years, only 1% had evidence of tumor progression using this treatment paradigm. There were no treatment-related deaths, and serious complications from surgery were limited to hemiparesis, new cranial nerve palsy, and osteomyelitis (2.8, 2.8, and 1.4% of surgical cases, respectively). In another series of 101 patients with presumed benign skull base meningiomas that were treated with RT alone (66 cases) or after STR (35 patients) [50], overall local control rates were 92% at both 10 and 15 years.

Optic nerve sheath meningiomas

Biopsy is generally not recommended. When MRI findings are inconclusive, molecular imaging using ^{68}Ga-DOTATATE PET should be considered to rule out differential diagnosis [1••]. Surgery is not an option in most cases, especially since tumor and optic nerve share the same blood supply. RT and fractionated SRS are the recommended treatment of choice. Initial observation may be warranted in pediatric cases where vision is not compromised due to a possibly favorable clinical course [1••].

Spinal meningiomas

Surgical resection to remove the tumor and decompress the spinal cord is the therapy of choice [1••, 5••]. The extent of resection should be adapted to the location of the tumor: for easily accessible, laterally or dorsally located meningiomas where dural repair is possible, Simpson grade I resection should be aimed for, but only if it can be achieved without compromising neurological function and if a safe and uncomplicated dural repair is feasible (*Recommendation level: good practice point*) [5••]. In ventrally located tumors, when neurological function is at risk or in case of calcified dural attachment, no resection but rather coagulation of the involved dura should be performed due to an increased risk of complications [1••, 51]. Adjuvant treatment should be in analogy to cranial meningiomas [1••].

The proportion of spinal meningiomas that recur after surgical resection has been reported to be 1.3–14.7% [5••, 51]. Incomplete resection is generally agreed to be a risk factor for recurrence, but whether Simpson grade I resection achieves better long-term outcomes than Simpson grade II resection is unclear [5••, 51]. For rare cases in which surgical resections cannot be performed for any reason, or decompression of the spinal cord does not seem necessary, hypofractionated SRS or RT is an alternative to resection (*Recommendation level: good practice point*) [5••]. Adjuvant therapy is done according to WHO grade and resection status as stated above for cranial meningiomas.

Multiple meningiomas

Multiple meningiomas occur mostly in the context of neurofibromatosis type 2 (NF2) or as radiation-induced lesions [52]. Meningiomas in NF2 are more likely to be higher in grade than sporadic cases [1••]. Multiple meningiomas are often asymptomatic. In a recent series of 133 patients harboring 395 synchronous and 53 metachronous meningiomas, approximately 2/3 of patients required therapy, but only 1/3 of all meningiomas needed active treatment [52]. Surveillance for stable and asymptomatic meningiomas and therapy for those that are symptomatic or growing is recommended for multiple meningiomas ≤3 cm in diameter, but more research is needed to establish its effectiveness and safety for this disease [52]. Each treatment decision in NF2 disease requires a complete evaluation of all cranial and spinal locations of the disease in order to establish surgical priorities and strategies [53].

Radiation-induced meningiomas

There are only limited data available for the treatment of radiation-induced meningiomas. The available evidence suggests that these should be managed in the same fashion as other meningiomas. Although surgery is the preferred modality, SRS/RT may be an option for patients whose tumors arise in critical locations or who are poor candidates for surgery. Because radiation-induced meningiomas are more commonly atypical and highly proliferative, higher doses in tumors without pathologic confirmation are advisable, but the prior radiation dose to the brain must be considered too when planning the treatment [2••, 5••].

Recurrent meningiomas after previous surgery

Adjuvant SRS/RT is suggested as the first option for appropriately sized recurrent meningiomas [54•, 55•]. Surgery should be considered when patients are symptomatic, although adequate counseling on the high risk of complication is essential.

In a recent series, Magill et al. analyzed results of a series convexity meningiomas undergoing second surgery: complications occurred in 33% and GTR was achieved in only 32.8%. The 2-, 5-, and 10-year survival rates were 91.0%, 68.8%, and 50.0%, respectively. Another operation was required in 40% of the cases [54•].

Redo surgery for tumors along the skull base is even more challenging and, especially when located in the posterior fossa, is associated with a high complication rate: 32% of cases in another series from the same group. Two-, 5-, and

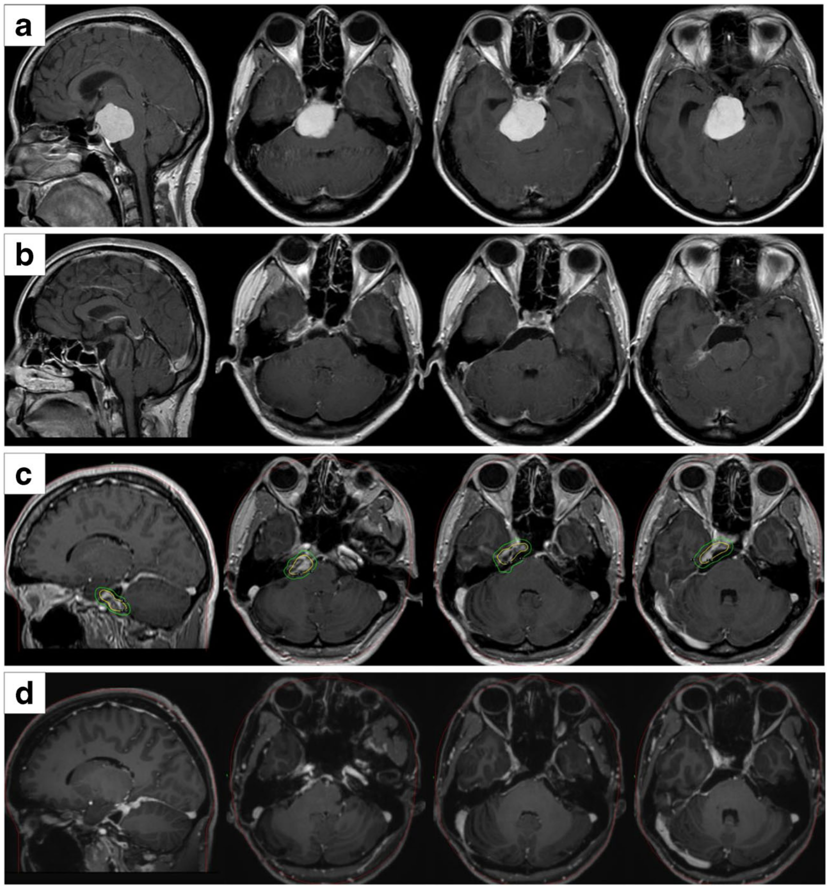

Fig. 1. An example of complementary treatment is provided. **a** Sagittal and axial contrast-enhanced (CE) magnetic resonance images (MRI) showing a large petroclival meningioma before surgical resection. **b** Sagittal and axial CE early postoperative MRI, no significant/definite residual tumor was identifiable; good facial nerve function (House-Brackman grade II) and motility of all ocular movements was preserved; functional hearing was already lost at the time of presentation. **c** At subsequent FU, a progressive thickening of the dural attachment was observed; Gamma Knife radiosurgery (GKRS) treatment was performed 5 years after surgery on the enlarging residual remnants of the tumor. **d** Sagittal and axial CE MRI FU acquired 3 years after GKRS treatment showing regression of the treated lesion without any additional morbidity.

10-year survival rates were 92%, 88%, and 76%, respectively, after the first reoperation [55•].

Scar from prior surgery (more than from prior SRS/RT) can create significant arachnoiditis. It is usually the location of the tumor and the repeated approach, more than the actual size, that drives the complications.

A clinical case of complementary treatment for petroclival meningioma is depicted in Fig. 1.

Advancement

Multiple advances in neurosurgery, including the use of the microscope and endoscope, improved preoperative neuroimaging, intraoperative neuronavigation, and intraoperative neurophysiological monitoring, have extended the neurosurgeon's ability to remove lesions that were previously considered only partially resectable or unresectable, while minimizing damage to the nervous structures [2••, 56•]. Minimally invasive keyhole approaches, which create a smaller craniotomy than traditional TCA, are also increasingly described, but with any of these evolving techniques, a goal for maximal safe resection should be maintained, especially when dealing with higher-grade tumors [49].

Advanced preoperative and postoperative imaging techniques are increasingly used for tumor delineation, determination of residual tumor mass, and identification of bone or brain invasion, and their use is encouraged (*RANO evidence level 2*) [1••, 57]. For example, ^{68}Ga-DOTATATE showed superior signal to background ratio for delineation of meningiomas in regions with low MRI contrast (skull base, orbital, sinus, or parafalcine region) or to detect bone infiltration [1••, 58]. Adjuncts such as 5-aminolevulinic acid fluorescence have been investigated for their role in improving detection of tumor satellite cells in adjacent brain, dura, and bone for invasive meningiomas, with initial promise [49].

It is inevitable that biology and surgery will become further intertwined. A particularly attractive prospect is the pre-surgical identification of targetable mutations with neoadjuvant drug therapy to reduce tumor size, rendering subsequent surgery safer [49].

Two, recently published, large longitudinal observational study compared 1469 and 817 patients, respectively, operated on for intracranial meningioma during the last three decades [56•, 59•]. The series from Meling et al. reported a significant reduction of patients presenting at surgery with a poor performance status, increased intracranial pressure, and/or neurologic deficits in the last analyzed decade [59•]. An increased availability of preoperative MRI and a decreased rate of angiography and tumor embolization were registered by Sicking et al. [56•] A trend toward operating on more elderly patients was noted by both series [56•, 59•]; this is probably the result of the combined effect of several factors including the increased life expectancy, the increased use of imaging in the later decades, and the fact that older patients are nowadays considered eligible for surgery. The proportion of higher-grade meningiomas over the years had conflicting results in the two series [59•]. The use of intraoperative neuronavigation and neuromonitoring was noted to increase [56].

Interestingly, the rate of Simpson grade I achievement increased from 33 to 46% after the year 2000 [59•] in one series, while it dropped from 42 to 24% in the other series [56•]. Different factors might come into play: on one hand, we have the earlier diagnosis that lead to smaller tumor size, together with the advancement of neuroimaging and intraoperative techniques (the use of neuronavigation has been reported to increase the frequency of Simpson grade I achievement over two times [60]), on the other hand, we are witnessing a growing attention toward the preservation of the quality of life, that has generated a trend toward combined approaches (e.g., STR followed by adjuvant SRS/RT on the residual tumor). Retreatment-free survival increased over time only in the series by Meling et al. [59•].

Despite the rising age, perioperative mortality and worsened neurologic outcome rate were significantly lower in the later decades [56•, 59•]. Conversely, no significant differences were found regarding postoperative infections and hematoma [56•, 59•]. Median duration of hospitalization decreased progressively [56•]: this can be partly explained by less emergency type and more planned admissions with organization of preoperative diagnostics, improved medical treatment, and, not be overlooked, financial pressure on neurosurgical departments.

Conclusion

The choice of a surgical strategy should be tailored based on the patient's existing condition; the location, origin, and extension of the meningioma; its suspected grade and consistency; the neurological symptoms inflicted; previous treatment history; a desire for disease control or palliation; a wish to avoid invasive treatments; and the surgeon's experience and repertoire. All things considered, complete tumor resection (with the involved dura and bone) remains the standard of care, if it can be performed with minimal or no morbidity, regardless of the size of the incision or specific approach employed [49]. That can be the case with convexity meningiomas. Most studies, however, suggest that surgery and SRS/RT have complementary roles in the management of critically located meningiomas: patients do best if all modalities are afforded to them [34]. Due to this reason, this is a field of complementary disciplines, and neurosurgeon need to work closely with radiation oncologists to pursue the best interest of these patients.

Compliance with Ethical Standards

Conflict of Interest
The authors declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent
This article does not contain any studies with human or animal subjects performed by any of the authors.

References and Recommended Reading

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1.•• Euskirchen P, Peyre M. Management of meningioma. Presse Med. 2018;47(11–12 Pt 2):e245–e52. https://doi.org/10.1016/j.lpm.2018.05.016
A recent review of current concepts of diagnosis, treatment, and follow-up with clinical decision-making informed by multimodal imaging, histology, and molecular biology.
2.•• Park JK, Shih HA. Management of known or presumed benign (WHO grade I) meningioma. UpToDate Inc., Waltham, MA. 2019 (Last Update May 08, 2019). https://www.uptodate.com/. Accessed May 23, 2019.
An updated, detailed, review of the literature on the management of WHO grade I meiningiomas.
3.• Kim KH, Kang SJ, Choi JW, Kong DS, Seol HJ, Nam DH et al. Clinical and radiological outcomes of proactive Gamma Knife surgery for asymptomatic meningiomas compared with the natural course without intervention. J Neurosurg. 2018:1–10. https://doi.org/10.3171/2017.12.JNS171943.
An interestng study analyzing the effect of proactive Gamma Knife radiosurgery in the treatment of asymptomatic

meningioma compared with the natural course among a cohort of 354 patients. The study concludes that GKRS is a reasonable treatment option when there are no comorbidities limiting life expectancy.

4.• Islim AI, Mohan M, Moon RDC, Srikandarajah N, Mills SJ, Brodbelt AR, et al. Incidental intracranial meningiomas: a systematic review and meta-analysis of prognostic factors and outcomes. J Neurooncol. 2019;142(2):211–21. https://doi.org/10.1007/s11060-019-03104-3

A review aiming to evaluate the outcomes of different management strategies for incidental intracranial meningiomas, with particular emphasis on active monitoring and the timing of meningioma progression during follow-up.

5.•• Goldbrunner R, Minniti G, Preusser M, Jenkinson MD, Sallabanda K, Houdart E, et al. EANO guidelines for the diagnosis and treatment of meningiomas. Lancet Oncol. 2016;17(9):e383–91. https://doi.org/10.1016/S1470-2045(16)30321-7

A framework of the best possible evidence-based recommendations for health professionals on the management of meningiomas, elaborated by a task force of the European Association of Neuro-Oncology (EANO).

6.• Flannery T, Poots J. Gamma Knife radiosurgery for meningiomaProg Neurol Surg. 2019;34:91–9. https://doi.org/10.1159/000493054

A review of the current indications, radiobiology, and patient outcomes following Gamma Knife radiosurgery for intracranial meningioma 50 years on from its inception.

7. de Boer AW, Drewes YM, de Mutsert R, Numans ME, den Heijer M, Dekkers OM, et al. Incidental findings in research: a focus group study about the perspective of the research participant. J Magn Reson Imaging. 2018;47(1):230–7. https://doi.org/10.1002/jmri.25739.

8. Oya S, Kim SH, Sade B, Lee JH. The natural history of intracranial meningiomas. J Neurosurg. 2011;114(5):1250–6. https://doi.org/10.3171/2010.12.JNS101623.

9. Lee EJ, Park JH, Park ES, Kim JH. "Wait-and-see" strategies for newly diagnosed intracranial meningiomas based on the risk of future observation failure. World Neurosurg. 2017;107:604–11. https://doi.org/10.1016/j.wneu.2017.08.060.

10.• Apra C, Peyre M, Kalamarides M. Current treatment options for meningioma. Expert Rev Neurother. 2018;18(3):241–9. https://doi.org/10.1080/14737175.2018.1429920

A detailed review of the current standard therapy for meningiomas, based on international guidelines and recent literature, also describing new approaches developed to treat refractory cases.

11. Shaikh N, Dixit K, Raizer J. Recent advances in managing/understanding meningioma. F1000Res. 2018;7. https://doi.org/10.12688/f1000research.13674.1.

12. Rogers L, Barani I, Chamberlain M, Kaley TJ, McDermott M, Raizer J, et al. Meningiomas: knowledge base, treatment outcomes, and uncertainties. A RANO review. J Neurosurg. 2015;122(1):4–23. https://doi.org/10.3171/2014.7.JNS131644.

13. van der Vossen S, Schepers VP, Berkelbach van der Sprenkel JW, Visser-Meily JM, Post MW. Cognitive and emotional problems in patients after cerebral meningioma surgery. J Rehabil Med. 2014;46(5):430–7. https://doi.org/10.2340/16501977-1795.

14. Nanda A, Bir SC, Maiti TK, Konar SK, Missios S, Guthikonda B. Relevance of Simpson grading system and recurrence-free survival after surgery for World Health Organization Grade I meningioma. J Neurosurg. 2017;126(1):201–11. https://doi.org/10.3171/2016.1.JNS151842.

15. Marciscano AE, Stemmer-Rachamimov AO, Niemierko A, Larvie M, Curry WT, Barker FG 2nd, et al. Benign meningiomas (WHO Grade I) with atypical histological features: correlation of histopathological features with clinical outcomes. J Neurosurg. 2016;124(1):106–14. https://doi.org/10.3171/2015.1.JNS142228.

16. Kotecha RS, Pascoe EM, Rushing EJ, Rorke-Adams LB, Zwerdling T, Gao X, et al. Meningiomas in children and adolescents: a meta-analysis of individual patient data. Lancet Oncol. 2011;12(13):1229–39. https://doi.org/10.1016/S1470-2045(11)70275-3.

17. Simpson D. The recurrence of intracranial meningiomas after surgical treatment. J Neurol Neurosurg Psychiatry. 1957;20(1):22–39. https://doi.org/10.1136/jnnp.20.1.22.

18. Shah AH, Patel N, Raper DM, Bregy A, Ashour R, Elhammady MS, et al. The role of preoperative embolization for intracranial meningiomas. J Neurosurg. 2013;119(2):364–72. https://doi.org/10.3171/2013.3.JNS121328.

19. Amano T, Nakamizo A, Michiwaki Y, Matsuo S, Fujioka Y, Nagata S. Surgical outcome in elderly patients with intracranial meningioma. J Clin Neurosci. 2018;56:63–6. https://doi.org/10.1016/j.jocn.2018.07.009.

20. Drappatz J, Avila EK. Seizures in patients with primary and metastatic brain tumors. UpToDate Inc., Waltham, MA. 2019 (Last Update Jun 12, 2019). https://www.uptodate.com/. Accessed Jun 15, 2019.

21. Carrabba G, Riva M, Conte V, Di Cristofori A, Caroli M, Locatelli M, et al. Risk of post-operative venous thromboembolism in patients with meningioma. J Neurooncol. 2018;138(2):401–6. https://doi.org/10.1007/s11060-018-2810-z.

22. Santacroce A, Walier M, Regis J, Liscak R, Motti E, Lindquist C, et al. Long-term tumor control of benign intracranial meningiomas after radiosurgery in a series of 4565 patients. Neurosurgery. 2012;70(1):32–9; discussion 9. https://doi.org/10.1227/NEU.0b013e31822d408a.

23. Kaur G, Sayegh ET, Larson A, Bloch O, Madden M, Sun MZ, et al. Adjuvant radiotherapy for atypical and malignant meningiomas: a systematic review. Neuro Oncol. 2014;16(5):628–36. https://doi.org/10.1093/neuonc/nou025.

24.• Shih HA, Park JK. Management of atypical and malignant (WHO grade II and III) meningioma. UpToDate Inc., Waltham, MA. 2019 (Last Update Aug, 2018). https://www.uptodate.com/. Accessed May 23, 2019.
An updated, detailed, review of the literature on the management of malignant and ayptical meiningiomas.
25. Korah MP, Nowlan AW, Johnstone PA, Crocker IR. Radiation therapy alone for imaging-defined meningiomas. Int J Radiat Oncol Biol Phys. 2010;76(1):181–6. https://doi.org/10.1016/j.ijrobp.2009.01.066.
26. Marta GN, Murphy E, Chao S, Yu JS, Suh JH. The incidence of second brain tumors related to cranial irradiation. Expert Rev Anticancer Ther. 2015;15(3):295–304. https://doi.org/10.1586/14737140.2015.989839.
27. Lindquist C, Paddick I. The Leksell Gamma Knife Perfexion and comparisons with its predecessors. Neurosurgery. 2007;61(3 Suppl):130–40; discussion 40–1. https://doi.org/10.1227/01.neu.0000289726.35330.8a.
28. Garcia-Barros M, Paris F, Cordon-Cardo C, Lyden D, Rafii S, Haimovitz-Friedman A, et al. Tumor response to radiotherapy regulated by endothelial cell apoptosis. Science. 2003;300(5622):1155–9. https://doi.org/10.1126/science.1082504.
29. Fuks Z, Kolesnick R. Engaging the vascular component of the tumor response. Cancer Cell. 2005;8(2):89–91. https://doi.org/10.1016/j.ccr.2005.07.014.
30. Kirkpatrick JP, Brenner DJ, Orton CG. Point/counterpoint. The linear-quadratic model is inappropriate to model high dose per fraction effects in radiosurgery. Med Phys. 2009;36(8):3381–4. https://doi.org/10.1118/1.3157095.
31. Song CW, Lee YJ, Griffin RJ, Park I, Koonce NA, Hui S, et al. Indirect tumor cell death after high-dose hypofractionated irradiation: implications for stereotactic body radiation therapy and stereotactic radiation surgery. Int J Radiat Oncol Biol Phys. 2015;93(1):166–72. https://doi.org/10.1016/j.ijrobp.2015.05.016.
32. Sperduto PW, Song CW, Kirkpatrick JP, Glatstein E. A hypothesis: indirect cell death in the radiosurgery era. Int J Radiat Oncol Biol Phys. 2015;91(1):11–3. https://doi.org/10.1016/j.ijrobp.2014.08.355.
33. Santacroce A, Kamp MA, Budach W, Hanggi D. Radiobiology of radiosurgery for the central nervous system. Biomed Res Int. 2013;2013:362761. https://doi.org/10.1155/2013/362761.
34. Prabhu VC, Melian E, Germanwala AV, Solanki AA, Borys E, Barton K, et al. Cranial base meningiomas. World Neurosurg. 2018;109:258–62. https://doi.org/10.1016/j.wneu.2017.09.207.
35. Hasseleid BF, Meling TR, Ronning P, Scheie D, Helseth E. Surgery for convexity meningioma: Simpson Grade I resection as the goal: clinical article. J Neurosurg. 2012;117(6):999–1006. https://doi.org/10.3171/2012.9.JNS12294.
36. Oya S, Kawai K, Nakatomi H, Saito N. Significance of Simpson grading system in modern meningioma surgery: integration of the grade with MIB-1 labeling index as a key to predict the recurrence of WHO Grade I meningiomas. J Neurosurg. 2012;117(1):121–8. https://doi.org/10.3171/2012.3.JNS111945.
37. Nanda A, Bir SC, Konar S, Maiti TK, Bollam P. World Health Organization grade I convexity meningiomas: study on outcomes, complications and recurrence rates. World Neurosurg. 2016;89:620–7 e2. https://doi.org/10.1016/j.wneu.2015.11.050.
38. Voss KM, Spille DC, Sauerland C, Suero Molina E, Brokinkel C, Paulus W, et al. The Simpson grading in meningioma surgery: does the tumor location influence the prognostic value? J Neurooncol. 2017;133(3):641–51. https://doi.org/10.1007/s11060-017-2481-1.
39. Morokoff AP, Zauberman J, Black PM. Surgery for convexity meningiomas. Neurosurgery. 2008;63(3):427–33; discussion 33–4. https://doi.org/10.1227/01.NEU.0000310692.80289.28.
40. Black PM, Villavicencio AT, Rhouddou C, Loeffler JS. Aggressive surgery and focal radiation in the management of meningiomas of the skull base: preservation of function with maintenance of local control. Acta Neurochir (Wien). 2001;143(6):555–62.
41. Goto T, Ohata K. Surgical resectability of skull base meningiomas. Neurol Med Chir (Tokyo). 2016;56(7):372–8. https://doi.org/10.2176/nmc.ra.2015-0354.
42. Wayhs SY, Lepski GA, Frighetto L, Isolan GR. Petroclival meningiomas: remaining controversies in light of minimally invasive approaches. Clin Neurol Neurosurg. 2017;152:68–75. https://doi.org/10.1016/j.clineuro.2016.11.021.
43. Seifert V. Clinical management of petroclival meningiomas and the eternal quest for preservation of quality of life: personal experiences over a period of 20 years. Acta Neurochir (Wien). 2010;152(7):1099–116. https://doi.org/10.1007/s00701-010-0633-6.
44. Maurer AJ, Safavi-Abbasi S, Cheema AA, Glenn CA, Sughrue ME. Management of petroclival meningiomas: a review of the development of current therapy. J Neurol Surg B Skull Base. 2014;75(5):358–67. https://doi.org/10.1055/s-0034-1373657.
45. Boari N, Gagliardi F, Spina A, Bailo M, Franzin A, Mortini P. Management of spheno-orbital en plaque meningiomas: clinical outcome in a consecutive series of 40 patients. Br J Neurosurg. 2013;27(1):84–90. https://doi.org/10.3109/02688697.2012.709557.
46. Ruggeri AG, Cappelletti M, Fazzolari B, Marotta N, Delfini R. Frontobasal midline meningiomas: is it right to shed doubt on the transcranial approaches? Updates and review of the literature. World Neurosurg. 2016;88:374–82. https://doi.org/10.1016/j.wneu.2015.11.002.
47. Wang EW, Gardner PA, Zanation AM. International consensus statement on endoscopic skull-base surgery: executive summary. Int Forum Allergy Rhinol. 2019. https://doi.org/10.1002/alr.22327.
48.• Muskens IS, Briceno V, Ouwehand TL, Castlen JP, Gormley WB, Aglio LS, et al. The endoscopic endonasal

approach is not superior to the microscopic transcranial approach for anterior skull base meningiomas—a meta-analysis. Acta Neurochir (Wien). 2018;160(1):59–75. https://doi.org/10.1007/s00701-017-3390-y

In the past decade, the endonasal transsphenoidal approach has become an alternative to the microsurgical transcranial approach for tuberculum sellae meningiomas and olfactory groove meningiomas. This is a recent meta-analysis comparing which approach offered the best surgical outcomes, concluding that endoscopic endonasal approach is, to date, not superior to the microscopic transcranial approach for anterior skull base meningiomas.

49. Bi WL, Dunn IF. Current and emerging principles in surgery for meningioma. Chin Clin Oncol. 2017;6(Suppl 1):S7. https://doi.org/10.21037/cco.2017.06.10.

50. Mendenhall WM, Morris CG, Amdur RJ, Foote KD, Friedman WA. Radiotherapy alone or after subtotal resection for benign skull base meningiomas. Cancer. 2003;98(7):1473–82. https://doi.org/10.1002/cncr.11645.

51. Kim CH, Chung CK, Lee SH, Jahng TA, Hyun SJ, Kim KJ, et al. Long-term recurrence rates after the removal of spinal meningiomas in relation to Simpson grades. Eur Spine J. 2016;25(12):4025–32. https://doi.org/10.1007/s00586-015-4306-2.

52. Tsermoulas G, Turel MK, Wilcox JT, Shultz D, Farb R, Zadeh G, et al. Management of multiple meningiomas. J Neurosurg. 2018;128(5):1403–9. https://doi.org/10.3171/2017.2.JNS162608.

53. Aboukais R, Bonne NX, Baroncini M, Zairi F, Schapira S, Vincent C, et al. Management of multiple tumors in neurofibromatosis type 2 patients. Neurochirurgie. 2018;64(5):364–9. https://doi.org/10.1016/j.neuchi.2014.11.012.

54.• Magill ST, Dalle Ore CL, Diaz MA, Jalili DD, Raleigh DR, Aghi MK, et al. Surgical outcomes after reoperation for recurrent non-skull base meningiomas. J Neurosurg. 2018:1–9. https://doi.org/10.3171/2018.6.JNS18118

One of the few studies reporting and analyzing surgical outcomes after reoperation for recurrent convexity, falcine, and parasagittal meningiomas. Reoperation was found to be associated with a high rate of complications; nevertheless, excellent long-term survival can be achieved without perioperative mortality.

55.• Magill ST, Lee DS, Yen AJ, Lucas CG, Raleigh DR, Aghi MK, et al. Surgical outcomes after reoperation for recurrent skull base meningiomas. J Neurosurg. 2018:1–8. https://doi.org/10.3171/2017.11.JNS172278

The largest surgical series published in the literature, to date, reporting and analyzing surgical outcomes for patients who underwent reoperations for skull base meningiomas.

56.• Sicking J, Voss KM, Spille DC, Schipmann S, Holling M, Paulus W, et al. The evolution of cranial meningioma surgery—a single-center 25-year experience. Acta Neurochir (Wien). 2018;160(9):1801–12. https://doi.org/10.1007/s00701-018-3617-6

There have been major developments in diagnostic and surgical and nonsurgical techniques used in the management of meningiomas over last three decades. This study, based on a series of 817 patients, who underwent surgery for primarily diagnosed meningioma between 1991 and 2015, set out to describe these changes in a systematic manner.

57. Galldiks N, Albert NL, Sommerauer M, Grosu AL, Ganswindt U, Law I, et al. PET imaging in patients with meningioma—report of the RANO/PET Group. Neuro Oncol. 2017;19(12):1576–87. https://doi.org/10.1093/neuonc/nox112.

58. Kunz WG, Jungblut LM, Kazmierczak PM, Vettermann FJ, Bollenbacher A, Tonn JC, et al. Improved detection of transosseous meningiomas using ^{68}Ga-DOTATATE PET/CT compared with contrast-enhanced MRI. J Nucl Med. 2017;58(10):1580–7. https://doi.org/10.2967/jnumed.117.191932.

59.• Meling TR, Da Broi M, Scheie D, Helseth E, Smoll NR. Meningioma surgery—are we making progress? World Neurosurg. 2019. https://doi.org/10.1016/j.wneu.2019.01.042

A longitudinal observational study comparing 1469 patients operated on for intracranial meningioma in four consecutive time frames (1990–1994, 1995–1999, 2000–2004, and 2005–2010). The aim was to evaluate improvements in outcomes after resection of meningiomas, with respect to extent of resection, neurologic outcome, complications, retreatment-free survival, and overall survival.

60. Bir SC, Konar SK, Maiti TK, Thakur JD, Guthikonda B, Nanda A. Utility of neuronavigation in intracranial meningioma resection: a single-center retrospective study. World Neurosurg. 2016;90:546–55 e1. https://doi.org/10.1016/j.wneu.2015.12.101.

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