Brain Tumor Surgery Last updated: January 16, 2021

PREOP

Determine Resectability

Extra-axial tumors

Anesthesiology

Approach Selection

Surgical Principles

Position

Monitoring

Mapping of eloquent cortex

Brain relaxation

Operative corridor

Blood supply

Tumor resection

Extent of tumor resection

Tumor fencing

Ventricular entry

Intraoperative MRI (iMRI, ioMRI)

Fluorescence-guided resection (i.e., chemoneavigation)

Fluorescein sodium

5-aminolevulinic acid (5-ALA)

vs. iMRI

Closure

Postoperative

Diuretics

Steroids

AED

Antithrombotic measures

Postoperative imaging

Complications

Anterior Skull Base

Cavernous Sinus and Middle Fossa

Posterior Fossa Tumors

Cerebellopontine Angle, 4th Ventricle

Brainstem Tumors

Cerebellar Tumors

Oligoastroblastoma

Third Ventricle

Endoscopic transventricular resection of 3rd ventricle colloid cyst

Transfornaminal resection of 3rd ventricle colloid cyst

Transsphenoidal (sphenoid ridge or suprasellar) approach

Interhemispheric approach

Lateral Ventricular Masses

Preoperative

Operative Technique

Temporal Lobe

Parietal Lobe

Occipital Lobe

Frontal Lobe

Corpus Callosum (transcallosal interhemispheric approach)

Indications

Procedure

Complications

Combined approaches (transcallosal + transcortical)

Postoperative Deficits

Intraventricular Tumors

Meningiomas

Preoperative

Principles in meningioma resection

Simpson Grades

Meningioma involving bone

Very Large Meningioma

Anterior Skull Base Meningiomas

Olfactory groove meningioma

Plumon sphenoidal meningioma

Tuberculum Sella / Anterior clinoid region meningiomas

Convexity meningioma

Parasagittal / Parafoveal Meningiomas

Sphenoid Wing meningioma

Cavernous Sinus Meningiomas

Petrous Apex Meningiomas

Cerebellopontine Angle Meningiomas

Clival and Petroclival Meningiomas

Tentorial and Tympanic Meningiomas

Chondotony details — see p. 3150 >>

Vestibular schwannoma — see p. Ons62 >>

Laser (LITT) — see p. Ons35 >>, also see individual tumors

PREOP

Detailed prep imaging studies - large lesions may distort normal anatomy (esp. vessels – consider CTA!)

angiography is important in evaluation of lesion’s vascular supply and venous drainage (prior to interhemispheric dissection).

preoperative tumor embolization can decrease intraoperative blood loss.

surgery is scheduled on elective, but preferably urgent, basis.

Determine Resectability

In almost every instance in which brain tumor is diagnosed, first consideration is its surgical resectability! (exception - multiple brain metastases)

Surgery should be first therapeutic modality for tumor!

- even potentially curable tumors (such as MENINGIOMAS OR ACUTE NEUROMAS) may reside in positions that make complete resection technically impossible!

- only 46% of malignant gliomas in USA are gross totally resected (mostly for fear of functional deficits; other gliomas – only cytodestructive resection); how it can be improved:
I. Intracranial Tumors

- not always amenable to radical surgical resection;
  - most gliomas lack microscopic boundaries; glioma cells may migrate several centimeters along white matter pathways, including corpus callosum, making complete resection impossible;
  - even small tumors may grow by expansion.
- debunking even of malignant gliomas has some benefit (cysto-resection).

II. Brain Stem Tumors

- not amenable to surgical therapy (even biopsy is hazardous!);
- solitary brain metastasis is indication for surgical resection (depending on systemic medical status).

III. Tumors in Sella Turcica

- partial removal may be surprisingly effective (if resection is confined to tumor itself, if rarely produces major new neurologic deficits)
- functional imaging (fMRI, DTTI, structural MRI) facilitates surgery by showing that tumor has pushed aside critical brain structures.

IV. Subcortical Tumors

- potentially curable by surgery, but often located in regions that are difficult to reach surgically.

ANESTHESIA

- in era of modern neuroanesthesia, it is rare that craniotomy must not be done because of poor general medical status.
- anesthesia with lack of effect on ICP;
  - increasing number of resections in dominant hemisphere are done under local anesthesia for purpose of speech mapping.

MANNITOL (1 g/kg) + hyperventilation (PeCO2 25-30 mmHg) for definitive ICP reduction in preparation for brain retraction; administration time varies—some experts give only at the beginning of “bony work”, others give at the time of prep start (i.e. “Broadus” “tacks 30 minutes for mannitol to start working and those 30 minutes are with increased rheological bleeding; mannitol peak effect lasts several hours”).

Dexamethasone (usually 10 mg IV) should be administered before manipulating nervous tissue.
- AED if cortex will be violated or significant retraction of lobes is expected.
- some routinely administer Bromofenacoumarin IV (during induction of anesthesia) - tumor labeling on fixed tissue postoperatively.

APPROACH SELECTION

For craniotomy details—see p. Op300

Tumors that reach cortical surface are approached through craniotomy at that site.

Subcortical tumors are approached through:

- deep sulci (vs. gyral crown) avoiding eloquent areas (e.g. approaching lesion obliquely).
- cortical incision in ≈ 3 cm in length.
- anterior corpus callosum (causes minimal, if any, deficit).
- dilated ventricles (intraventricular neoplasms).
- localization of subcortical tumors.
- intraoperative ultrasonography
- frameless MRI-guided navigation (markers on patient's scalp).

Skull base tumors:

Anterior skull base:
- tumor behind orbit (incl. tumors of gasserian ganglion and cavernous sinus) → subzygomatic approach (osteotomy through zygoma and orbital roof).
- tumors in sella turcica → trans-sphenoidal approach.
- tumors of upper one third of clivus, lesions of odontal process → transoral or transpalatal approach (may be extended by osteotomy of mandible).
- tumors of pons and parasellar sinuses and upper one third of clivus → transfacial approach (to expose mandible for orbital surface can be deluged).
- Lateral approaches through temporal bone to middle skull base (e.g. petrosal or presigmoid approach in which petrosal bone is drilled away).

Posterior approaches:
- extreme lateral approach → exposes lower third of clivus, cerebellopontine angle, and petrous surface temporal bone.
- lesions of cerebellopontine angle → retrosigmoid craniotomy.
- lesions of petrous surface of temporal bone → suboccipital craniotomy.

Surgical Principles

For craniotomy details—see p. Op300

There is no surgical method that can eliminate all of obstacles.

Position

- prone position is comfortable for surgeon (registration for navigation might be challenging – solutions: a) skin fiducials, b) O-arm automatic registration.
- sitting position - risk of air embolism, less comfortable for operating physician, but field is much clearer because drainage is easier.
- head is held rigidly with pin fixation to minimize movement (for infants, use soft rings - pins can perforate infant's skull or cause depressed fracture, may use pediatric pins).

Monitoring

- EEG (including on-line monitoring)
- ICP monitoring (arterial/capillary)
- transcranial Doppler
- transcranial echography
- continuous electrocardiogram
- respiratory monitoring
- oximetry
- blood gases
intraoperative cranial nerve monitoring alerts surgeon when nerves are at risk of damage; cranial nerves II-XII can be monitored intraoperatively (e.g. CN7 monitored with EMG, CN8 monitored with BEAR).

intraoperative electrocorticography (ECoG) is useful in guiding epilepsy surgery, e.g. tumor-associated epilepsy (esp. in long-standing or severe seizures).

MAPPING OF ELOCUENT CORTEX

- see “Awake craniotomy” in p. Op300

BRAIN RELAXATION

dura is opened only after brain has been softened completely by mannitol diuresis and intraoperative hyperventilation (sometimes few minutes) wait is necessary - this brief pause can be critical to success!

- in some cases, it is worth placing lumbar drain to drain CSF – causes further brain relaxation.

OPERATIVE CORRIDOR

1. Sutural approach to limit cortical manipulation (need to access large lesions deep in brain may make this too confining).

- No gyrus should be entered, unless it is involved in tumor.

2. Use natural corridor:

1) fissures (do not violate normal cortex; e.g. medial temporal tumor - approach from Sylvian fissure split above Sylvian vessels (up to choroidal fissure)).

- *medial temporal region (memory) is phylogenetically different than lateral (Wernicke, auditory); tumors do not spread through these regions.

2) sulci (e.g. BrainPath circular retractor – anatomic transsulcal approach)

3) venous structures – to operate endoendoscopically (through ventricles), need large hydrocephalus (e.g. clamp EVD at midnight - enlarged ventricles can be used to surgeon's advantage in planning access)

- optimal corridor to ventricles should not compromise neurological function through direct manipulation of eloquent cortical structures (shortest pathway to lesion is not necessarily best option)

- deliver lesion into field of view without excessive retraction (requires patience)

- one of most common causes of postoperative neurological deficits is excessive retraction (to expose mass or to stop bleeding).

3. Corticotomy (most likely at cortex closest to tumor surface) - coagulate with bipolar + cut with microscissors / spread with bipolar procs (or sucker tip)

- incisions through cortex or corpus callosum should be covered with absorbable hemostatic barrier* (such as Surgicel or Gelfoam) to keep fluid contained within ventricles

- *make sure material does not fall into ventricle to cause obstruction.

4. Retractors - Greenberg retractors.

- for intraventricular tumors - use Vycor / BrainPath retractors (connect to Greenberg frame) / Greenberg retractors.

- handheld retractors are less traumatic (retraction injury) – so called dynamic retraction

- gravity retraction – explained by Dr. Lawton – sometimes counterintuitive gravity retraction gives better access and view.

BLOOD SUPPLY

Early access to blood supply – obtain proximal control.

- initial portions of tumor resection should be directed toward gaining access to vascular supply.

- intraventricular tumors may receive blood supply from choroidal vessels of both anterior and posterior circulations.

- exanguination is likely cause of earlier reports of high mortality in infants with choroid plexus papillomas.

- preserve vessels (they may be en passage - violating them will cause stroke); if both arterial and venous supplies of structure are to be sacrificed, atrophic supply should be interrupted first (to avoid congestion, bleeding, and swelling).

TUMOR RESSECTION

1. Piecemeal removal of large masses (bipolar & gentle suction, CUSA) - debulking tumor center – dissecting remaining shell from surrounding normal brain tissue by advancing patty / Yella into interface (i.e. resection proceeds from inside out so that surrounding normal white matter is disturbed minimally).

- N.B. resist temptation to pull the tumor en bloc – there could be a critical vessel attached to tumor base (where you cannot see and can be avulsed); also tumor base can be attached to dural sinus wall, etc.

- may use saline spray with blunt needle tip to open plane.

- piecemeal resections will result in bleeding, and many times this cannot be avoided.

- intraventricular bleeding – protect foramen of Monro with cotton square* (to avoid obscuration of this structure and to prevent blood from pooling in ventricles) – corkscrew irrigation (risk of postoperative ventricular obstruction and probably postoperative headache).

*of foramen of Monro cannot be cleared of obstruction, open window in septum pellucidum (almost routinely).

- early reports of lateral ventricular tumors that display entire lesion as gross pathological specimen clearly demonstrate why surgery caused profound neurological deficits and high mortality.
• removal of firm, adherent, or calcified tumor is simplified by Cavitron ultrasonic aspirator (CUSA) - tip vibrates at 22,000 Hz - ultrasonically disrupts tumor; tip is surrounded by two concentric channels, one dispensing saline to solubilize fragments and another suctioning away that suspension.
  • allows for internal debulking of large tumors and reduces amount of brain retraction needed for tumor removal.
• in limited access locations, CO2 laser can vaporize tumor tissue with hands-off technique (such tumor removal is slow).
• for low grade gliomas – remove entire gyrus using subpial dissection - hold edge of pia with pickup and suck parenchyma with sucker along pial inner surface.

2. Total resection should be goal of surgery.
• glistening peritumoral white matter is seen easily through microscope as tumor's margin is reached - at this interface resection is stopped.
• incomplete removal may be preferable when site of attachment invades into deep structures such as thalamus (goal is debulking when mass effect is cause of symptoms).

3. Intraleisional (piecemeal) vs. circumferential perilesional (en bloc*) resection

* GBM is known to be infiltrative, and thus a true en bloc resection is not possible
• intraleisional fashion - contrast enhancing portion of the tumor is entered, and the tumor is removed from the center toward the edges.
• perilesional fashion:
  - intraoperative ultrasound and stereotactic image guidance identify the cortical margins of the tumor and its subcortical extension.
  - because the tumor is not “decompressed”, shift does not happen and computer-assisted surgical guidance is relatively well maintained throughout the case.
  - perilesional tumor resection was associated with a significantly higher rate of GTR than intraleisional resection (81% vs 62%, multivariate odds ratio = 2.5).
  - among tumors in eloquent cortex, perilesional resection had a higher rate of GTR (79% vs 58%, respectively, P < 0.001) and a lower rate of neurological complications (11% vs 20%, P = 0.018).

EXTENT OF TUMOR RESECTION

Goal - resection of maximal amount of tumor consistent with functional preservation
• gross total resection may extend survival from around 11 to 14 months in glioblastoma and from 60 to 90 months in low grade glioma (Sanai 2009).

High-grade gliomas – see p. Onc10 >>
Low-grade gliomas – see p. Onc10 >>
TUMOR FENCING
- inserting along tumor perimeter (using navigation, before tumor resection – to avoid shift) Becker ventricular catheters (cut flush to brain surface but still tend to fall out – so suture to dura edges or strings of patties)
  During tumor resection keep going until encounter “fence poles” – serve also as depth guides (not just perimeter guides).

VENTRICULAR ENTRY
- during resection of high-grade gliomas (HGG):
  - higher odds of leptomeningeal dissemination (sOR: 3.91 [95% confidence interval (CI): 1.89-8.10]; P = .0002; 86/410 vs 57/847 patients in 9 studies)
  - higher odds of hydrocephalus (sOR: 7.78 [95% CI: 3.77-16.05]; P < .00001; 58/431 vs 11/565 patients in 11 studies).
  - decreased survival (median survival: 16.8 vs 19.1 mo. 413 vs 322 patients in 10 studies; hazard ratio: 1.25 [95% CI: 1.05-1.48], P = .01).

Intraoperative MRI (iMRI, ioMRI)
- be aware of thin rim enhancement along the surface of the resection cavity artifact caused by surgeon’s mechanical disruption to BBB - may be difficult to distinguish from tumor-specific enhancement (esp. when a low-resolution 0.15 T magnet is used).

FLUORESCENCE-GUIDED RESECTION (S. CHEMONAVIGATION)
A must for high-grade glioma surgery!

FLUORESCENCE-NONIONAL
- 3-20 mg/kg IV at dural opening (i.e. does not delay surgery vs. 5-ALA); 560 nm microscope filter.
  - $5 per vial.
  - contraindication – serum creatinine > 2 mg/dL.

5-AMINOLEVULINIC ACID (5-ALA)
Fluorescence rates
  - 100% high-grade glioma
  - 20% of low-grade gliomas
  - 77-94% of meningiomas (grade I-III)
  - 80% of ependymomas
  - 43% of PNETs
  - 40% of gangliogliomas
  - 25% of medulloblastomas
  - 15% of pilocytic astrocytomas

FDA approval
- June 6, 2017 - FDA has approved Gleolan™ (aminolevulinic acid hydrochloride (ALA HCl)) as an optical imaging agent indicated in patients with gliomas (suspected World Health Organization Grades III or IV on preoperative imaging) as an adjunct for the visualization of malignant tissue during surgery; both – new and recurrent.
  - vial price - $2500.

Indications
1. Surgery: guidance for high-grade glioma (in the future may be also used as an agent for photodynamic therapy for remaining glioma cells)
2. High-grade glioma / lymphoma / germ cell tumor biopsy verification – if biopsy material fluoresces, no need to wait for frozen pathology confirmation (may take up to 30-45 minutes)

Mechanism of action
- 5-ALA is metabolized to protoporphyrin IX, an endogenous fluorescent bioproduct, as part of the heme biosynthesis pathway.
- in malignant glioma cells, but not in healthy brain cells, exposure to 5-ALA results in tumor-specific accumulation of protoporphyrin IX as a result of alterations in enzymes and cell transporters involved in heme biosynthesis - useful for the intraoperative discrimination of tumor and normal tissue in the operating room, as well as 5-ALA –based photodynamic therapy.
Very high PPV, sensitivity and specificity!

**Pivotal Efficacy Studies: Biopsy-Based Diagnostic Measures**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Study 1* (Primary)</th>
<th>Study 2† (Recurrent)</th>
<th>Study 3‡ (Primary)</th>
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<td>PPV</td>
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**Practical**

- **Indication:** high-grade gliomas (suspected WHO grades III-IV on preoperative imaging).
- **Contraindication:** porphyrias.
- **Dosage:** 20 mg/kg (1 vial, 2500-2700 $ = 1500 mg; patient > 75 kg needs to vials)
- **Timing:** 3 hours (range 2 to 4 hours) prior to induction of anesthesia.
  - N.B. there is no data on redosing!
  - Must be reconstituted as 1500 mg/50 mL of water per vial.
- **ALA leads to accumulation of fluorescent porphyrins (protoporphyrin IX) in tumor tissue.**
- **Max fluorescence time is 5-8 hours, thus, experts recommend administer 6 hours before resection.**
- **False positive:**
  - within tumor vicinity, metastases, inflammation, radiation necrosis.
  - anecdotal brain fluorescence due to mechanical disturbance (due to BBB damage).
- **False negative:**
  - surgery too early after administration.
  - necrotic tissue will not fluoresce.
  - intensity of fluorescence will diminish as a function of the focal distance of the microscope beyond 300 mm from the tumor, which is the point at which it becomes increasingly difficult to adequately visualize tumor fluorescence - fluorescence energy declines by the 4th power of the focal distance.
  - Microscope focal point – no more than 30 cm!
  - fluorescence intensity will diminish with time of light excitation due to photobleaching / fluorescence decay upon exposure to light (starts at 20 mins of exposure).
  - experts recommend completing conventional resection under normal light, then turn eyes away (let brain “rest” from image) and turn blue light on.
- **Target region:** exposed to blue laser light with 405 (375-440) nm peak wavelength (with handheld device or microscope):
  - there is a phantom available to test microscope (blue light source must be replaced every 250 hours).
  - tumor tissue glows red (620-710 nm).**
Pharmacokinetics (PK), Pharmacodynamics (PD)
- drink room temperature.
- vial wrapped in yellow bag.
- mean absolute bioavailability - 100%.
- maximum ALA plasma concentration - within a median of 0.8 hour.
- T½ - 1 hour.
- Tmax for PyiH - 4 hours.
- Tmax for PpiH - 3.6 hours.
- the fraction of administered ALA that is metabolized to PyiH is unknown.
- the effect of renal or hepatic impairment is unknown.

Adverse reactions (> 1% of patients in the week following surgery): pyrexia, hypotension, nausea, and vomiting.
N.B. essentially non-toxic!
1. Photosensitivity
- reduce exposure to sunlight or room lights for 48 hours postoperatively (place wristband on the patient indicating the time when this 48-hr period will end).
- do not administer photosensitizing agent for 24 hours pre and 24 hours postoperatively - phototoxic skin reaction (severe sunburn) may result. St. John’s wort, griseofulvin, thiazide diuretics, sulfonylureas, phenothiazines, sulphonamides, quinolones, and tricyclics.
- turn OR lights away from the patient until fully draped.
2. One patient experienced respiratory failure due to drug overdose.
3. No liver failure cases reported (but LFTs may become elevated up to 10-fold in 11-15% of patients in a first week, and return to normal at 6 weeks).

Studies
3-ALA fluorescence-assisted surgery vs. conventional surgery
- class I evidence.

Gadolinium is better than 5-ALA
- ALA fluorescence is a good marker of tumor presence but is not a good indicator for the absence of tumor when no fluorescence is present (negative predictive value only 37%).
- ALA is more sensitive than contrast MRI or amino acid positron emission tomography (18F-FET PET) in glioblastoma surgery. Neurol. Res. 2012;34(3):314 – 317
- ALA and iMRI are synergistic.

5-ALA is better than more than expected from gadolinium enhancement
- it is well established that even MRI-nonenhancing low- and high-grade gliomas will show fluorescence in about 20% of cases.
- Fluorescence shows even beyond the fluoro-ethyl-tyrosine-PET zone of hypermetabolism.
tumor cavity is then examined for bleeding points, and meticulous hemicorpusion (sometimes difficult but must be perfect) is created prior to closure: — persistent bleeding may be due to residual tumor, and it will require direct bipolar coagulation and topical gelatin foam, activated cellulose or microfibrillar collagen application for control. — Dr. Graham lays Surgicel in tumor cavity — if brain swelling is worrisome at time of closure (rare situation), ICP catheter is left in subarachnoid space.

cyst may be drained and, when possible, fenestrated into adjacent ventricle to prevent reaccumulation.

about CSF drainage — see p. Onl185

After

The pia-arachnoid is opened using bipolar coagulation along line of incision which is made by sharp dissection. It is usually safe to make subdural to adjacent sulcus, continuing into white matter and seeking plane between tumor and edematous brain. Some tumors present with false capsule, but such lines of demarcation are usually delimited. Generally, brain substance is divided by suction or hemostasis sometimes difficult — even for patients with preoperative seizures, postoperatively for most seizures cease spontaneously (when patients are initially seizure free after surgery, seizure recurrence is as low as 8%). Some tumors present with false capsule, but such lines of demarcation are usually delimited. Generally, brain substance is divided by suction or hemostasis sometimes difficult — even for patients with preoperative seizures, postoperatively for most seizures cease spontaneously (when patients are initially seizure free after surgery, seizure recurrence is as low as 8%).

There are studies that group (p = 1.0).

incidence of early seizures (< 30 days after surgery) was 8% in observation group

prophylactic AEDs, and incidence of clinically significant seizures is even lower (3%).

if adequate surgical decompression is achieved, steroid can be tapered if brain stem involvement was minimal, patient may be extubated in operating room.

turbulent dissection. It is usually safe to make subpial dissection to adjacent sulcus, continuing

and surrounding brain, aided by strips of cottonoid to wall off brain. Bridging vessels are divided, and separation along lines of cleavage is continued until tumor is surrounded. Many infiltrating lesions have pseudocapsules that may be well-decorticated, but usually such lines of delineation fade out so that separation must continue along areas of infiltration. In other cases where infiltrating lesion is limited to lobe, standard lobectomy may be selected, dividing pia and pial vessels, and transsecting lobar structures so as to include neoplasm. If cortex is reached opposite entry site, cortical vessels must be individually occluded and divided by sharp dissection. Ultrasonic aspiration may supplement suction and coagulation.

Resection of infiltrating lesions requires debulking of mass—usually by aspiration and often with ultrasonic aspiration. Generally, blood loss from highly vascular neoplasms will be less by working at edge of tumor. When this is impossible, aspiration must begin within tumor. Care must be taken against undermining or even excessive retraction of functional cortex to be preserved. Hemostasis during dissection aids visualization of structures and identification of vessels. When bulk of tumor has been removed, further search for additional tumor is carried out and such fragments are removed. The ultrasonic aspirator is helpful in this maneuver.

POSTOPERATIVELY

extubation:
— a) if surgery entails significant manipulation of brain stem, patient should remain intubated for first postsurgical night and be extubated carefully once lower cranial nerves function has been assessed;
— b) if brain stem involvement was minimal, patient may be extubated in operating room.

DICP

ICU for at least 1 night; increasing trend for adult supratentorial tumor resections

— no ICU, unless"

— reduced complication rates and length of stay while keeping patients satisfied + hospital costs related to the admission have been significantly reduced.

if adult supratentorial tumor resections

— if adequate surgical decompression is achieved, steroid can be tapered if brain stem involvement was minimal, patient may be extubated in operating room.

STEROIDS

Continue DRAMEXHARZON for at least 5 days (to minimize surgically induced brain edema);

if adequate surgical decompression is achieved, steroid can be discontinued within first 1–2 weeks.

speed of weaning depends on:
— 1) postop new deficits
— 2) amount of tumor in part of FLAIR MRI
— 3) indications for steroid maintenance:

1. large volume of tumor remains, large edema — check on postop MRI

2. unexpected (likely from edema) new / worsening postoperative deficits

3. tumor in brainstem or spinal cord

4. steroid dependence

corticosteroids again may be needed during or after radiation therapy.

AED

Continue anticonvulsants for at least 7 days (few recommend - 1 year).

— incidence of seizures after surgery for brain tumors is low (8% [95% CI 3%–18%]) even without prophylactic AEDs, and incidence of clinically significant seizures is even lower (3%).

— if brain stem involvement was minimal, patient may be extubated in operating room.

— even for patients with preoperative seizures, postoperatively for most seizures cease spontaneously (when patients are initially seizure free after surgery, seizure recurrence is associated with tumor progression).

— 1) intrinsic epilepticogenic nature of the tumor, particularly in certain locations such as temporal and parietal temporal lobes

— 2) surgical factors associated with craniotomy (brain retraction and cortical irritation)

— postsurgical complications (hydrocephalus, edema, or infection).

— traditional AEDs are potent enzyme-inducing (PHENYTOIN, CARBAMAZEPINE, PHENOBARBITAL) or inhibiting (VALPROIC ACID) — reduce / increase serum concentration of chemotherapy agents.

— new generation of AEDs (GBPAPTITIN, LENVITRACEPT) are not metabolized by CYP isoenzymes.

There are studies that do not support prophylaxis: AED use:


incidence of seizures after surgery for brain tumors without a previous history of seizures.

— PHENYTOIN vs. placebo for 7 days postop.

— incidence of all seizures was 18% in observation group and 24% in prophylaxis group (p = 0.51).

— incidence of early seizures (within 30 days after surgery) was 8% in observation group and 20% in prophylaxis group (p = 0.05).

— steroid dependence

— in accordance with previous history of seizures.
incidence of clinically significant early seizures was 3% in observation group and 2% in prophylaxis group (p = 0.62). 

prophylaxis group experienced significantly more adverse events (18% vs. 0%, p < 0.01). 


• review of 698 patients 

• no significant differences in incidence of early or late seizures between AED and no-AED cohorts. 

• conclusions - prophylactic administration of anticonvulsants during resection of supratentorial meningiomas provides no benefit in prevention of either early or late postoperative seizures.

ANTEROMEDIAL MEASURES 

• compression boots, subQ heparin immediately postop – early passive exercises and mobilization!!!

POSTOPERATIVE IMAGING 

• baseline contrast MRI within 48 hours - to evaluate resection success (later, prominent enhancement of neovascularized reactive gliosis develops - interferes with image interpretation); absence of abnormal enhancement indicates gross total resection. 

• look at DWI and ADC - postcontrast MRI may show great tumor resection but if there is adjacent stroke it will start enhancing (as natural evolution) 3-4 weeks later and radiologist will call it as “tumor progression”.

• for tumors with propensity for leptomeningeal spread (MEDULLOBLASTOMAS, EPENDYOMAS, CHOROID PLEXUS CARCINOMAS, certain PINEAL GERMINOMAS), test before further postoperative therapy: 

  1) CSF cytologic examination at least 2 weeks after surgery (LP is safe = 10-21 days after intracranial decompression); 

  some authors suggest obtaining CSF at time of surgery from cisterna magna for cytologic analysis. 

  2) spinal MRI yearly during first 24 months (CSF exam alone is inadequate – may be false-negative in up to 50% cases); routine spinal evaluations beyond this time may not be practical (local recurrences are far more likely). 

if MRI is contraindicated, CT myelography is utilized. 

N.B. baseline spinal MRI is best done prior to surgery (to avoid postoperative artifacts); first postoperative spinal MRI - at least 2 weeks after surgery (spinal canal enhancement can occur in early postoperative period); if equivocal - repeat after 1-2 weeks (artifacts secondary to surgery regress while drop metastasis remain stable or increase).

ROUTINE SURVEILLANCE (unwarranted in asymptomatic patients following complete resection of benign tumors): 

• every 3-5 months during first 2 years; 

• every 6-12 months for following 2-3 years 

• every 3-5-years (for detection of late events such as radiation-induced meningiomas). 

• residual or recurrent contrast enhancement ≥ 3 months after surgery suggests recurrence. 

N.B. true tumor progression cannot be confirmed on MRI prior to 3 months! 

• differentiation of residual tumor from scar (region of linear, rim enhancement) is improved by gadolinium. 

• tumor recurrence – consider reoperation. see p. Onc3 >>

COMPLICATIONS 

• operative morbidity rate depends largely on tumor location (highest – 10-20% – in diencephalic tumors) 

• operative mortality rates < 1%; 30-day mortality rate after brain tumor surgery is 2.2-2.9% - postoperative hemorrhota is the most frequent cause of death. 


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SKULL BASE TUMORS 


ANTERIOR SKULL BASE 

See also p. Op300 >>

CAVERNOUS SINUS AND MIDDLE FOSSA 

PINEAL REGION TUMORS 


POSTERIOR FOSSA TUMORS 

• EVD can be placed frontally prior to positioning or occupationally once the patient has been positioned place EVD in OR prior to craniotomy (or at least prep for occipital Frazier but hole). 

• important to avoid hyperventilation immediately postop – risk of bleeding into posterior fossa!

PINEAL REGION TUMORS 

CEREBELLOPONTINE ANGLE, 4TH VENTRICLE

Vestibular schwannoma → p. Onc62 →

BRAINSTEM TUMORS

CEREBELLAR TUMORS

- navigation is not necessary but useful!
- prone on chest rolls or white Wilson frame; head in Mayfield frame.
- open cisterna magna (by opening arachnoid) – will drop cerebellum by gravity.
- mark floor of 4th ventricle – by advancing Telfa / putty / cut finger of glove into 4th ventricle from below (start between cerebellar tonsils) – or will fail Oral Boards!

Cerebellar tumors are best approached along the shortest transparenchymal route to the lesion.

A. Superior hemispheric lesions - via the supracerebellar cistern and by incising the cerebellum at the closest point to the tumor - requires a high suboccipital craniotomy with exposure of the transverse sinuses.
B. Inferior cerebellar tumors require opening of the foramen magnum.
C. Midline tumors can be resected after splitting the inferior vermis.
D. Lateral hemispheric lesions - directly from a posterior trajectory; entering the paracerebellar cisterns is generally not necessary, thus avoiding exposure of the cranial nerves; split hemispheric pia horizontally (parallel to widened folia):

postoperative deficits:
1. Cranial nerve deficits
2. Cerebellar mutism (anatomic origin - deep cerebellar nuclei) - one of most commonly cited complications.

HEMANGIOBLASTOMA

A. Cerebellar lesions - via suboccipital craniectomy;
   Hydrocephalus → external ventricular drain prior to tumor resection! (hydrocephalus resolves in > 90% patients postop)
B. Spinal lesions - via laminectomy:
   no syrinx – remove upper ones (tumors);
   syrinx present – remove largest one (tumor) – syrinx resolves in 1-3 months (if not – means residual tumor)

• target - mural nodule (otherwise, cyst will recur), no need to resect capsule if it is nonenhancing on MRI
  — cyst wall is not removed unless there is evidence of tumor within the cyst wall on MRI (typically thick-walled cysts) or visually at the time of surgery (5-ALA fluorescence may aid in visual localization of small hemangio- and blastomas within the cyst wall).
• surgical principles similar to those used in treating AVMs:
  — pre-operative embolization may help reduce the vascularity
  — identify feeding vessels → coagulate and cut (arterial feeders prior to draining veins!)
  — do not remove in piece meal fashion - significant bleeding may ensue!
• coagulate tumor surface (to shrink the tumor) with wide bipolar forceps (avoid penetration of tumor itself due to its extreme vascularity and difficulties with hemostasis).
• dissect tumor circumferentially by careful devascularizing blood supply (coagulation and cutting small feeding vessels), releasing adhesions between tumor and surrounding tissue by putting cottonoid strips into developing plane to avoid direct pressure on brain or spinal cord tissue.
• HGBs with attachment to floor of 4th ventricle may be hazardous to remove (cardio-respiratory complications).
• gently pack resection cavity with wet cotton balls → blood oozing stops after few minutes.
• need for permanent shunt is determined by response to EVD clamping.

N.B. all patients must be screened for pheochromocytomas preop (may cause perioperative hypertensive crisis induced by anesthetic or analgesic agents) - 24-hour urine free cortisol or plasma concentrations of metanephrine and normetanephrine → CT; if evaluation reveals pheochromocytoma → resect pheo first (if resection is prohibitive, preoperative α-blockade with β-blockade begun only after α-blockade to avoid unopposed α-activity)

THIRD VENTRICLE

Pending read:
Approaches to the Third Ventricle - Interhemispheric Transcallosal
A. Transcortical approach - facilitated by ventriculomegaly
B. Transcallosal (interhemispheric) approach - equally effective in reaching foramen of Monro with large or small ventricles
C. Transforaminal approach
D. Transchoroidal approach
E. Interforniceal approach
experts say that it is OK to divide massa intermedia.

**ENDOSCOPIC TRANSVENTRICULAR RESECTION OF 3rd VENTRICLE COLLOID CYST**

Pending
Jandial, procedure 47

**TRANSFORAMINAL RESECTION OF 3rd VENTRICLE COLLOID CYST**

- lesions in the anterior portion of the third ventricle are often easily accessible through the foramen of Monro and sometimes even expand and protrude through the foramen.
- for lesions that are soft or cystic, it is often appropriate to resect and deliver the lesion through the foramen of Monro.
- lesions with significant mass effect sometimes already have caused dilation of the foramen, facilitating the surgical approach; foraminal patency can be assessed with the use of forceps or with probing with a Silastic shunt tube.
Surgical approaches:
Also see above for principles

Etiologies

- Masses
- Postoperative

Midline division of the fornix or the choroid plexus
- Lateral ventricles, endolymph
- Lateral ventricles (involving septum pellucidum)
- Lateral ventricle (more common in children)
- Trigone of lateral ventricle
- Foramen of Monro / 3
- Foramen of Monro

Operative technique

Also see above for principles >>

Surgical approaches.
TEMPORAL LOBE

- incisions provide access to temporal horn (least likely site for mass lesion).
- temporal approaches provide early access to anterior choroidal artery but poor visualization of posterior choroidal vessels (until lesion is almost completely resected).
- if mastoid air cells are entered → close with generous use of bone wax.
- normally temporal horn is approximately 3.5 cm from temporal tip.

Safest temporal corticotomy is ANTERIOR INFERIOR TEMPORAL GYRUS (middle temporal gyrus might be OK on nondominant side)

Access to temporal horn:
A. Temporoparietal junction:
   1) traverse angular gyrus → dyslexia, agraphia, acalculia, idiomotor apraxia in dominant hemisphere (in nondominant hemisphere - impaired visual memory, construction deficits, neglect).
   2) cross optic radiations → visual field deficit
B. Middle temporal gyrus – high-risk of damage to speech cortex in dominant hemisphere (H: cortical stimulation); in nondominant hemisphere it is acceptable route!
C. Transtemporal horn occipitotemporal gyrus (originally developed for resection of hippocampus in treatment of intractable seizures) - provides exposure to temporal horn and atrium
   • may result in superior quadrant field deficit.

PARIETAL LOBE

- incisions contraindicated in dominant hemisphere (→ speech deficits).
- vascular supply is away from surgeon’s line of vision.

Access to parietal:
A. Transtemporal horn occipitotemporal gyrus – see above
B. Occipital lobe incision / lobectomy – see below
C. Transtoscalloal approach – see below
D. Superior parietal lobule incision (first choice approach per Dr. Graham) - most commonly used approach; avoid significant retraction → risk of acalculia and apraxia (dominant hemisphere), visual-spatial processing problems, homonymous hemianopia and hemiparesis.
   • incision should be sufficiently large to permit use of 2-cm retractor blade without tension.
   • when ventricle is opened, retraction should be minimized on lateral white matter by gently elevating brain rather than pushing it out of way.
BRAIN TUMOR SURGERY

OCCIPITAL LOBE
Occipital lobectomy can provide access to entire ipsilateral ventricle.
- causes permanent loss of homonymous visual field (may be acceptable, if present preoperatively).
- does not permit early access to choroidal vessels – prepare for considerable blood loss.

FRONTAL LOBE
Access to anterior ventricle:
A. Transcallosal approach - see below
B. Middle frontal gyrus incisions.
- particularly helpful for tumors with broad ependymal attachment in frontal horn.
- incision in middle frontal gyrus at level of coronal suture (3-5 cm from midline, 1 cm anterior to coronal suture) – direct approach to frontal horn and foramen of Monro.
- significant speech problems may occur even when Broca's area is undisturbed.
- incisions in either hemisphere can result in attention deficits.

CORPUS CALLOSUM (TRANSCALLOSAL INTERHEMISHERIC APPROACH)
Used literature: R. Jandial “Core Techniques in Operative Neurosurgery” (2011), procedure 8
Pending:
Lab Demo - Transcallosal Approach to Lateral & Third Ventricle >>

INDICATIONS
1. Third ventricular tumors
2. Lateral ventricular tumors – relatively safe access to all areas except temporal horn and posterior occipital horn H: transcortical approach.

PROCEDURE
- brain relaxation is particularly important.
  - mannitol
  - gravity can be used to surgeon's advantage - patient in lateral decubitus position with involved hemisphere dependent - falx acts as retractor to hold contralateral hemisphere while involved hemisphere is gently retracted – greater risk of midline disorientation; other experts (Dr. Graham) prefer straight supine position (neck flexed 45 degrees) – easiest for orientation but it is difficult to work with both hands (instruments above each other).
- long and narrow craniotomy (to parallel interhemispheric corridor).
- arachnoid adhesions can be dense near ACAs – risk of pericallosal arteries damage!
- slight change in angle can result in opening wrong lateral ventricle (H: identify septum pellucidum and redirect surgical angle).
- superior portion of mass should be delivered into surgeon's line of view rather than retracting hemisphere to expose it.
- most difficult area to see – inferior lateral corner (roof of basal ganglia, thalamus).
- use microscope and Greenberg/Budde with 3/8 retractor blades.
  - access to corpus callosum requires preservation of medial (bridging) draining veins (but still provide space for 3-cm retractor blade) - look at preop imaging (MRV/CTV up to formal catheter angiography) for large vessels that may preclude entry.
  - “Dr. Graham’s area” – from 3-5 cm anterior to coronal suture to just (max 2 cm) behind it.
  - paucity of bridging veins – best area for craniotomy.
  - most often there are 2-3 large veins that serve medial hemisphere, but there is no clear rule on which may be sacrificed (smallest anterior vein usually can be coagulated and transected if necessary).
  - dissect veins from their pial attachment to reduce tension.
  - near coronal suture there are no bridging veins!
  - open along nondominant (usually right) side.
- use navigation to limit extent of callosotomy just over tumor
- dissect and retract ACA (pericallosal arteries – place cotton balls to keep those arteries retracted from each other)
- corpus callosum can be identified easily because of its very bright glistening and relatively hypovascular aspect

N.B. with ventricular masses, there may be midline distortion of corpus callosum (review preoperative imaging).

- callosotomy is done with suction tip; limit AP extent (usually 1-2 cm is enough) – rather go side-to-side (opening corridor by taking already sectioned fibers)
- retractor is gradually (to let ventricles accommodate*) advanced to expose the lateral ventricular anatomy.
- to prevent venous infarction secondary to overretraction, limit retraction to < 2 cm along any part of the corridor; pauses of 2 to 3 minutes should be observed after every advancement of the retractor blade down the interhemispheric fissure (pause allows for the ventricular pressures to equilibrate in the face of forces exerted by the retractor itself).

Complications

- disconnection of hemispheres, esp. in patients with anomalous cortical organization (H. Wada test prior to transcallosal surgery):
  - mutism, akinesia, aphasia, unilateral weakness (leg > arm), forced grasping, fixed gaze, disinhibition, incontinence, right-left confusion
  - sectioning of splenium in patients with dominant hemisphere homonymous hemianopia will cause alexia and visual agnosia
- transcallosal surgery in left-handed, left-hemisphere speech-dominant and right-handed and right-hemisphere speech-dominant patients can cause agraphia and speech impairment.
- transcallosal surgery in left-hemisphere speech-dominant patients with right-hemisphere memory only or right-hemisphere speech-dominant patients with left-hemisphere memory only could result in memory disorder.
- certain early childhood injuries can cause reorganization of cerebral function such that interhemispheric communication becomes critical (both hemispheres contribute to speech or unilateral motor function); callosal disconnection → altered speech and motor function.

Crossed dominance, wherein the hemisphere controlling the dominant hand is contralateral to the hemisphere controlling speech and language, is a contraindication. Crossed dominance can arise after cerebral injury during childhood that resulted in cortical functional reorganization. These patients may develop writing and speech deficits postoperatively. Special consideration should be given to cases in which a more posterior callosotomy (splenium) is required, increasing the risks of cognitive dysfunction (e.g., alexia), particularly in patients with established preoperative visual field cuts (e.g., homonymous hemianopsia).
An acute syndrome of decreased speech spontaneity, ranging from mild slowness of speech initiation to frank mutism, with onset in the hours and days after surgery and possibly persisting for several months, has been described after transcallosal injury. Although longer callosal incisions (2 to 3 cm compared with 0.8 to 2 cm) may be associated with this syndrome, other manifestations of this acute syndrome, including lower extremity paresis, incontinence, emotional disturbance, and seizures, suggest that additional neural structures are likely involved. Mutism may also be caused either by direct retraction of the anterior cingulate gyrus, septum pellucidum, and fornix or by circulatory disturbances of the supplementary motor area, thalamus, and basal ganglia. Disorders of interhemispheric transfer of information, which can include visuospatial and tactile information and bimanual motor learning, are another potential complication.

- leg motor cortex injury – venous infarction or retraction injury.
- short term memory deficits – from fornix manipulation.

**COMBINED APPROACHES (TRANSCALLOSAL + TRANSCORTICAL)**

a) for masses that are too large to remove through single approach.

b) when hemisphere is distended by tumor (rather than by CSF) aka transcallosal incision and partial decompression to obtain sufficient relaxation → interhemispheric dissection for callosotomy.

c) portions of tumor with broad ependymal attachment along superior portion of frontal horn may not be accessible from interhemispheric approach.

- combined cortical incision and callosotomy can be performed safely in adults.
- transcallosal incision usually goes first → safer interhemispheric dissection with relaxed hemisphere.

**POSTOPERATIVE DEFICITS**

- visual field loss is one of most common focal deficits.
- hemiparesis is frequently observed during immediate postoperative period.
- speech deficits complicate surgery in dominant hemisphere.
- seizures can occur in any patient (29-70% after transcallosal resections; significantly lower after transcortical surgery).
- memory deficits if damaged fornices (e.g. colloid cyst resection).
- subdural hematoma and hygroma are significant problems in patients with preoperative hydrocephalus.
  - avoid excessive CSF drainage via EVD
  - mobilization out of bed should proceed slowly
  - postoperative ventricular enlargement is noted frequently in spite of total tumor resection; 35% patients require shunt
  - enlarged ventricles and normal ICP may present condition analogous to NPH.
  - incomplete resection occurs in 33-50% cases.
  - mortality for surgery on lateral ventricular mass lesion ranges 12-75% (massive brain swelling or intraventricular hemorrhage were most common causes).
  - in one series of meningiomas, all deaths occurred when tumor was removed en bloc.

**ININSULAR TUMORS**

- Berger-Sanai insular glioma classification system - tumor types that may benefit from more aggressive surgery.
Although meningiomas are benign and potentially curable, total removal may be impossible* without unacceptable destruction of normal structures because of location, compression of vital structures, and vascularity leaving some tumor behind is often better than risking neurologic function for sake of complete removal.

**PREOPERATIVE**

- **prospective endovascular embolization** of vascular feeders from external circulation is beneficial in extremely vascular meningiomas → resection 0-96 hrs after embolization (to decrease likelihood of tumor revascularization).
  - embolization facilitates surgery by reducing blood loss (esp. when blood supply is on other side of tumor vis-a-vis surgeon’s line of sight)
  - embolization may help to achieve gross-total resection of both skull base and large supratentorial meningiomas
  - embolization is performed using polyvinyl alcohol microspheres (PVA) 150-300 μm; smaller particles (Gelfiasm powder) or liquid agents (Onyx, phenytoin, Lipiodol) may provide deeper tumor penetration but increased risk of side effects; other agents: porous cellulose beads, hydroxyapatite, trisacryl gelatin (TAG) microspheres – increasing interest in intraoperative direct needle puncture intratumoral embolization
- corticosteroids (preoperatively and postoperatively) significantly decrease mortality & morbidity.
- antiepileptics are started preoperatively in supratentorial surgery and continued postoperatively for no less than 3 months.
- **Corticosteroids**
  - preoperative endovascular embolization of vascular feeders from external circulation is beneficial in extremely vascular meningiomas → resection 0-96 hrs after embolization (to decrease likelihood of tumor revascularization).
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  - corticosteroids (preoperatively and postoperatively) significantly decrease mortality & morbidity.
  - antiepileptics are started preoperatively in supratentorial surgery and continued postoperatively for no less than 3 months.

**PRINCIPLES IN MENINGIOMA RESECTION**

- tumor removing technique – using bipolar / Penfield #1, disconnect tumor at base from dura (disconnects blood supply).
- always start by coagulating arterial feeders to meningioma.
- if preop MRI shows no or little adjacent brain edema – expect no or minimal leptomeningeal feeders (easy development of tumor-brain plane).
- involved dura as well as dural rim free from tumor should be resected (= duraplasty*); dural tails (apparent on MRI) are best removed.
- *from best to worst results: pericranium > fascia lata > commercial dural substitutes.
- if meningioma cannot be removed completely → try (if safe) detaching tumor from its dural origin and therefore from its predominant blood supply; then may also cauterize dural surface.

<table>
<thead>
<tr>
<th>Table 21-25: Simpson grading system for removal of meningiomas&lt;br&gt;&lt;br&gt;<strong>Grade</strong></th>
<th><strong>Degree of resection</strong></th>
<th><strong>Recurrence rate</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>macroscopically complete removal with excision of dural attachment and abnormal bone (including suture line when involved)</td>
<td>9%</td>
</tr>
<tr>
<td>II</td>
<td>macroscopically complete with enucleation of craniotomy defect</td>
<td>19%</td>
</tr>
<tr>
<td>III</td>
<td>macroscopically complete without enucleation of craniotomy defect or resection of dural attachment or of its extradural extensions (e.g. hypertrophic bone)</td>
<td>29%</td>
</tr>
<tr>
<td>IV</td>
<td>partial removal leaving tumor in situ</td>
<td>40%</td>
</tr>
<tr>
<td>V</td>
<td>simple decompression (e.g. biopsy)</td>
<td>NA</td>
</tr>
</tbody>
</table>

D. Simpson 1957

Likelihood of Total Excision (MGH, n=225)

<table>
<thead>
<tr>
<th>Tumor Location</th>
<th>n</th>
<th>% Total Excisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal</td>
<td>25</td>
<td>96.4%</td>
</tr>
<tr>
<td>Olfactory Groove</td>
<td>19</td>
<td>78.6%</td>
</tr>
<tr>
<td>Periocular Areas/Fish</td>
<td>22</td>
<td>77.3%</td>
</tr>
<tr>
<td>Parasellar Regions</td>
<td>20</td>
<td>57.1%</td>
</tr>
<tr>
<td>Pretectal Fossa</td>
<td>31</td>
<td>32%</td>
</tr>
<tr>
<td>Sphenoid Ridge</td>
<td>27</td>
<td>28%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>225</td>
<td>64.4%</td>
</tr>
</tbody>
</table>

**MENINGIOMA INVOLVING BONE**

- all involved / hyperostotic bone should be removed
  - 5-ALA has sensitivity of 89.06% and specificity of 100% in detecting bone invasion, while positive and negative predictive values are 100% and 82.93%.

20 mg/kg of 5-ALA orally 2-4 hours before surgery

- 5-ALA has sensitivity of 89.06% and specificity of 100% in detecting bone invasion, while positive and negative predictive values are 100% and 82.93%.

— sometimes surgery is done cosmetically just for involved bone, then replace bone flap with prosthetic cosmetically-acceptable flap. historically, attempts were to boil bone flap in OR while removing meningioma (autoclaving is worse – destroys cells and bone matrix)

- remove bone flap \(\rightarrow\) intraoperative bone flap irradiation (e.g. 100 Gy)
- if there is more affected bone – drill it off with diamond drill bit (useful to have CT loaded for navigation).
- only after bone work is finished, open dura to remove tumor (most likely will be able to excise with whole dural base which needs to be repaired with Dura-Guard)

**VERY LARGE MENINGIOMA**

- consider preoperative embolization (space closely with resective surgery as tumor recruits new vessels very fast, plus, tumor swells due to necrosis and patient may deteriorate)
- tumor might be invading brain cortex – better to debulk (make cruciate durotomy over tumor center to start debulking) but leave tiny rim of tumor on cortex \(\rightarrow\) postop radiation (it will take long time until tumor grows back to fill original volume again).

**ANTERIOR SKULL BASE MENINGIOMAS**

A. Endoscopic (transnasal) approach – early tumor devascularization, no retraction on brain [e.g. already pre-existing significant frontal edema], risk for anosmia (olfactory groove tumors, but not for more posterior tumors), leaves high-flow CSF leak (nasoseptal flap is a must).

B. Craniotomy

Anterior \(\rightarrow\) posterior
1. Olfactory groove tumors
2. Planum sphenoidale tumors
3. Tuberculum sellae tumors

---

**OLFACTORY GROOVE MENINGIOMA**

A. Transnasal endoscopic approach – for small tumors located between mid-orbital planes, tumors with significant intranasal extension, anosmia present. See p. Op300

B. Craniotomy (for large tumors with lateral extensions, neurovascular encasement, preserved olfaction)

a) (Unilateral*) Subfrontal craniotomy \(\pm\) orbital osteotomy
b) Frontal interhemispheric approach (ligating anterior portion of superior sagittal sinus)

*unilateral approach is usually sufficient

N.B. craniotomy is better – preserves smell (transnasal approach \(\sim\) 100% postop anosmia, vs. craniotomy \(\sim\) 50%)
2) branches from middle meningeal artery
3) carotid arteries.

- to avoid undue retraction of frontal lobes, these tumors are best approached through low frontal craniotomy entering frontal sinus (up to removing supraorbital rim).
  - Dr. Graham likes for large tumors opening dura higher (than for subfrontal approach) and using interhemispheric approach.
- to allow adequate visualization, falx should be completely sectioned after 2-0 silk suture ligating most anterior aspect of SSS.
  - do not use ligating suture for falx retraction
  - no need to reattach falx at the end of surgery
- attempt to preserve at least one of olfactory nerves.
  - olfactory bulbs and tracts are often displaced laterally by tumor and may be preserved!
- these tumors often invade ethmoid sinuses and, at times, sphenoid sinus.
- care should be taken to identify and preserve both optic nerves. Note that usual relationship between optic nerves and carotid arteries might not hold true owing to displacement of these vital structures by tumor.

**PLANUM SPHENOIDALE MENINGIOMA**

- preoperative imaging of clinoid region meningiomas can accurately predict the presence or absence of tumor involvement of the clinoid in only 75% of cases. In light of the fact that a quarter of patients with radiographically negative clinoids will have tumor present on pathological analysis, recommend clinoidectomy for all clinoid region meningiomas.
Endoscopic approach:

Lateral see-through illustration of a typical meningioma of the tuberculum sellae. The extent of bone removal underlying the typical dural attachment is highlighted in blue. Note the anterior extension along the planum sphenoidale and the inferior extension into the sella turcica. Inset: Suprolateral view demonstrating the typical planum attachment, optical canal invasion, and displacement of the optic apparatus and surrounding vasculature.
CONVEXITY MENINGIOMA

- although large tumor, presents little problem in removal.
- large bone flap is made around tumor, dural incision circumscribes tumor, and dura attached to tumor is used to retract tumor from brain as microdissection frees adhesions between tumor and surrounding brain.

- in dealing with convexity tumor invading dura and cranium, elevation of bone flap in usual manner may damage underlying brain. One plan is to form free flap of bone immediately adjacent to tumor, separated from larger second flap that encompasses entire area. The second flap may be elevated to expose dura surrounding tumor and invaded dura and bone. The tumor may be separated from brain by careful dissection of arachnoid and separation of tumor from brain, preferably using magnification.\(^1\) The brain should be protected by cottonoid or Telfa strips.
- Invaded bone may be discarded. If invasion involves inner table only, this may be removed by burning. If removal is more extensive, bone flap may be autoclaved and replaced. A defect left by discarded flap may be corrected by prosthesis at same, or at later, operation.
- opening scalp and skull may be bloody because of hypertrophy of blood vessels originating from external circulation.
- dural blood vessels should be coagulated before opening dura to decrease tumor vascularity.
- usually tumor is separated from underlying brain parenchyma by arachnoid layer. This layer may not be complete at depth of tumor. In this location, separating tumor from brain may be difficult.
- unless tumor is small and can be removed in 1 piece, best strategy for excising convexity meningiomas is to find arachnoidal plane and dissect it gently.
- placing patties circumferentially around tumor allows quick identification of this crucial plane at later time.
- coagulate surface of tumor, then core it and invaginate outer layer to allow further circumferential dissection.
PARASAGITTAL / PARAFALCINE MENINGIOMA

- foremost consideration in surgically treating parasagittal meningiomas is to decide what to do with SSS (MRV is not yet sensitive enough to confirm unequivocally complete occlusion of SSS). Diagnostic test of choice is still endovascular angiography with late venous images to look for possible delayed filling of involved portion of SSS.
  - a) If SSS is completely obliterated by tumor, it can be ligated safely and excised. The surgeon should be careful not to injure veins that run anteriorly and posteriorly to tumor. These veins may provide crucial collateral circulation for venous drainage of cerebrum and should be preserved at all costs.
  - b) If SSS is only partially involved, decision of whether to sacrifice it depends on involved segment.
- anterior third of SSS (i.e. anterior to central (rolandic) veins) can usually be sacrificed with impunity; middle third, sacrificed at times; and posterior third, never ligated. In this author's experience, SSS is never sacrificed beyond anterior third.
- some surgeons resect partially involved sinuses and reconstruct it later (either with vein or prostatic graft).
- author's opinion is that explaining to patient that some tumor was left behind that may need further resection at later date is better than taking undue risk of neurological deficit by obliterating more of SSS.

dependence, SSS is never sacrificed beyond anterior third. In this author's experience, SSS is never sacrificed beyond anterior third.

Sindou classification - stages of tumor invasion and the level of blood flow restriction within the SSS:
- type I: lesion attached to the outer surface of the sinus wall
- type II: tumor fragment inside the lateral recess
- type III: invasion of the ipsilateral wall
- type IV: invasion of the contralateral wall and roof
- type V: complete sinus occlusion with one wall free from invasion
- type VI: complete sinus occlusion with no wall free from invasion

Chinese classification (Tongshen Yin et al., Neurosurgery 2020)

- type I - tumor originates from the lateral angle of SSS wall (parasagittal meningiomas, PSM) – sinus displaced and/or constricted
  - type Ia: tumor involves only the lateral recess or the outer surface of sinus wall
  - type Ib: tumor invades 1 to 2 inner walls with or without sinus displacement or constriction
  - type Ic: complete sinus occlusion with or without 1 wall free

- type II - tumor originates inside the SSS (sagittal sinus meningiomas, SSM) – sinus enlargement extending bilaterally
  - type IIa: tumor involves the lateral recess or ipsilateral medial surface of sinus wall
  - type IIb: tumor involves 2 medial walls surfaces with sinus enlargement bilaterally
  - type IIc: tumor involves all medial surfaces of the sinus walls and the sinus is completely occluded, with or without tumor invasion to subdural cavity

SPHENOID WING MENINGIOMA

- sphenoid-wing meningiomas present either as en plaque meningiomas or as globular masses.
- sphenoid ridge meningiomas vary in approach, depending on whether they occupy outer, middle, or inner third of sphenoid bone.
  1) outer-third tumors can be problem purely of tumor mass, purely of massive temporal hyperostosis from en plaque tumor invading bone, or combination of both. When it is present, tumor mass insinuates itself in sylvian tissue, and its removal through frontotemporal approach is through frontotemporal craniotomy with base of tumor approached first to eliminate blood supply. Surgical cure is likely.
  2) middle-third tumors grow through both frontal and temporal fossae in globular fashion. The approach is through frontotemporal craniotomy, with base of tumor approached first to eliminate blood supply. Surgical cure is likely.
  3) inner-third tumors arise from anterior clinoid process and compress optic nerve and enucleate carotid and middle cerebral arteries. In addition, medial sphenoidal meningiomas can grow diffusely into cavernous sinus and optic canal. Only in those situations where tumor is early because of optic nerve compression is total removal even feasible. Most commonly, complete resection is not possible, and surgeon stops when risk of surgery exceeds potential benefits.
- need pretrional to fronto-temporo-zygomatic craniotomy – see p. Op300
- removing zygoma and orbital rim allows wider exposure of sphenoid wing, middle cranial fossa, anterior cranial fossa, and anterior clinoid.
- expose temporal floor and sphenoid wing.
- drift off bone to reduce risk of recurrence.
- tumor capsule incision at where tumor comes to surface – debulk – dissect away from vessels.
- careful when bipolarizing dura on temporal floor – trigeminal ganglion underneath (sensory loss).
issue of meningiomas involving cavernous sinus is currently area of intense interest in neurosurgery. No one doubts that, in experienced hands, such meningiomas can be treated successfully. 

— debate centers on 2 points: when to operate and how aggressive resection should be. The following opinion is personal reflection on matter, and diverging views may be found in literature.

— Asymptomatic cavernous sinus meningiomas should not be operated but should be monitored carefully by means of repeated physical examination and serial MRI.

— Symptomatic meningiomas in otherwise healthy patients should be resected by neurosurgeons who are trained for such procedures.

— avoid injuring cranial nerves or carotid artery. This author does not believe in benefit of bypassing and resecting cavernous carotid artery in these cases.

— surgeon should remember that multitude of processes may affect cavernous sinus and mimic meningioma, including sarcoidosis and infection/inflammation that lead to Tolosa-Hunt syndrome.

PETROUS APEX MENINGIOMA

CEREBELLOPONTINE ANGLE MENINGIOMAS

— in acoustic neuromas, facial nerve usually lies anterosuperiorly to tumor and is encountered late in surgery. This relationship is lost in cerebellopontine angle meningiomas, because facial nerve may lie along posterior tumor edge and can be injured early in surgery (unless care is taken to identify it).

— before attempting to remove tumor, surgeon should first diminish its blood supply by coagulating its supplying arteries from dura. To do so, interface of tumor and petrous bone should be followed. A partial cerebellar resection may be necessary to avoid undue retraction of brain.

— SRS is good alternative or adjuvant to surgery.

CLIVAL AND PETROCLIVAL MENINGIOMAS

— although partial resection is relatively straightforward, complete resection remains daunting task.

— partial resection usually does not translate into any benefit for patient and only renders further surgeries more difficult; therefore, every attempt should be made to complete resection. If surgery has to be interrupted for logistical reasons, second operation should be scheduled earliest possible opportunity.

— multitude of approaches has been devised for these tumors.

— traditional approaches such as suboccipital or retrosigmoid are usually insufficient to allow complete removal.

— more extensive approaches, such as petrosal (Kawase) approach, are needed. This approach consists of combined supratentorial and infratentorial craniotomies, associated with simple mastoidectomy down to solid angle (i.e. bone encasing inner ear). After tentorium is split, petroclival meningioma can be visualized in its entirety.

TENTORIAL AND TORcular MENINGIOMAS

— tentorial meningiomas may be supplied by multitude of vessels that arise from tentorial leaf. These should be coagulated thoroughly before one attempts to remove tumor.

— major supply may be Bernasconi-Cassinari artery, which arises from cavernous portion of carotid artery and runs posteriorly to supply tentorium.

— this artery is usually not apparent on normal angiograms but may be conspicuous in angiograms of tentorial meningiomas.

— definite attempt should be made at recognizing Bernasconi-Cassinari artery during surgery and coagulating it to decrease tumor vascularity.

— tentorial meningiomas often grow in both infratentorial and supratentorial compartments and should be approached accordingly.

— studying preoperative angiogram is imperative in cases of torcular meningiomas to delineate patency of different sinuses and available collateral circulation. Removing these tumors completely is often impossible because of partial involvement of venous sinuses.

— adequate demonstrable patency of opposite lateral or sigmoid sinus may permit resection of involved sinus. The size of sinus, however, at times may permit reconstruction of sinus after removal of one wall from which tumor extends into lumen.

— anterolateral (AL) incisural meningiomas - middle third of the tentorial free margin: ptorial, subtemporal, and retrosigmoid approaches.

— posteromedial (PM) incisural meningiomas - posterior third of the tentorial free margin: occipital or supracerebellar infratentorial approaches.