Brain Tumor Surgery

Last updated: January 16, 2021

CRANIOTOMY DETAILS – see p. Op300 >>
VESTIBULAR SCHWANNOMA – see p. Onc62 >>
LASER (LITT) – see p. Op345 >>; also see individual tumors

PREOP

Detailed preop **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). see p. Onc1 >>
- 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 *ACOUSTIC 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 cytoreductive resection); how it can be improved:

1. **fMRI** for ***cortical*** mapping (BOLD - shows increased venous drainage [not electrical activity of neurons] from active cortex).
2. **DTI (tractography)** for ***subcortical*** structures - to see not if tract is involved (usually that can tell clinically) but where eloquent tract is displaced by tumor (so will see how safely approach tumor).
3. **Awake craniotomy**.

N.B. if tumor seems to involve eloquent areas but patient becomes asymptomatic on steroids – means symptoms were coming from edema and tumor is not invading – likely resectable!

INTRA-AXIAL 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.
  - nonglial tumors generally grow by expansion.
- debulking even of malignant gliomas has some benefit (cytoreduction).
  N.B. brain stem tumors are not amenable to surgical therapy (even biopsy is hazardous!)
- solitary brain metastasis is indication for surgical resection (depending on systemic medical status). see p. Onc32 >>
- avoid ***radical**** operations on tumors involving: language areas, sensorimotor regions, basal ganglia, corpus callosum, brain stem.
  **partial* removal may be surprisingly effective (if resection is confined to tumor itself, it rarely produces major new neurologic deficits)
- *functional imaging* (fMRI, DTI tractography) facilitates surgery by showing that tumor has pushed aside critical brain structures.

EXTRA-AXIAL 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** (P_{CO2} 25-30 mmHg) for definitive ICP reduction in preparation for brain retraction; administration time varies – some experts give only at the beginning of "bone work", others give at the time of prep start (Dr. Broaddus "It takes 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 *BROMODEOXYURIDINE* 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:

a) **deep sulci** (vs. gyral crown) avoiding eloquent areas (e.g. approaching lesion obliquely).
   – cortical incision is ≈ 3 cm in length.
b) **anterior corpus callosum** (causes minimal, if any, deficit).
c) **dilated ventricles** (intraventricular neoplasms).

- localization of subcortical tumors:
  a) intraoperative ultrasonography
  b) frameless MRI-guided navigation (markers on patient's scalp).

Skull base tumors:

Anterior skull base:

a) tumor behind orbit (incl. tumors of gasserian ganglion and cavernous sinus) → **orbitozygomatic approach** (osteotomy through zygoma and orbital roof).
b) tumors in sella turcica → **trans-sphenoid approach**.
c) tumors of upper one third of clivus, lesions of odontoid process → **transoral** or **transpalatal approach** (may be extended by osteotomy of mandible).
d) tumors of paranasal sinuses and upper one third of clivus → **transfacial approach** (to expose mandible for osteotomy, midface can be degloved).

Lateral approaches through temporal bone to middle skull base (e.g. petrosal or presigmoid approach in which petrosal bone is drilled away).

Posterior approaches:

a) **extreme lateral approach** - exposes lower third of clivus, cerebellopontine angle, and petrous surface temporal bone.
b) lesions of cerebellopontine angle → **retromastoid craniotomy**.
c) 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

- ***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 ELOQUENT 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. **Sulcal 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. <u>Use natural corridors</u>:
   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 between these regions.
   2) **sulci** (e.g. BrainPath circular retractor – atraumatic transsulcal approach)
   3) **ventricles** – to operate <u>endoscopically</u> (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)

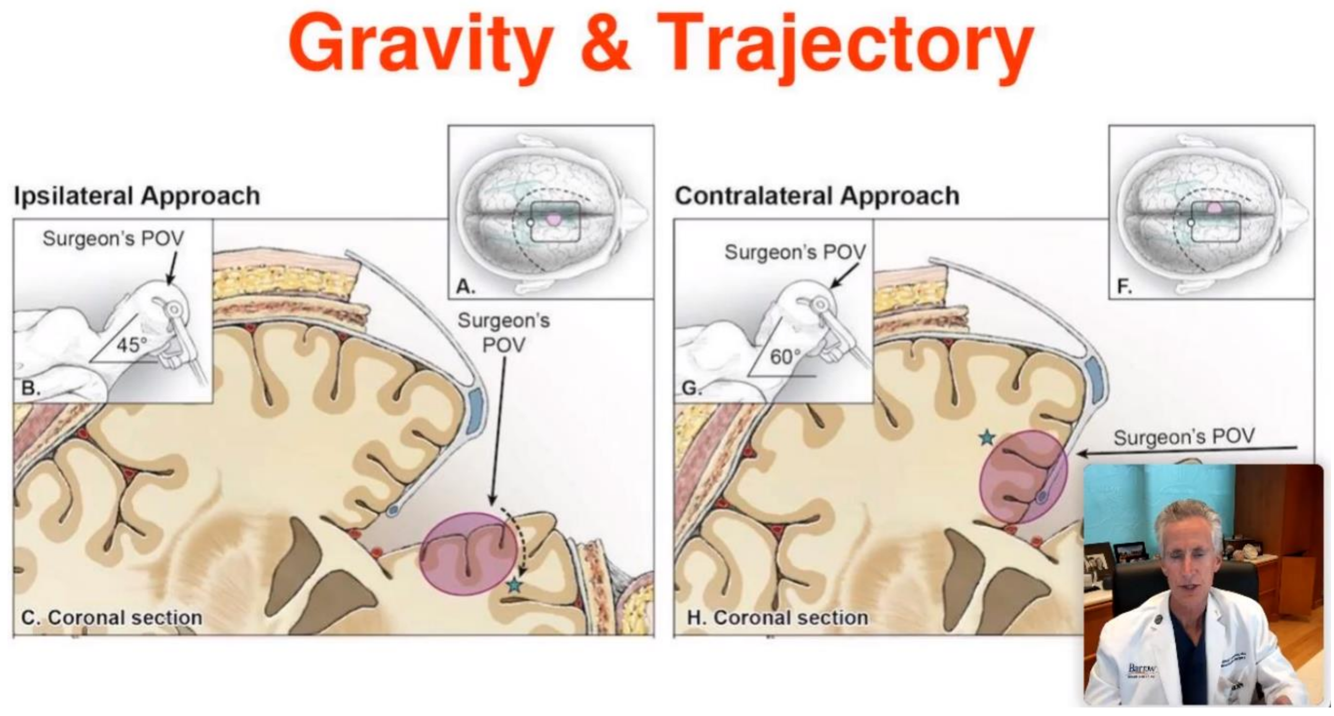
3. **Corticotomy** (most likely at cortex closest to tumor surface) - coagulate with bipolar + cut with microscissors / spread with bipolar prongs (or sucker tip).

- 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. <u>Retractors</u> - 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.
- exsanguination 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, *arterial supply should be interrupted first* (to avoid congestion, bleeding, and swelling).

TUMOR RESECTION

1. **<u>Piecemeal removal</u>** <u>of large masses</u> (bipolar & gentle suction, CUSA): debulking tumor center → dissecting remaining shell from surrounding normal brain tissue by advancing patties / Telfa 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) → copious irrigation (↓risk of postoperative ventricular obstruction and probably postoperative headache).

  *if 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*, *CO_2 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.

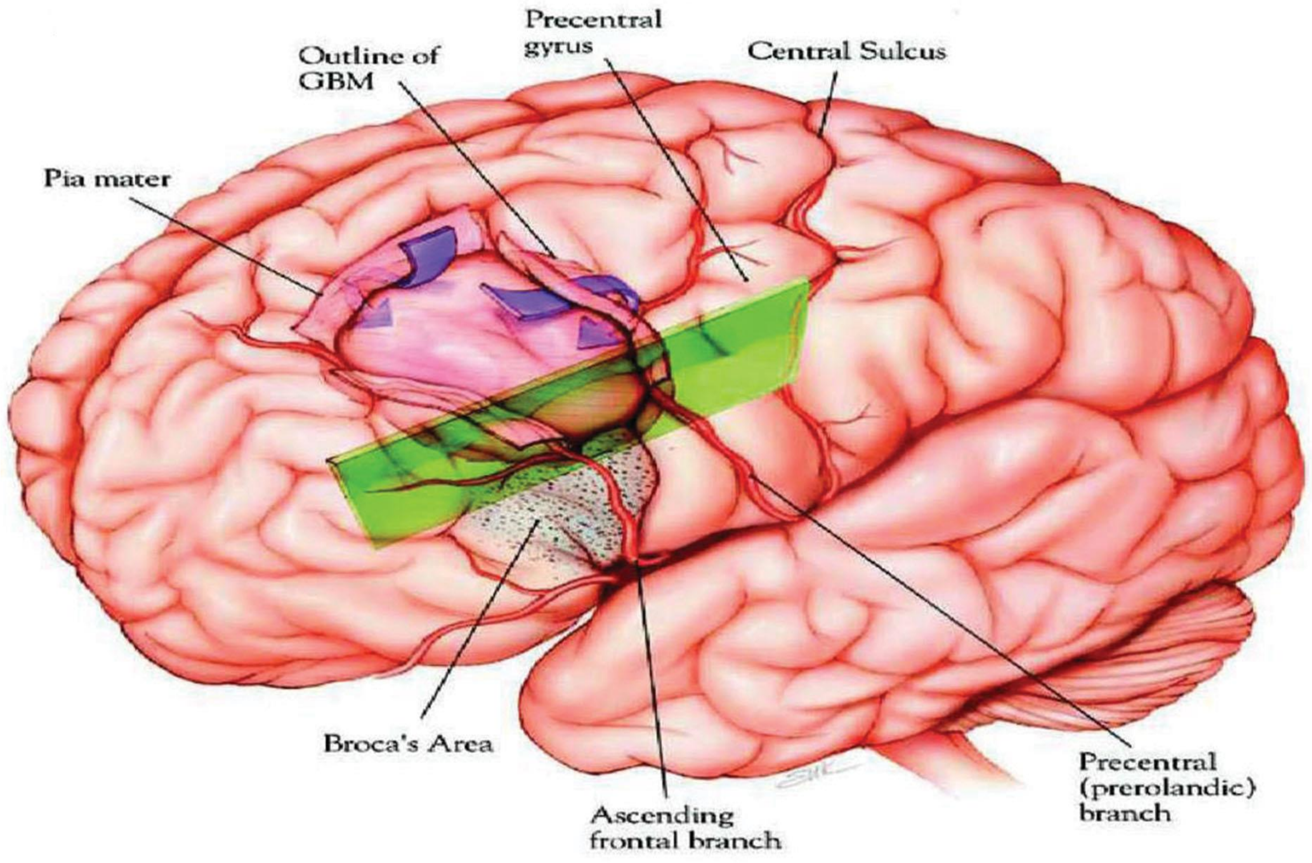
- glistening peritumoral white matter is seen easily through microscope as tumor's margin is reached - at this interface resection is stopped.
- incomplete removal may be preferable when site of attachment invades into deep structures such as thalamus (goal is debulking when mass effect is cause of symptoms).

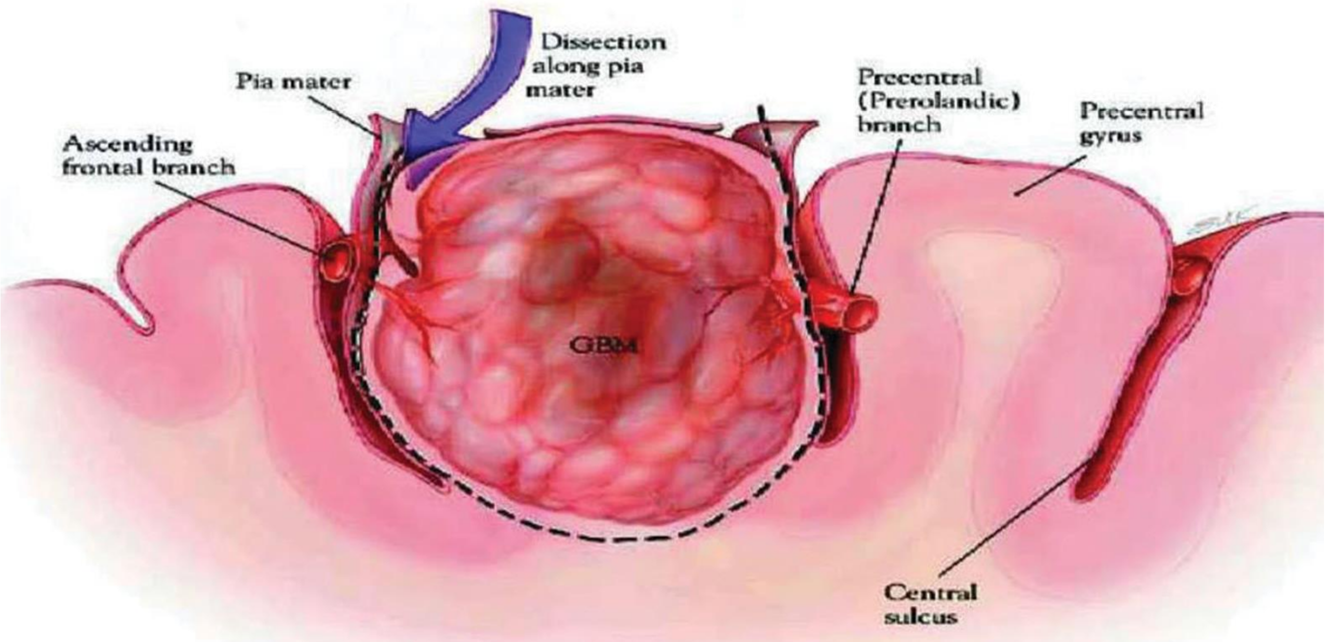
3. **Intralesional (piecemeal) vs. circumferential perilesional (en bloc*) resection**

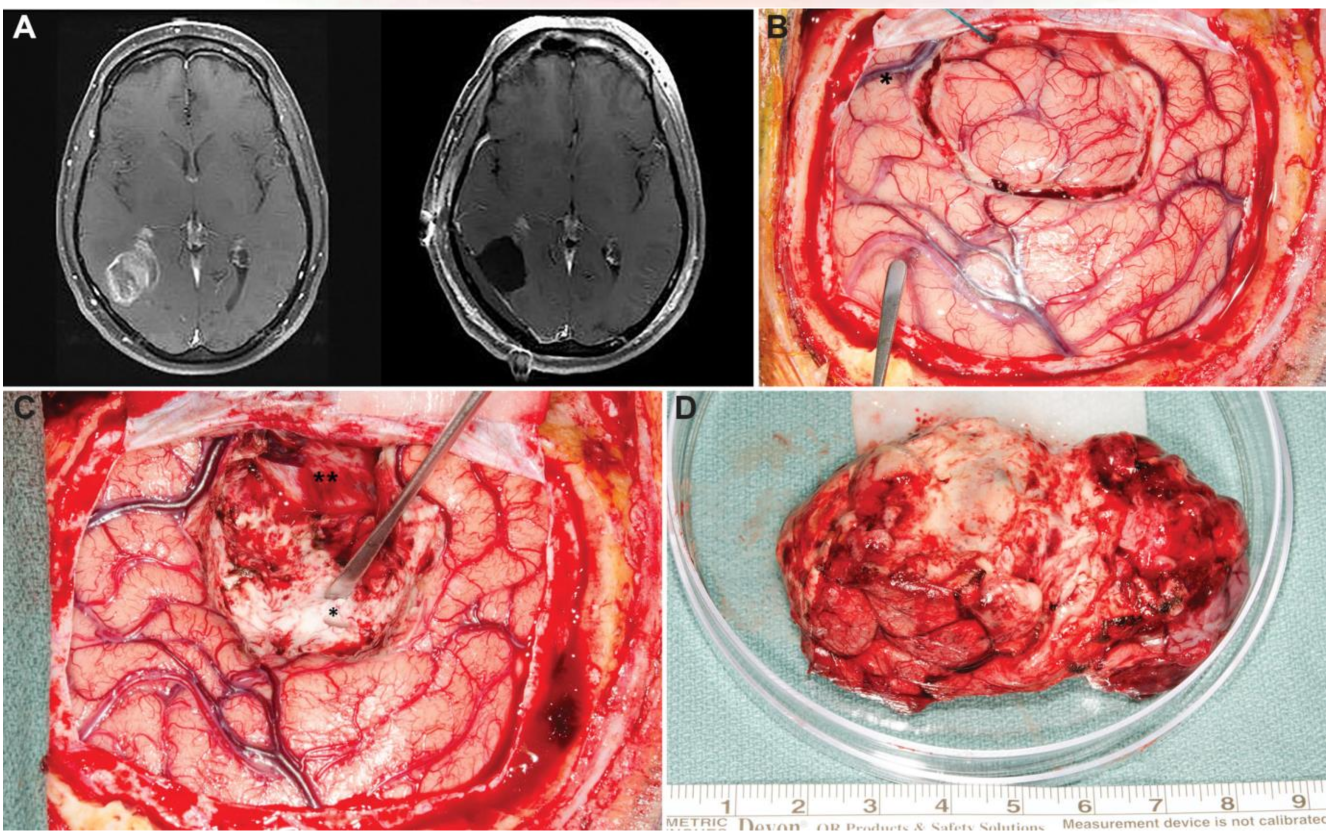
Al-Holou et al. Perilesional Resection of Glioblastoma Is Independently Associated With Improved Outcomes. Neurosurgery 86:112–121, 2020

*GBM is known to be infiltrative, and thus a true en bloc resection is not possible

- intralesional 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 intralesional 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):

  Cancer Dissemination, Hydrocephalus, and Survival After Cerebral Ventricular Entry During High-Grade Glioma Surgery: A Meta-Analysis Akshitkumar M Mistry, MD Patrick D Kelly, MD Reid C Thompson, MD Lola B Chambless, MD Neurosurgery, nyy202, https://doi.org/10.1093/neuros/nyy202 Published: 22 May 2018

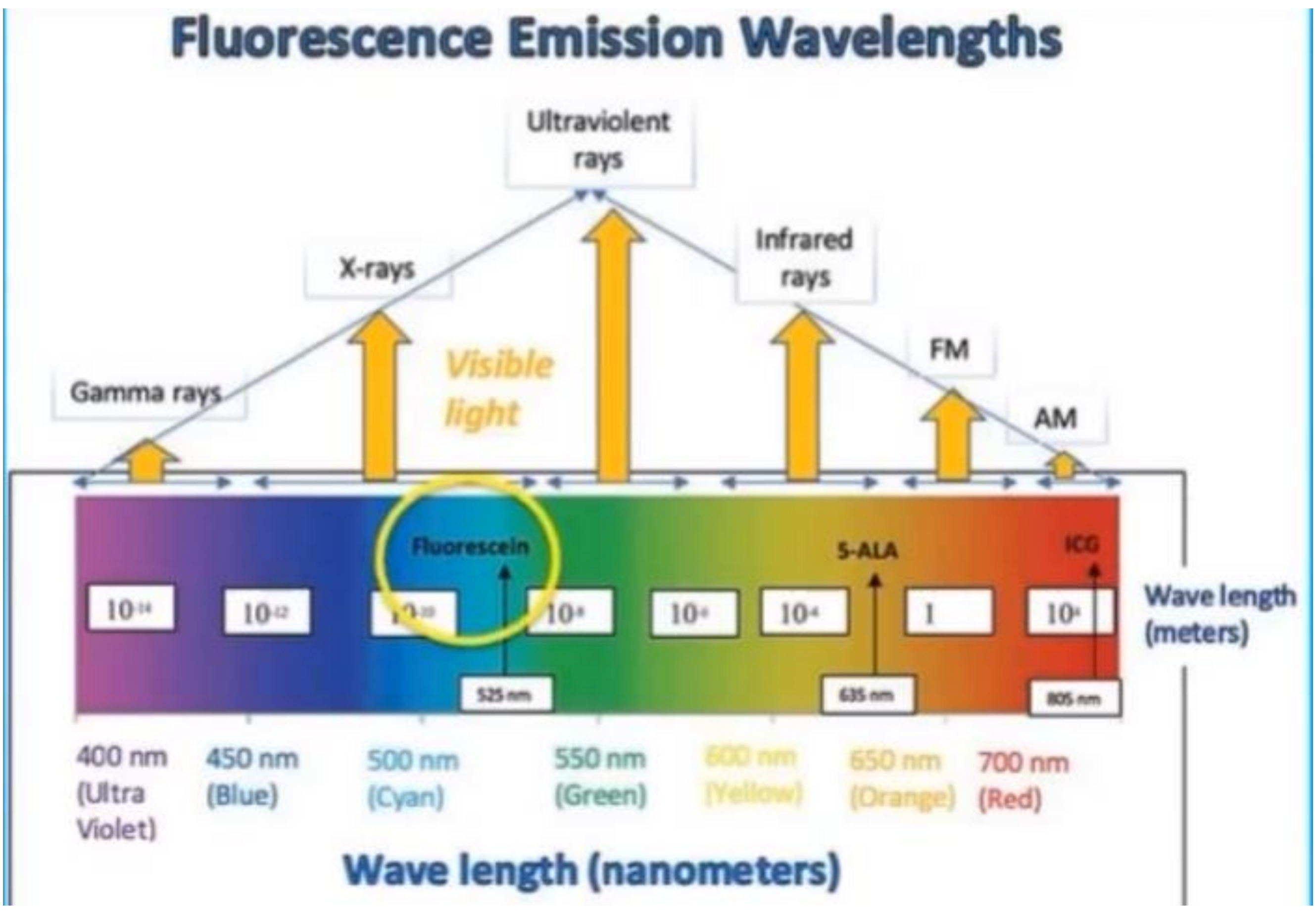
- higher odds of leptomeningeal dissemination (sOR: 3.91 [95% confidence interval (CI): 1.89-8.10]; P = .0002; 86/410 vs 57/847 patients in 9 studies)
- higher odds of hydrocephalus (sOR: 7.78 [95% CI: 3.77-16.05]; P < .00001; 58/431 vs 11/565 patients in 11 studies).
- decreased survival (median survival: 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!



FLUORESCEIN SODIUM

– 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.
- labeling mechanism is based on **BBB leakage** (during surgery BBB gets damaged anyways – false positive labeling).

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 (first drug approved in US based only on European trials).

- 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.
- commercially in US became available in October 2018.
- vial price - $2500.

Indications

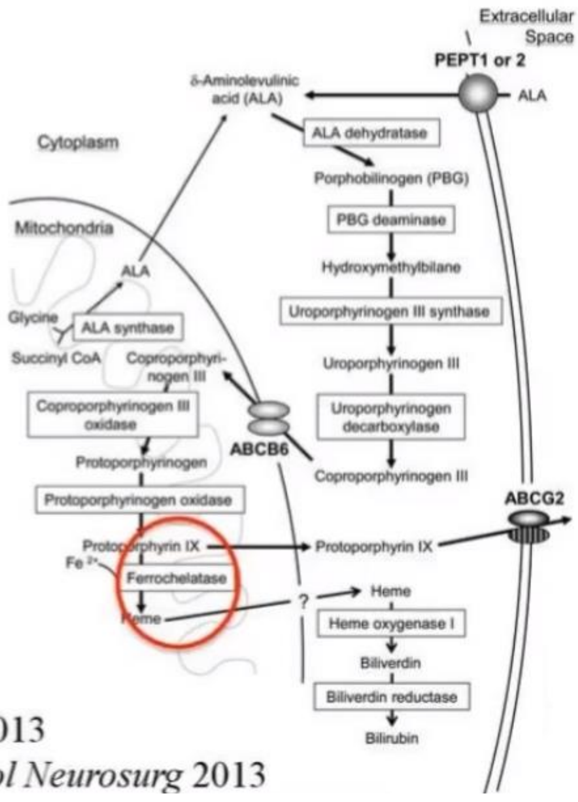
1. **Surgery guidance** for high-grade glioma (in the future may be also used as an agent for photodynamic therapy for remaining glioma cells)
2. High-grade glioma / lymphoma / germ cell tumor **biopsy verification** – if biopsy material fluoresces, no need to wait for frozen pathology confirmation (may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

Accumulaton of PPIX in tumor cells:

- Decreased ferrochelatase activity permitting accumulation of PpIX.
- Increased 5-ALA uptake by tumor cells
- Disturbance in outflow of PpIX
- Presence of aquaporin-4



Zhao SG et al. *Ann Surg Oncol* 2013
Suero Molina EJ et al. *Clin Neurol Neurosurg* 2013

Very high PPV, sensitivity and specificity!

Pivotal Efficacy Studies: Biopsy-Based Diagnostic Measures

Measure	Study 1* (Primary)	Study 2§ (Recurrent)	Study 3† (Primary)
PPV	96.2	96.6	97.8
NPV	24.1	18.8	18.8
Sensitivity	67.7	96.3	70.6
Specificity	79.4	20.0	81.1

*Stummer, et al. *Neurosurgery 2014;* 74:310-320.
§Nabavi, et al. *Neurosurgery 2009;* 65:1070-1077.
†Stummer, et al. *Lancet Oncol. 2006;* 7:392–401.

Summary for fluorescence analysis

	Fluorescence		Total
HGG	Yes	No	
Yes	205	2	207
No	13	5	18
Total	218	7	225

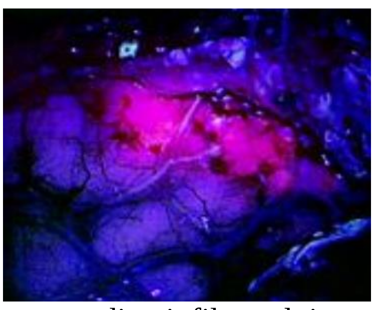
Summary Statistics

HGG Sensitivity	94.04
HGG Specificity	71.43
Positive Predictive Value	**99.03**
Negative Predictive Value	27.78
False Positive Probability	28.57
False Negative Probability	5.96
Accuracy	93.33
Odds Ratio(95% CI)	39.42(6.97,223.04)

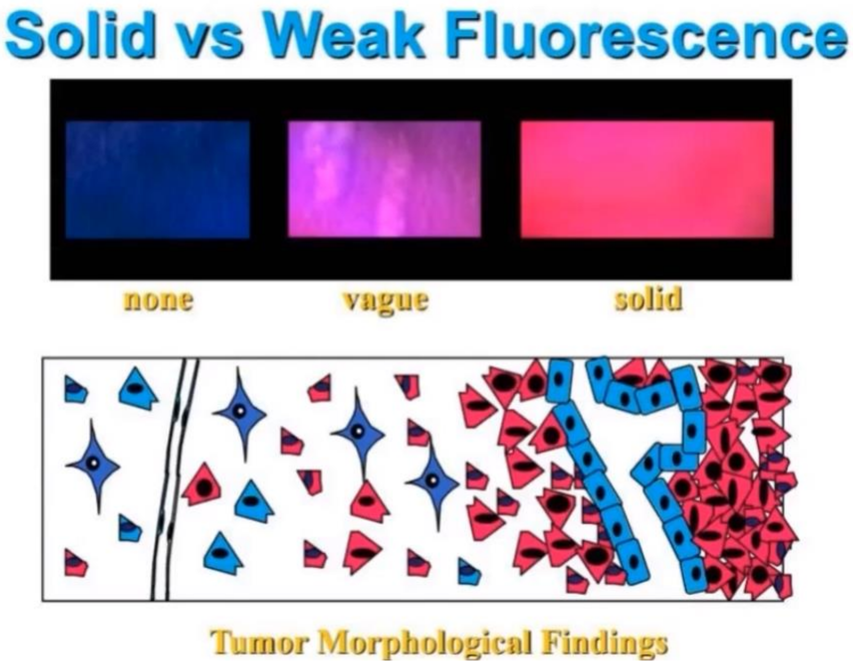
Schupper AJ et al. Manuscript in preparation

Practical

- **indication**: ***high-grade gliomas*** (suspected WHO grades III-IV on preoperative imaging).
- **contraindication**: *porphyrias*.
- 20 mg/kg (1 vial, 2500-2700$ = 1500 mg; patient > 75 kg needs to vials) is taken PO 3 hours (range 2 to 4 hours) prior to induction of anesthesia.
  N.B. there is no data on redosing!
  Must be reconstituted 1500 mg/50 mL of water per vial
- 5-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 is exposed to blue laser light with 405 (375-440) nm peak wavelength (with hand-held 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). operative video >>



– surrounding infiltrated tissue glows orange.
– tissue lacking sufficient PpIX concentrations appears blue.



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 PpIX - 4 hours.
- T½ of PpIX - 3.6 hours.
- the fraction of administered ALA that is metabolized to PpIX 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 nontoxic!
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 tetracyclines.
   — 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
5-ALA fluorescence-assisted surgery vs. conventional surgery

Stummer W et al; ALA-Glioma Study Group. Fluorescence-guided surgery with 5-alaminovulinic acid for resection of malignant glioma: a randomised controlled multicentre phase III trial. Lancet Oncol 2006 ; 7 : 392 – 401

- class I evidence.

	Fluorescence-assisted surgery	Conventional surgery	Statistical significance
Percentage of complete resections	65%	36%	$p < 0.0001$
PFS (6 months)	41%	21%	$p = 0.0003$

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%)

Hauser, Sonja B. "Combining 5-Aminolevulinic Acid Fluorescence and Intraoperative Magnetic Resonance Imaging in Glioblastoma Surgery: A Histology-Based Evaluation" Neurosurgery: April 2016 - Volume 78 - Issue 4 - p 475–483

— in 11 of 12 operations, residual contrast enhancement on iMRI was found after complete resection of 5-ALA fluorescent tissue.
— not all glioblastoma tissue exhibits 5-ALA fluorescence and not all areas of iMRI contrast enhancement represent tumor. iMRI performed after complete resection of 5-ALA fluorescent tissue shows contrast-enhancing regions suspicious for tumor in a high percentage of cases (91.6%), whereas these regions in fact contain tumor in only 64.3%.

5-ALA is better than gadolinium
- it is well established that even MRI-nonenhancing low- and high-grade gliomas will show fluorescence in about 20% of cases.

Fluorescence shows more than expected from gadolinium enhancement
10-20% low-grade gliomas show visible 5-ALA accumulation!

Aldave G, Tejada S, Pay E, et al. Prognostic value of residual fluorescent tissue in glioblastoma patients after gross total resection in 5-aminolevulinic acid-guided surgery. Neurosurgery. 2013;72(6):915–920.

— 2 cohorts of patients with GBM (n = 50), both without residual enhancement on early postoperative (1.5 T) MRI, 1 cohort with and 1 cohort without residual fluorescence; cohort without residual fluorescence survived 10 months longer.

Schucht P, Knittel S, Slotboom J, et al. 5-ALA complete resections go beyond MR contrast enhancement: shift corrected volumetric analysis of the extent of resection in surgery for glioblastoma. Acta Neurochir (Wien). 2014;156(2):305–312

— volume of fluorescing tissue is about double the volume of enhancement on MRI.

Roessler K, Becherer A, Donat M, Cejna M, Zachenhofer I. Intraoperative tissue fluorescence using 5-aminolevolinic acid (5-ALA) is more sensitive than contrast MRI or amino acid positron emission tomography ((18)F-FET PET) in glioblastoma surgery. Neurol Res. 2012;34(3):314–317

— fluorescence extends even beyond the fluoro-ethyl-tyrosine-PET zone of hypermetabolism.

VS. IMRI

5-ALA and iMRI work synergistically!

- fluorescence gives 2-D real-time surface information and may sometimes be hidden behind overhanging edges or obscured by blood, can be used to wisely augment the capabilities of more complex and non-real-time iMRI, which gives 3-D information, to safely optimize resections.

CLOSURE

- tumor cavity is then examined for bleeding points, and meticulous **hemostasis** (sometimes difficult but must be perfect) is secured prior to closure.
  - persistent bleeding may be due to residual tumor, and it will require direct bipolar cauterization or 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 subdural space.
- *tumor cysts* can be drained and, when possible, fenestrated into adjacent ventricle to prevent reaccumulation.
- about CSF drainage → see p. Onc18 >>

Allen

The pia-arachnoid is opened using bipolar coagulation along line of incision which is made by sharp dissection. It is usually safe to make subpial dissection 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 blunt dissection. Division of low-grade gliomas or sclerotic areas may require sharp dissection or ultrasonic aspiration. Dissection around base of tumor continues until tumor is isolated. If ventricle is opened, it should be walled off to prevent blood from collecting within it. If cortex is reached opposite entry site, cortical vessels must be individually occluded and divided by sharp dissection. The plane of dissection can be preserved by use of cottonoid strips to protect brain.
Planes of demarcation can usually be developed between metastatic lesions 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-demarcated, 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 transecting 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 postoperative night and be extubated carefully once lower cranial nerve function has been assessed;
  b) if brain stem involvement was minimal, patient may be extubated in operating room.

DISPO

- ICU for at least 1 night; increasing trend for selective ICU admission ("ICU, unless" → "no ICU, unless") - reduced complication rates and length of stay while keeping patients satisfied + hospital costs related to the admission have been significantly reduced.
  Mark ter Laan et al. Selective Intensive Care Unit Admission After Adult Supratentorial Tumor Craniotomy: Complications, Length of Stay, and Costs. Neurosurgery, nyz388, https://doi.org/10.1093/neuros/nyz388 Published: 20 September 2019
- serum **electrolyte levels** and **osmolality** are measured often (also to detect possible onset of SIADH or diabetes insipidus, esp. after endoventricular manipulations).

STEROIDS

Continue DEXAMETHASONE 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 edema on postop FLAIR MRI
- 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%).
- 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).
- ***3 mechanisms*** by which a seizure may occur in setting of neurosurgery for tumors:
  1) intrinsic epileptogenic nature of the tumor, particularly in certain locations such as temporal and parietal lobes
  2) surgical factors associated with craniotomy (brain retraction and cortical irritation)
  3) postsurgical complications (hydrocephalus, edema, or infection).
- traditional AEDs are potent enzyme-inducing (PHENYTOIN, CARBAMAZEPINE, PHENOBARBITAL) or inhibiting (VALPROIC ACID) – reduce / increase serum concentration of chemotherapeutics.
- new generation of AEDs (GABAPENTIN, LEVETIRACETAM) are not metabolized by CYP isoenzymes.

There are studies that do not support prophylactic AED use:

Adam S. Wu "*A prospective randomized trial of perioperative seizure prophylaxis in patients with intraparenchymal brain tumors*". J Neurosurg 118:873–883, 2013
- patients undergoing resection 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 (< 30 days after surgery) was 8% in observation group vs.10% in prophylaxis group (p = 1.0).

- 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).

Ricardo J. Komotar "Prophylactic antiepileptic drug therapy in patients undergoing supratentorial meningioma resection: a systematic analysis of efficacy". J Neurosurg 115:483–490, 2011

- 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.

ANTIEMBOLIC 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*, *EPENDYMOMAS*, *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 3-6 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 depends largely on tumor location (highest – 10-20% – in diencephalic tumors).
- operative MORTALITY rates are < 1%; 30-day mortality rate after brain tumor surgery is 2.2-2.9% - **postoperative hematoma** is the most frequent cause of death.

  Teruyoshi Kageji et al. Postoperative Hematoma Requiring Recraniotomy in 1149 Consecutive Patients With Intracranial Tumors. Oper Neurosurg (Hagerstown) (2017) 13 (3): 392-397
  - incidence of a POH requiring a recraniotomy was 2.09%.
  - among recraniotomy patients, 12.5% died within 30 days of the first surgery.
  - incidence of recraniotomy significantly correlated with the incidence of a hemangioblastoma, infratentorial tumors, and a prolonged operative time (>10 h).

SKULL BASE TUMORS

http://www.neurosurgicalatlas.com/grand-rounds/minimally-invasive-transcranial-operative-corridors-techniques
http://www.neurosurgicalatlas.com/grand-rounds/transcranial-and-endoscopic-microsurgical-operative-corridors-accessing-dif
http://www.neurosurgicalatlas.com/grand-rounds/endoscopic-skull-base-surgery-transclival-transmaxillary-transodont

ANTERIOR SKULL BASE

See also p. Op300 >>

CAVERNOUS SINUS AND MIDDLE FOSSA

PINEAL REGION TUMORS

http://www.neurosurgicalatlas.com/grand-rounds/resection-of-pineal-region-tumors-pearls-and-pitfalls

POSTERIOR FOSSA TUMORS

- EVD can be placed frontally prior to positioning or occipitally once the patient has been positioned
- place EVD in OR prior to craniotomy (or at least prep for occipital Frazer bur hole).
- important to avoid hypertension immediately postop – risk of bleeding into posterior fossa!

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 / patty / 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

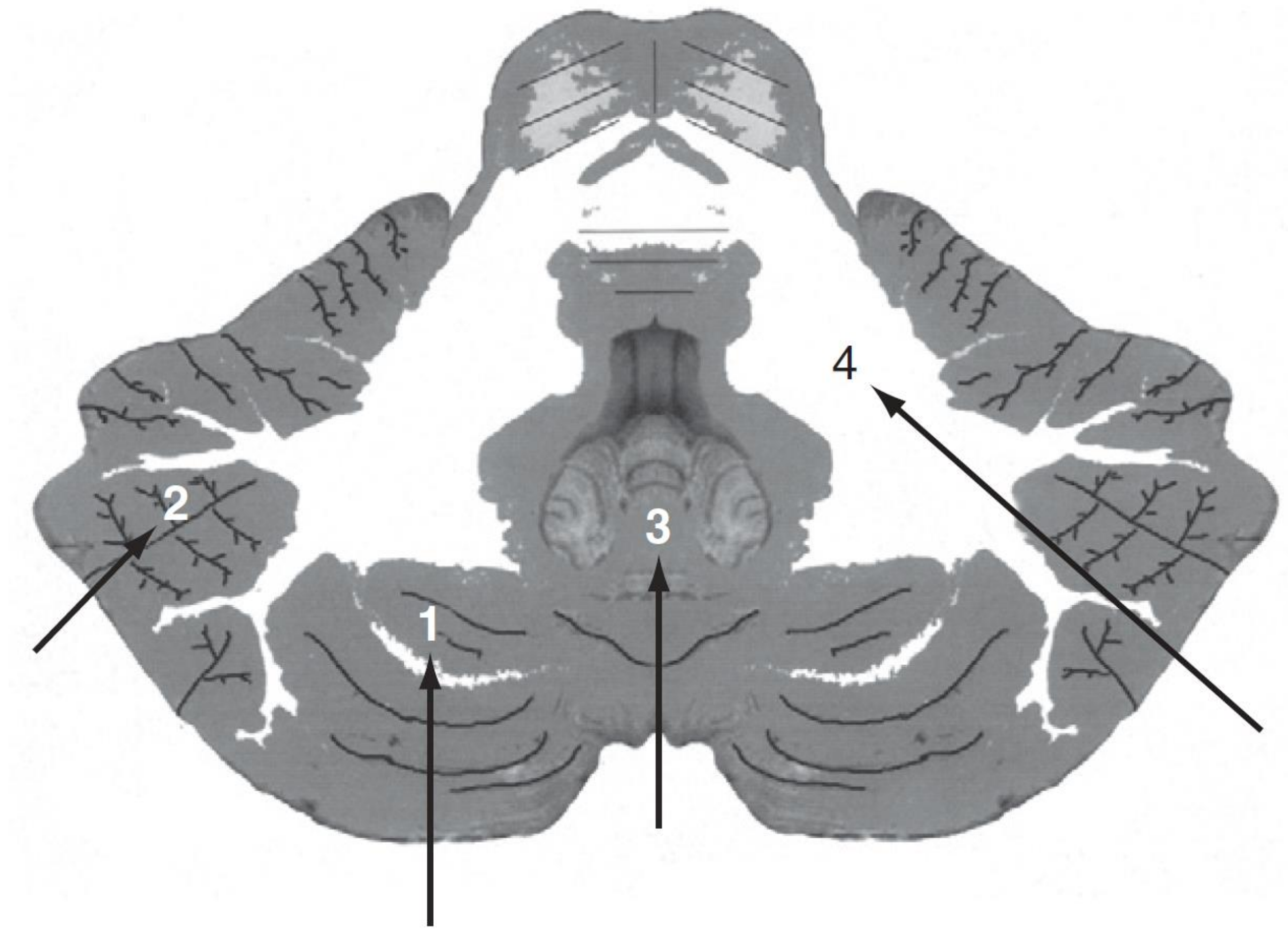
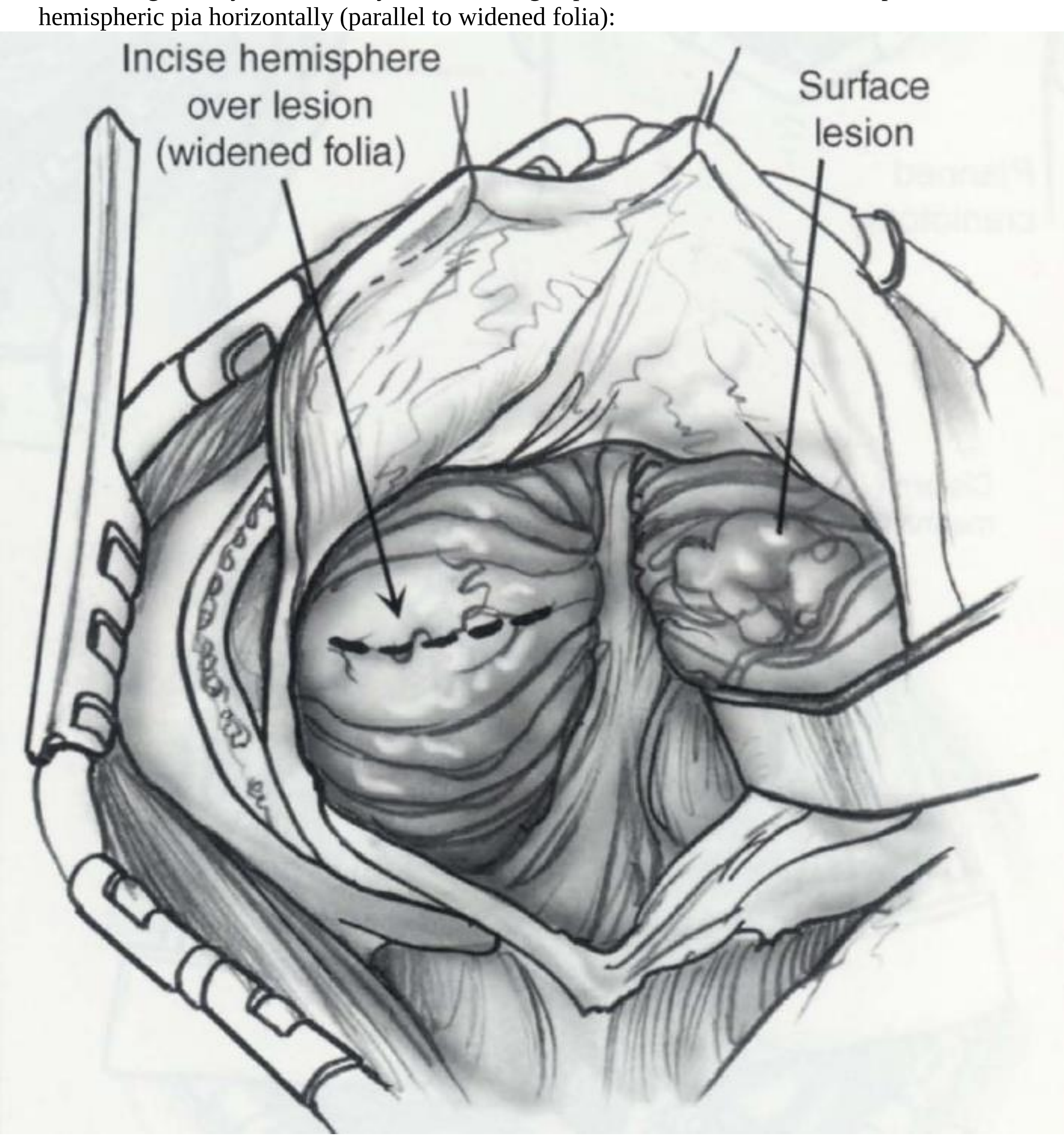
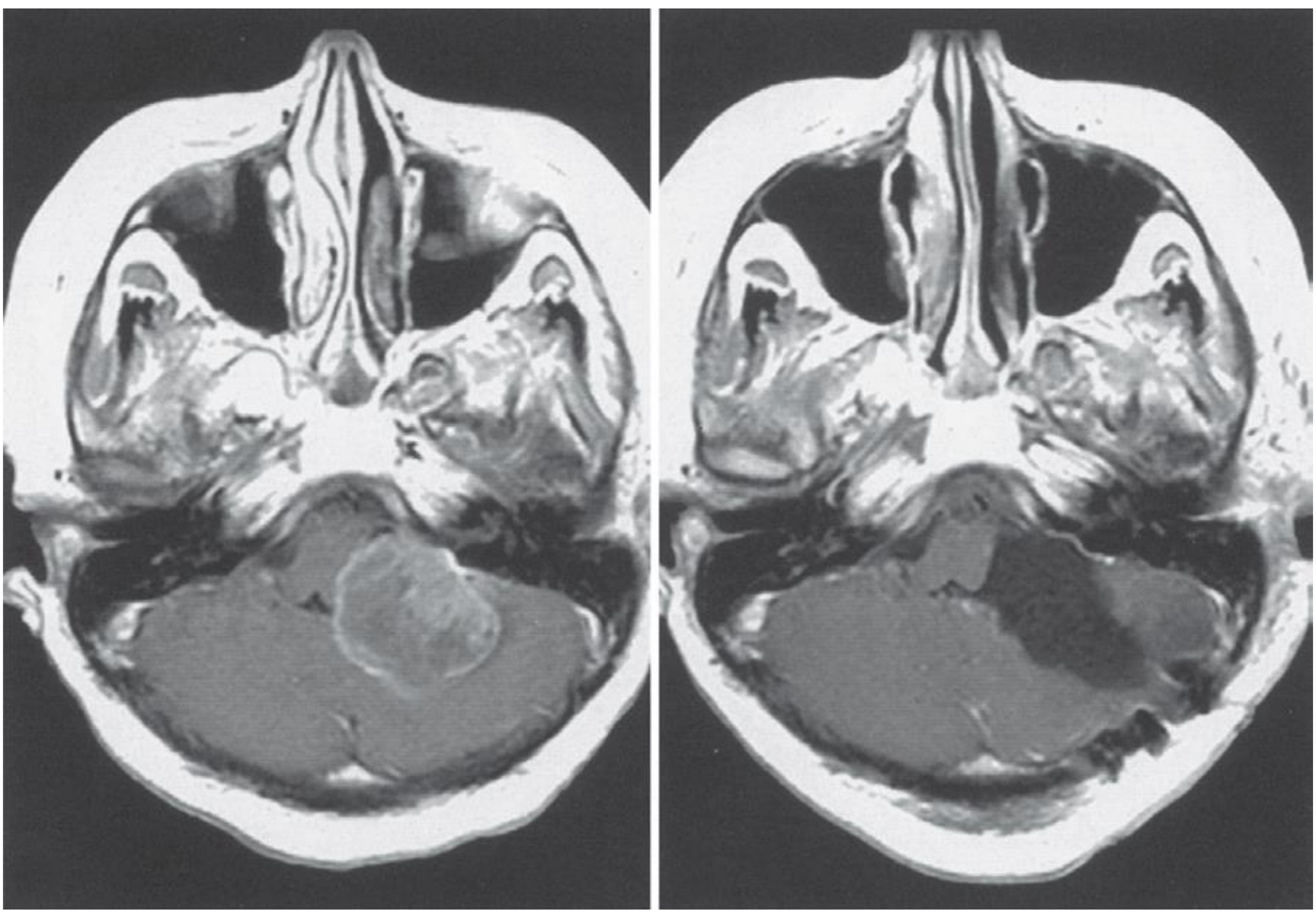


FIGURE 130-2 Anatomic location of cerebellar metastases and the corresponding approaches for resection. 1, Medial hemispheric metastasis. 2, Lateral hemispheric metastasis. 3, Vermian metastasis. 4, Deep cerebellar metastasis. *(From Lang FF, Sawaya R. Surgical management of cerebral metastases.* Neurosurg Clin N Am. *1996;7:459-484.)*

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 sinus.
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 hemangioblastomas 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 piecemeal 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.

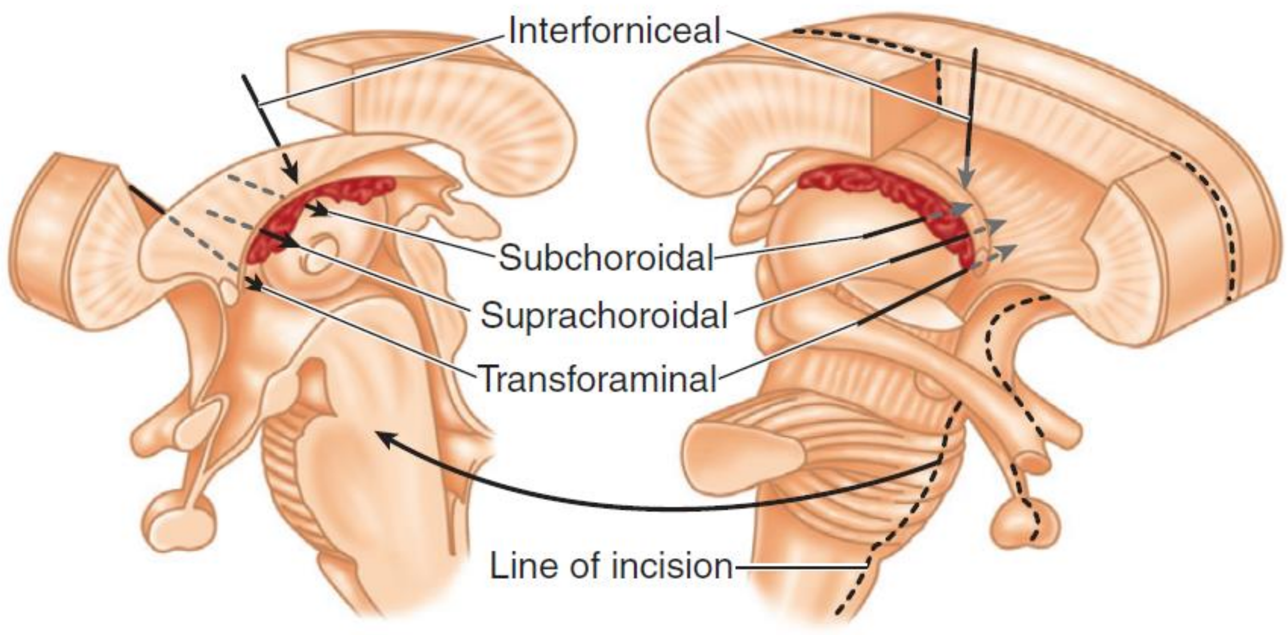
N.B. *all patients must be screened for PHEOCHROMOCYTOMAS* preop (may cause perioperative hypertensive crisis induced by anesthetic or analgesic agents) - 24-hour urine free cortisol or plasma concentrations of metanephrine and normetanephrine → CT; if evaluation reveals pheochromocytoma → resect pheo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

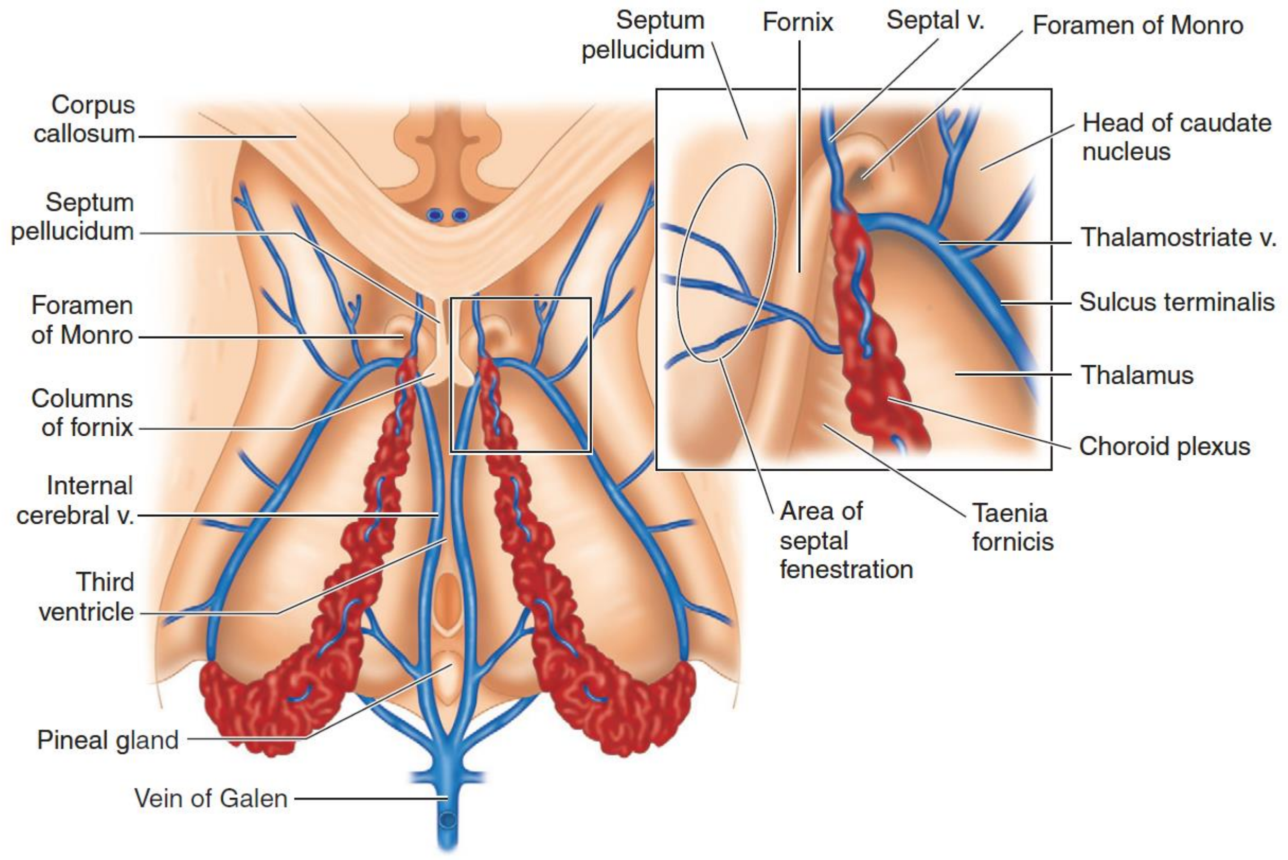
THIRD VENTRICLE

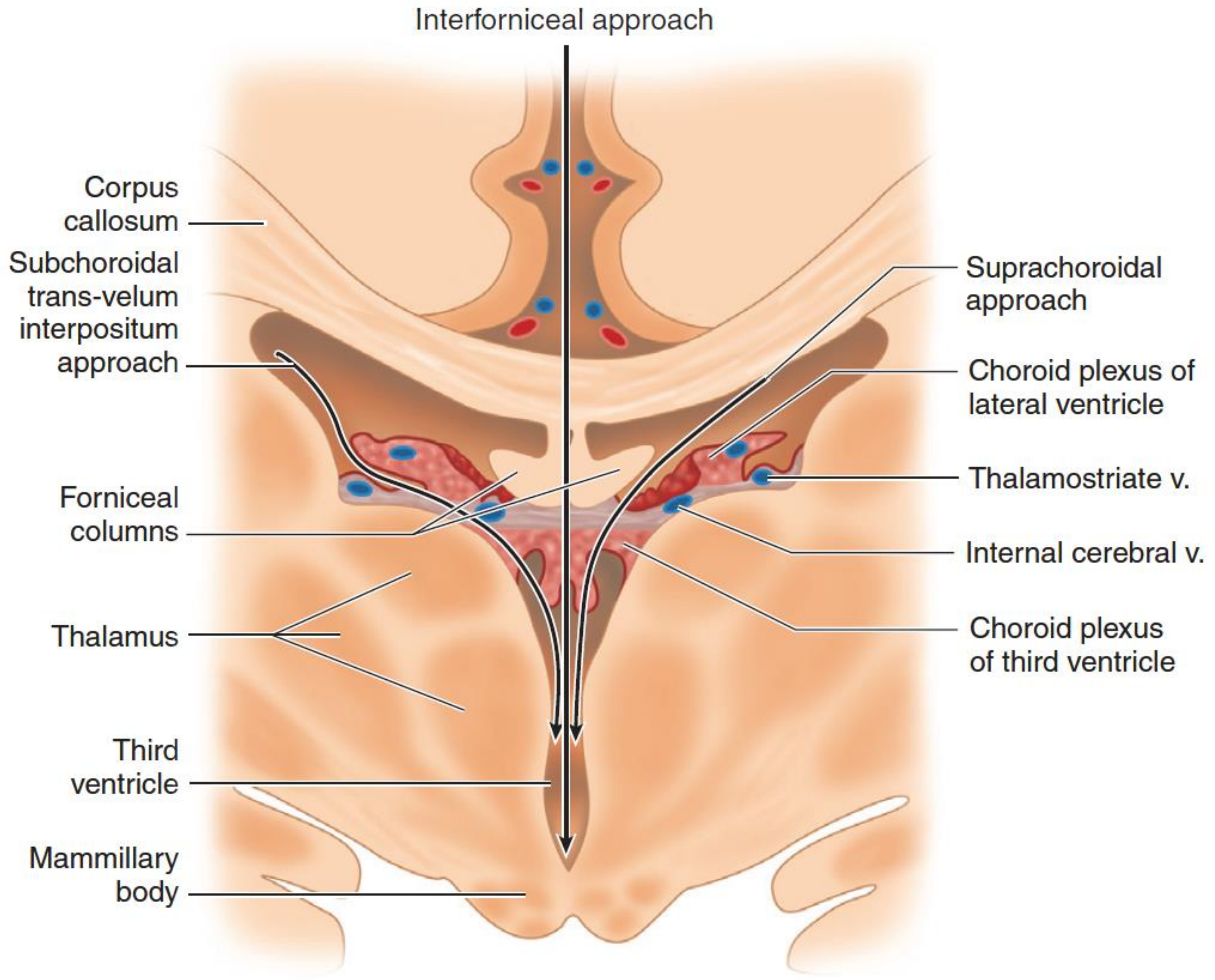
Pending read:
Approaches to the Third Ventricle - Interhemispheric Transcallosal

A. **Transcortical approach** – facilitated by ventriculomegaly
B. **Transcallosal (interhemispheric) approach** – equally effective in reaching foramen of Monro with large or small ventricles >>

A. Transforaminal approach
B. Transchoroidal approach
C. Interforniceal approach







Source of pictures: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

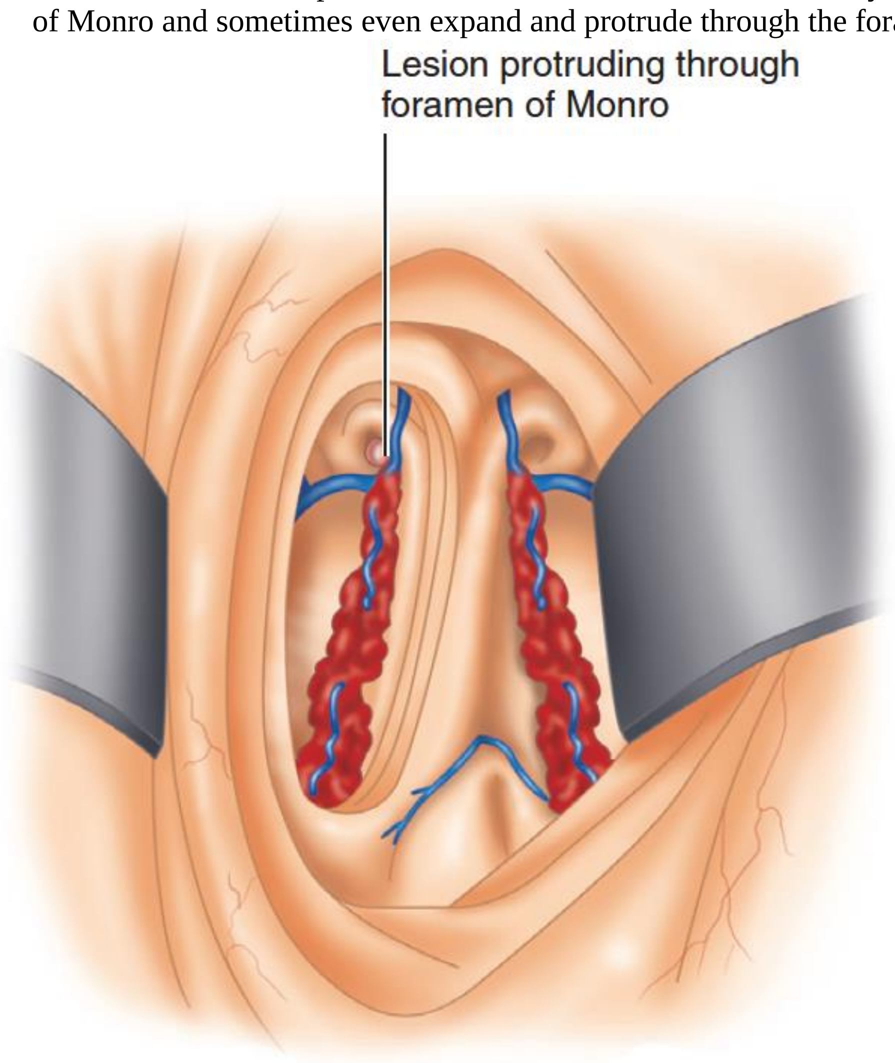
- experts say that it is OK to divide massa intermedia.

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.



Source of picture: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

- 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.

N.B. dilating the foramen can lead to postoperative memory deficits due to fornix injury! Also lateral side of foramen of Monroe is made of genu of internal capsule!

- dexamethasone, mannitol, no AED.
- frontal parasaggital craniotomy:
  - supine position with head in Mayfield headholder.
  - lazy-S incision in transverse fashion over midline, just in front of coronal suture (two thirds anterior and one third posterior to coronal suture; there are no bridging veins near coronal suture)
  - 2 bur holes (4 cm apart) with Acorn drill bit over superior sagittal sinus; time should be taken to dissect the dura carefully from the inner table working away from the sagittal sinus; connect bur holes with footplate – one side just parasagittal, other side 3 cm from midline
  - dura reflected towards sagittal sinus
- Greenberg/Budde retractor, microscope
- gentle retraction of frontal lobe away from falx.
- separate both cingulate gyri
- bilateral pericallosal arteries gently separated
- 1-2 cm midline callosotomy using microsuction tip (verify with navigation trajectory)
  N.B. corpus callosum is very shiny brightly white!
- enter lateral ventricle
- venous angle and choroid plexus lead into foramen of Monroe.
- incision into tumor capsule and attempt debulking with pituitary rongeur (may fail due to rubbery nature of cyst contents).
- very gentle tumor rocking allows tumor delivery into lateral ventricle via foramen of Monroe.

Postoperative – see p. Onc30 >>

TRANSCHOROIDAL (SUBCHOROIDAL OR SUPRACHOROIDAL) APPROACH

- entering either above or below the choroid plexus in the body of the lateral ventricle.
- access into the third ventricle through the velum interpositum, which serves as the roof for the third ventricle.
- **subchoroidal approach** - incision is made in the taenia choroidea, and the choroid plexus is reflected upward; may be necessary to cauterize one of the thalamostriate veins, which may be a limiting factor in the untethering of the choroid – potential* consequences of sacrificing a unilateral striate vein include hemiplegia, mutism, and drowsiness.
  *these postoperative morbidities may not occur, however, because of collateralization by superficial cortical, posterior medullary, and galenic venous systems
- **suprachoroidal approach** (correct route on board exam for transchoroidal approach) - incision is made above and medial to the choroid plexus in the taenia fornicis, and the choroid is deflected inferiorly - approach requires less manipulation of the superficial thalamic and caudate veins - safer.

INTERFORNICEAL APPROACH

- midline division of the forniceal bodies

- bilateral forniceal injury can occur through manipulation (→ devastating memory impairment) - approach is reserved for cases in which there is significant mass effect that distends the roof of the third ventricle.
- during development of a dissection plane in the interforniceal approach, remain cognizant of the hippocampal commissure in the posterior component of fornices.
- preserve and retract gently the internal cerebral veins (appearance may mimic colloid cyst)
- most commonly encountered postoperative problem is transient amnesia of recent events (30% of cases); most striking 24 to 72 hours postoperatively and resolves completely within 21 days.

LATERAL VENTRICULAR MASSES

Relatively high risk for mortality and neurological morbidity.

Masses in this location:
- often are benign tumors - grow at slow rate - reach very large size before identified.
- cause hydrocephalus (headache, poor balance, difficulty with memory)
- localizing findings (aphasia, agnosia, hemiparesis, etc) are rarely present – mostly occur with entrapment of occipital and temporal horns.

Etiologies:

Tumor	Typical site
COLLOID CYST	Foramen of Monro / 3rd ventricle
SEGA	Foramen of Monro
MENINGIOMA	Trigone of lateral ventricle
CHOROID PLEXUS PAPILLOMA	4th ventricle
EPENDYMOMA	Lateral ventricle (more common in children), 4th ventricle
*NEUROCYTOMA**	Lateral ventricles (involving septum pellucidum)
METASTASES	Lateral ventricles, ependyma and choroid plexus

*most common lateral ventricle tumor in young adults

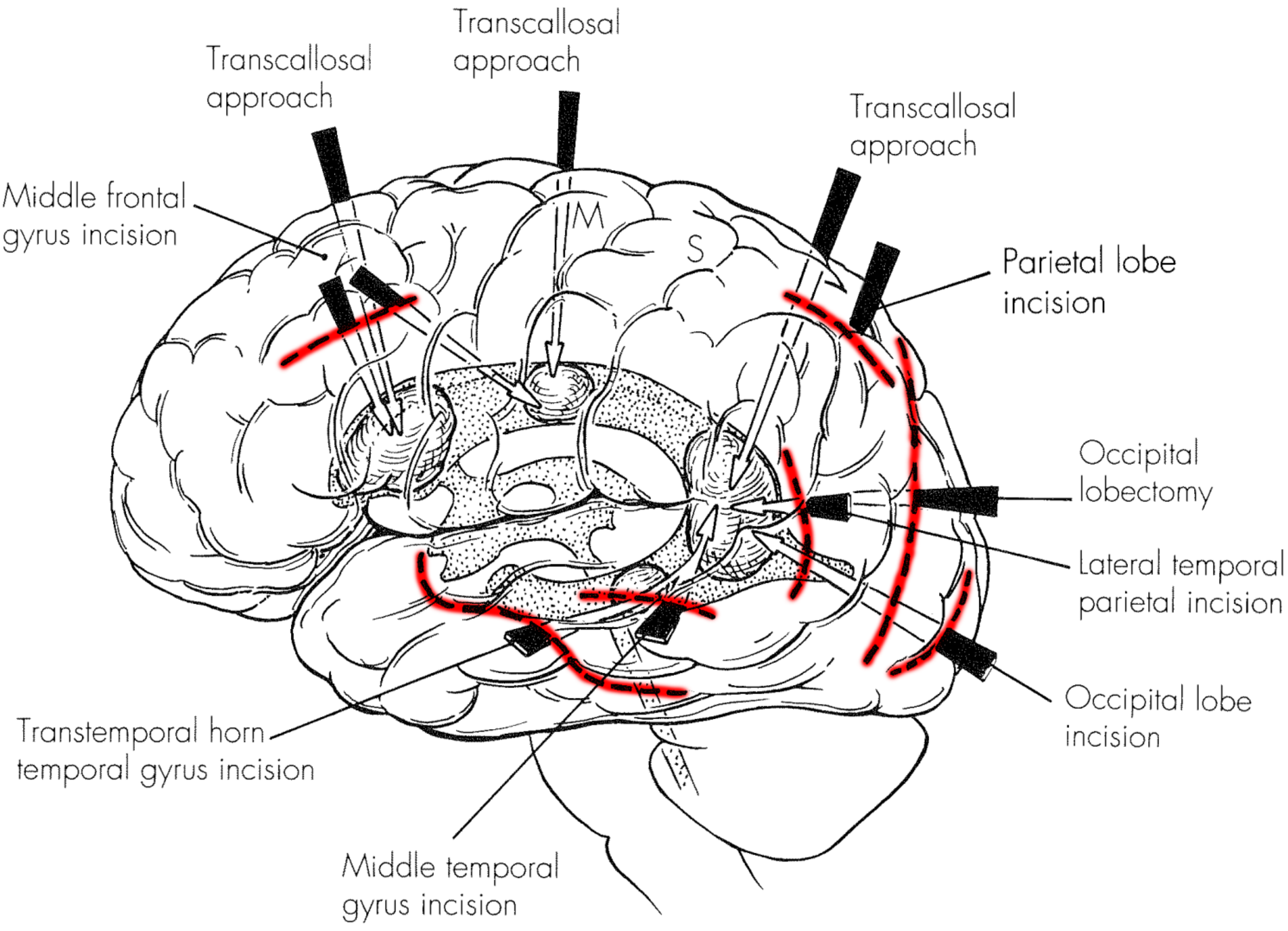
PREOPERATIVE

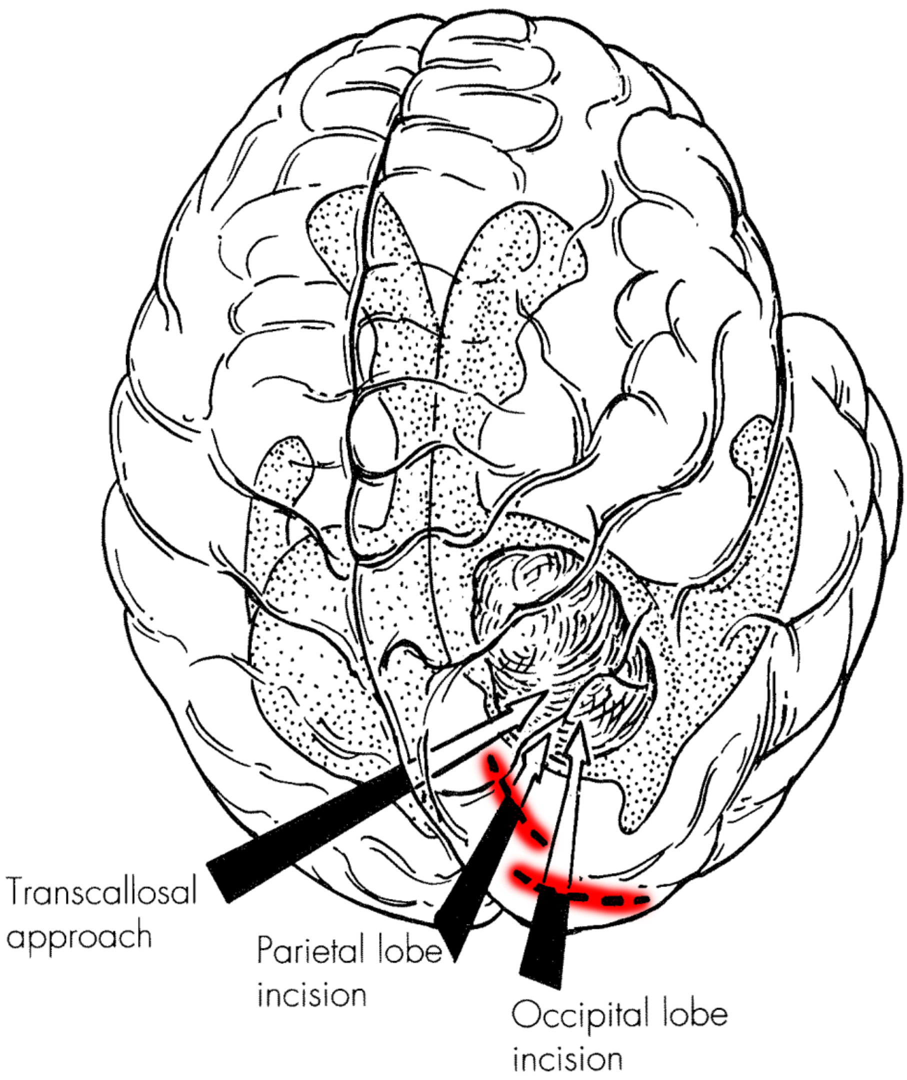
- routine **EVD**.

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, ideomotor 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 trigone:

A. **Transtemporal horn occipitotemporal gyrus** – see above

B. **Occipital lobe** incision / lobectomy – see below

C. **Transcallosal** 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.

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

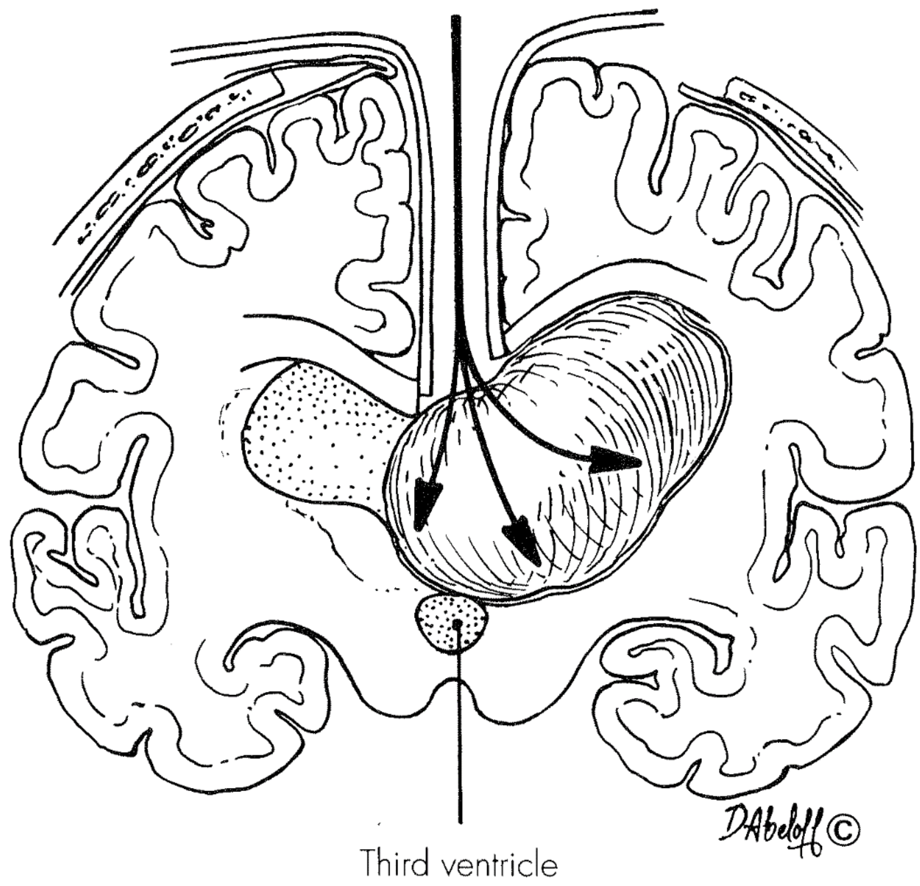
Pending:
Lab Demo - Transcallosal Approach to Lateral & Third Ventricle >>

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.

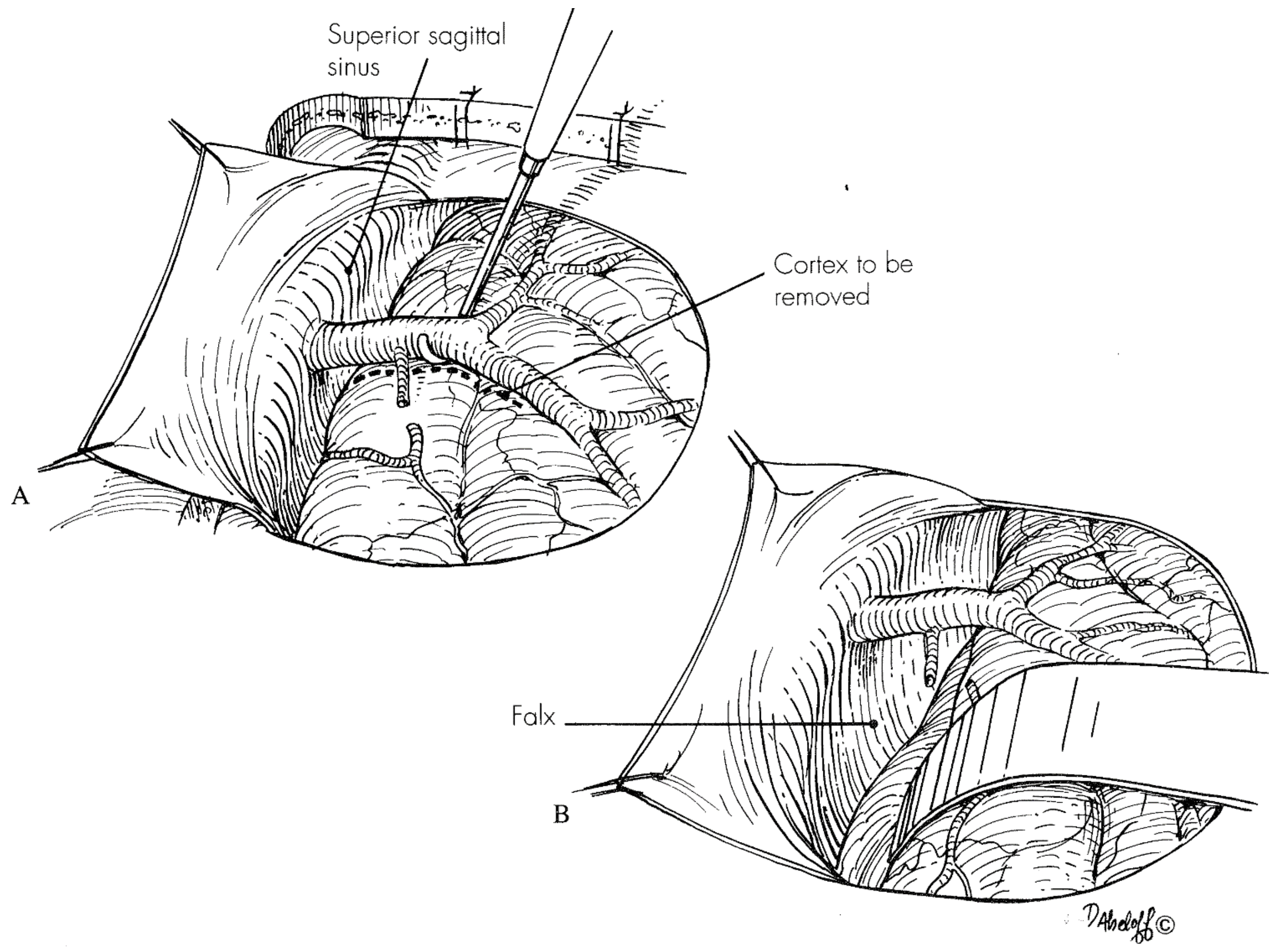
PROCEDURE

- 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).



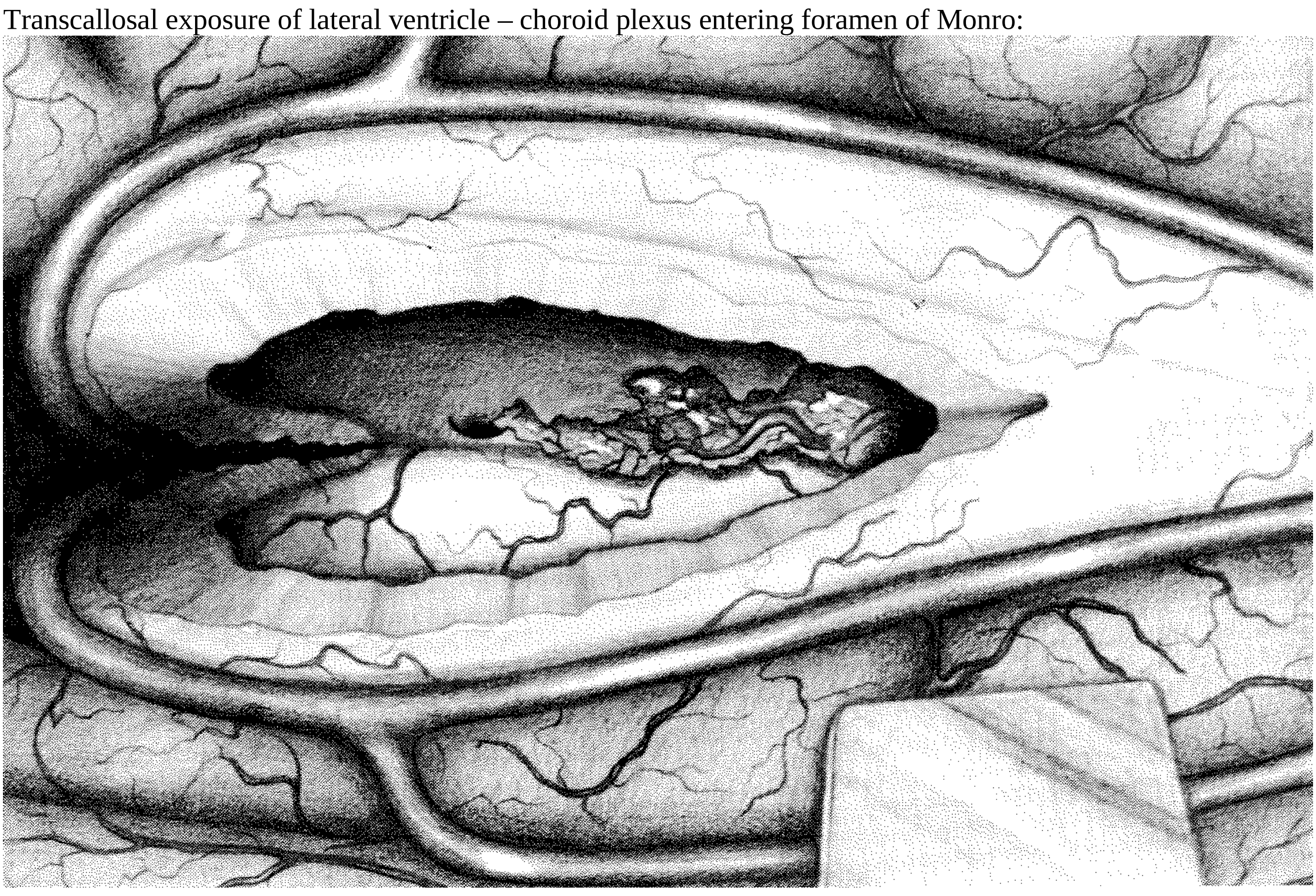
Third ventricle

- 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).
- if the foramen of Monro is open, a physical barrier should immediately be placed at its entry to prevent blood from pooling into the third ventricle.
- if contralateral ventricle is entered, fenestration or excision of the septum pellucidum can open access into the ipsilateral lateral ventricle; fenestration of the septum also allows for the alternative pathway for CSF flow.
- fornices travel across the base of the septum and must be preserved.
- following the thalamostriate vein, septal vein, fornices, or choroid plexus reliably guides the surgeon to the foramen of Monro.
- ependymal surface adjacent to the callosotomy and abraded medial and paramedial cortical surface are particularly susceptible to postoperative hemorrhage.
- EVD should be left in the lateral ventricle for about 48 hours postoperatively.
- if expect that redo will be needed in the future, leave gel film in the interhemispheric fissure to prevent adhesions.

Transcallosal exposure of lateral ventricle – choroid plexus entering foramen of Monro:



COMPLICATIONS

- **disconnection of hemispheres**, esp. in patients with anomalous cortical organization (H: Wada test prior to transcallosal surgery):
  - mutism, akinesia, apathy, 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).

Limited incision of the callosal trunk usually leads to minimal physiologic complications.

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. Although the exact deficits depend on the topographic relationship within the corpus callosum, several studies have suggested that interhemispheric transfer should be preserved as long as the splenium is intact.

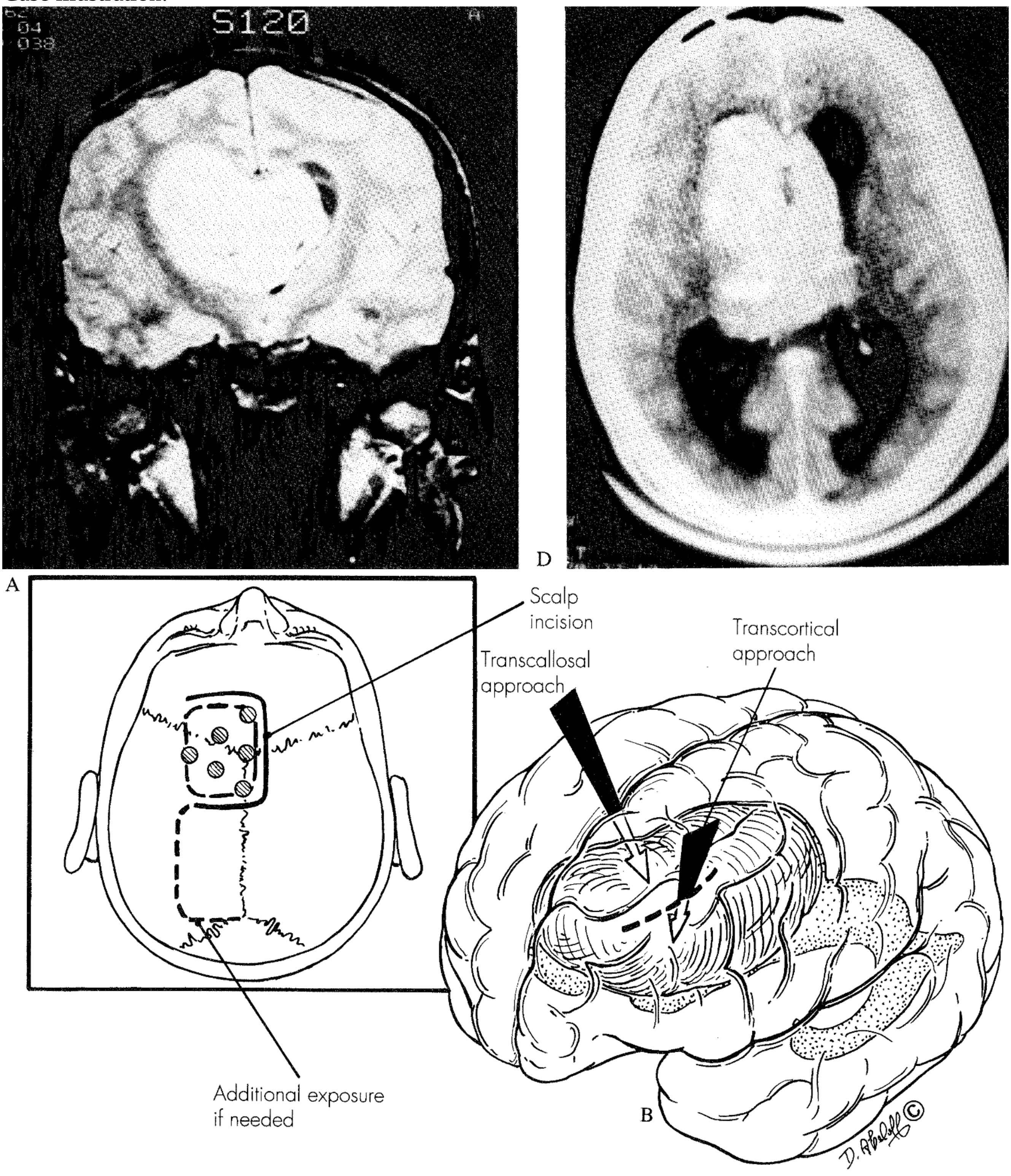
- **leg motor cortex injury** – venous infarction or retraction injury.
- **short term memory deficits** – from fornix manipulation

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) → transcortical 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**.
- transcortical incision usually goes first → safer interhemispheric dissection with relaxed hemisphere.

Case illustration:



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 transcortical resections; significantly lower after transcallosal 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.

INSULAR TUMORS

LITT for insular oligodendroglioma – see p. Onc12 >>

- **Berger-Sanai insular glioma classification system** - tumor types that may benefit from more aggressive surgery.

MENINGIOMAS

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

- 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).
  - embolization facilitates surgery by reducing blood loss (esp. when blood supply is on other side of tumor vis-à-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 microparticles (PVA)** 150-300 μm; smaller particles (Gelfoam 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.

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.

SIMPSON GRADES

Table 21-25 Simpson grading system for removal of meningiomas[212]

Grade	Degree of removal
I	macroscopically complete removal with excision of dural attachment and abnormal bone (including sinus resection when involved)
II	macroscopically complete with endothermy coagulation (Bovie, or laser) of dural attachment
III	macroscopically complete without resection or coagulation of dural attachment or of its extradural extensions (e.g. hyperostotic bone)
IV	partial removal leaving tumor in situ
V	simple decompression (± biopsy)

Degree of Resection	Recurrence rate
Complete resection with dural margin	9%
Complete resection with coagulation of dura	19 %
Complete resection (no treatment of dura)	29 %
Partial removal leaving tumor *in situ*	40 %
Decompression	NA

D. Simpson 1957

Likelihood of Total Excision (MGH, n=225)

Tumor Location	n	% Total Excision
Convexity	47	96 %
Orbit	5	80 %
Spine	18	78 %
Olfactory Groove	22	77 %
Parasagittal Area/Falx	38	76 %
Parasellar Region	28	57 %
Posterior Fossa	31	32 %
Sphenoid Ridge	36	28 %
TOTAL:	225	64%

Mirimanoff *et al*, J Neurosurg 62: 18 – 24, 1985

MENINGIOMA INVOLVING BONE

- all involved / hyperostotic **bone** should be removed.

  — some centers use 5-ALA to guide bone resection (or avoid extensive resections if bone is nonfluorescent and thus likely just with reactive changes)

  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%.

    Della Puppa A 'Predictive value of intraoperative 5-aminolevulinic acid-induced fluorescence for detecting bone invasion in meningioma surgery.' J Neurosurg. 2014 Apr;120(4):840-5.

— 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 → **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)

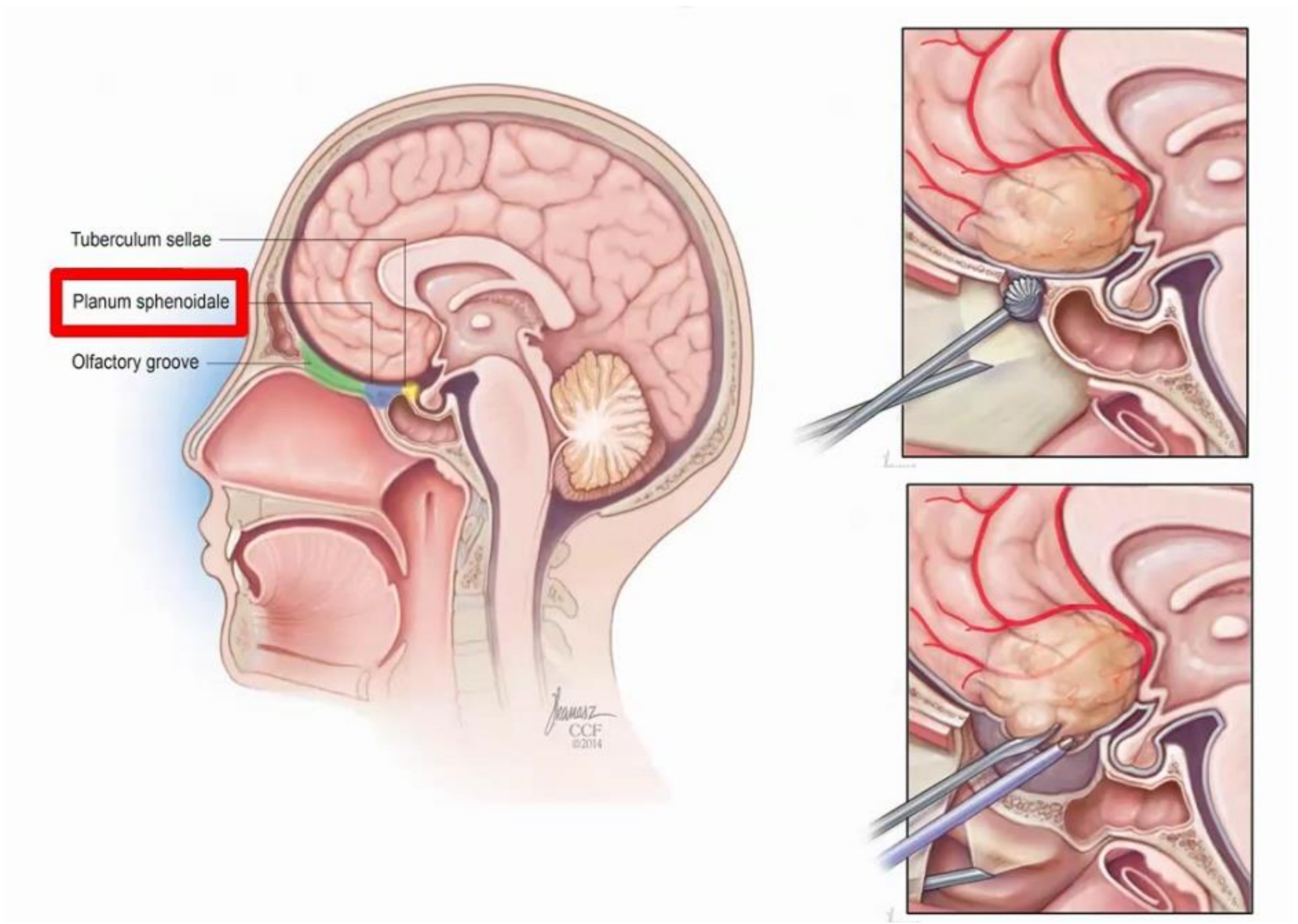
VERY LARGE MENINGIOMA

- 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 → postop radiation (it will take long time until tumor grows back to fill original volume again).

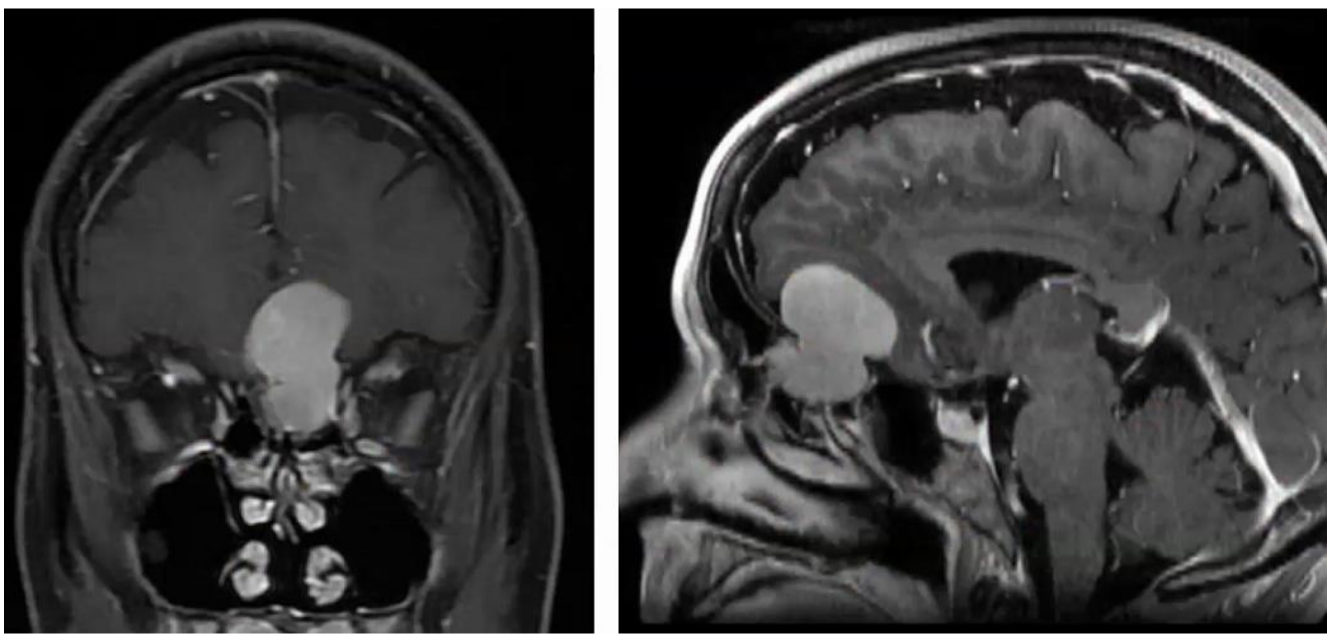
ANTERIOR SKULL BASE MENINGIOMAS

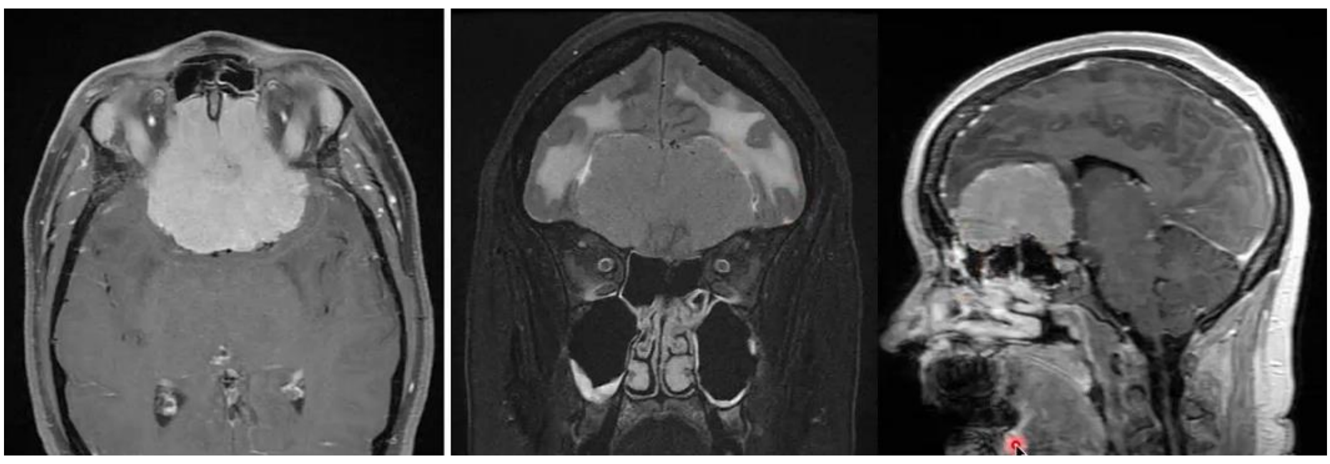
A. **Endoscopic (transnasal)** approach – early tumor devascularization, no retraction on brain [e.g. already pre-existing significant frontal edema], risk for anosmia (olfactory grove tumors, but not for more posterior tumors), leaves high-flow CSF leak (nasoseptal flap is a must).
B. **Craniotomy**

Anterior → 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 ± orbital osteotomy
   b) Frontal interhemispheric approach (ligating anterior portion of superior sagittal sinus)

*unilateral approach is usually sufficient

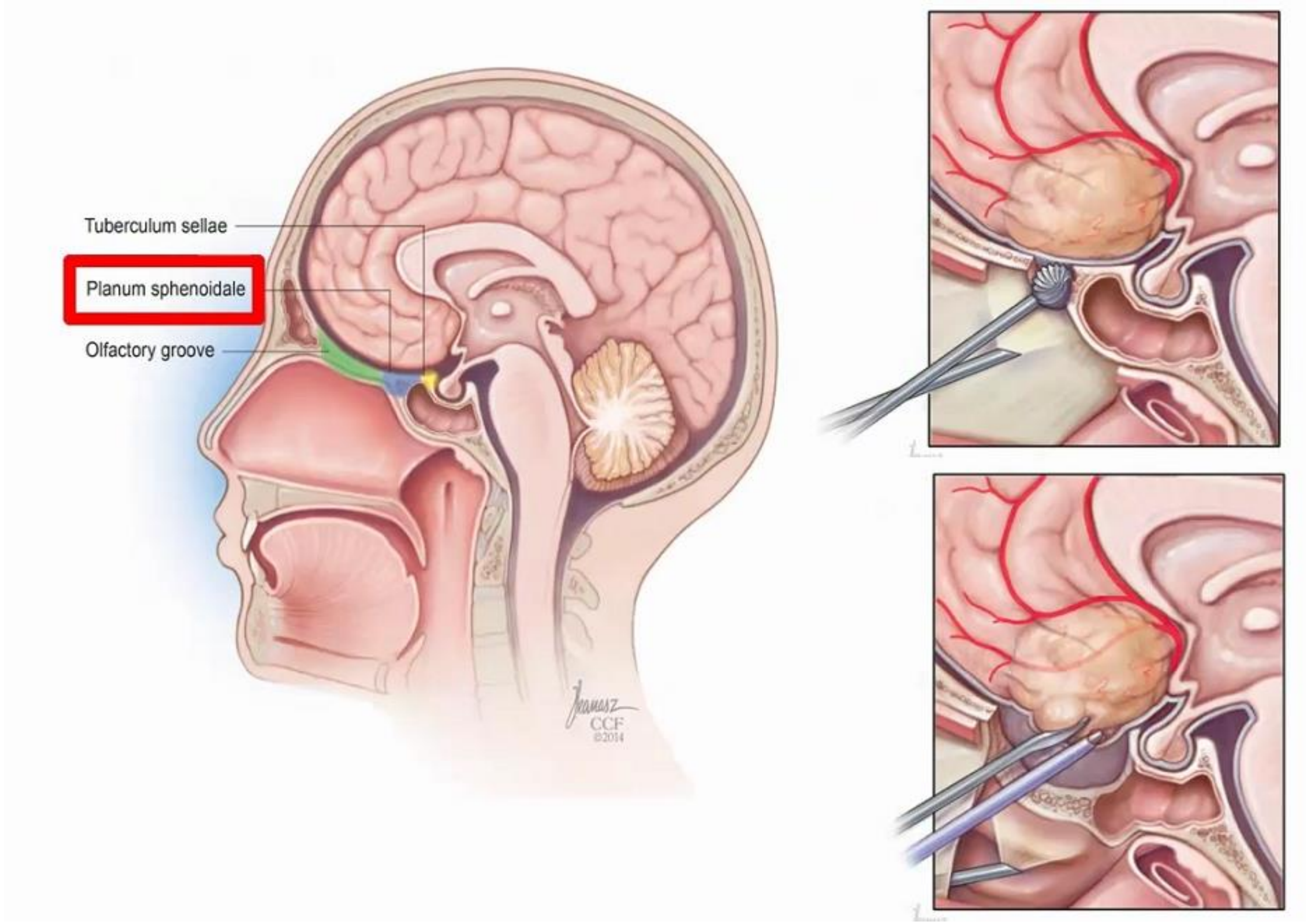
N.B. craniotomy is better - preserves smell (transnasal approach - 100% postop anosmia, vs. craniotomy - 50%)

- ± microscope (Dr. JRC – yes; Dr. Broaddus – no).
- tumor arterial supply and perforator arteries to hypothalamus must be differentiated because both arise from anterior circulation.
- these tumors receive their blood supply through various sources:
   1) ***ethmoidal arteries*** (branches of ophthalmic arteries)

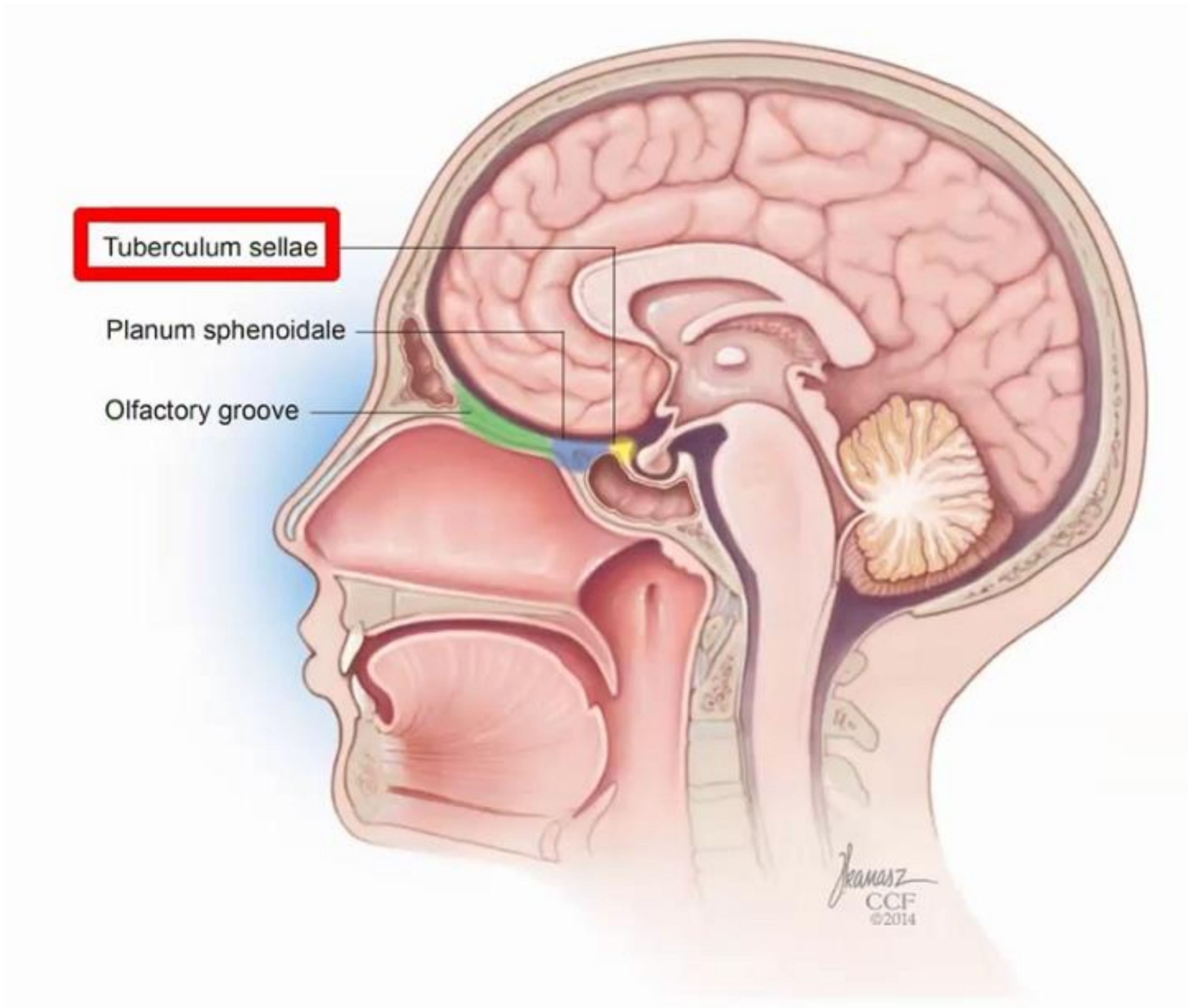
2) branches from middle meningeal artery
3) carotid arteries.

- to avoid undue retraction of frontal lobes, these tumors are best approached through low fontal 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.

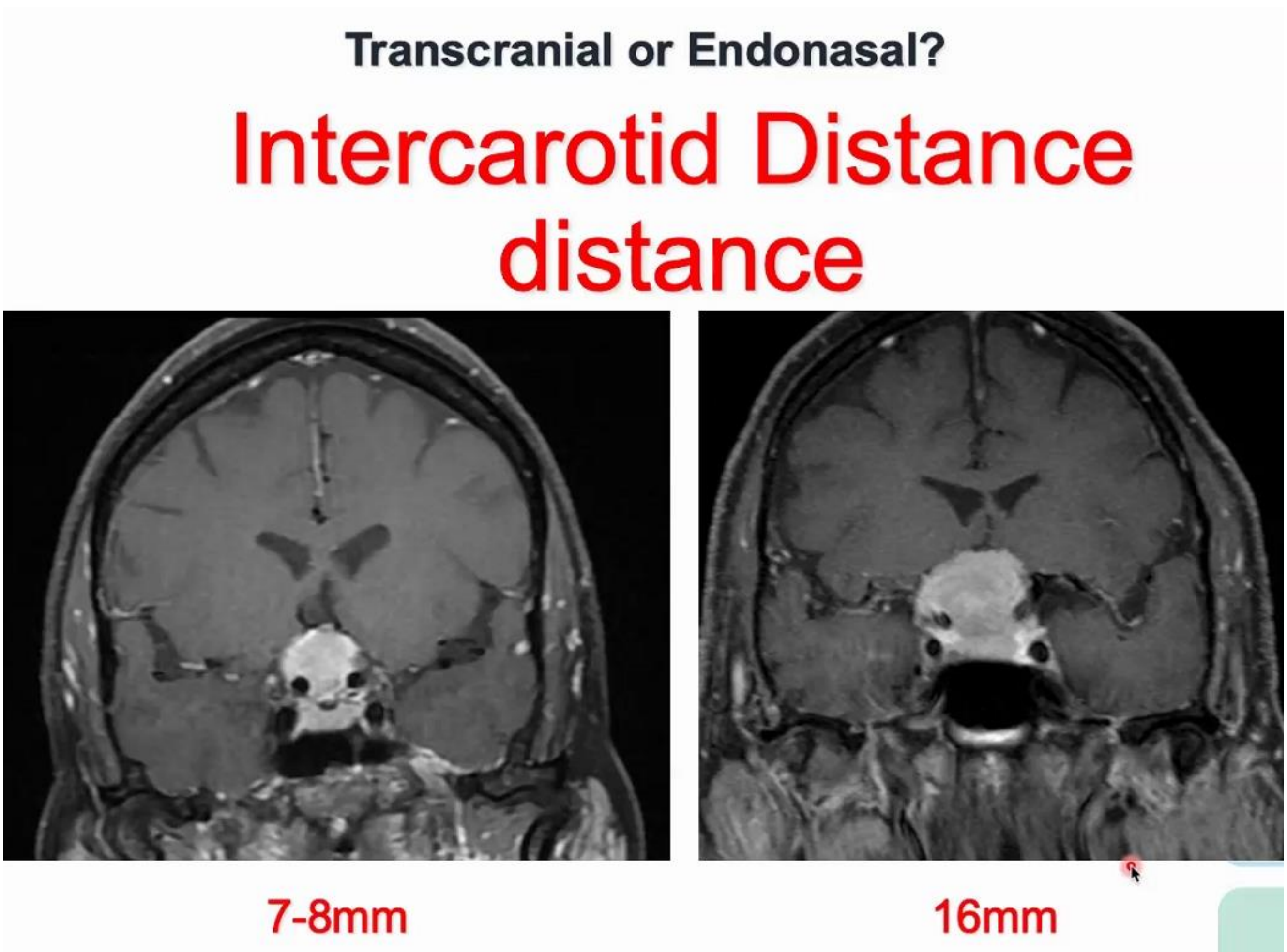
PLANUM SPHENOIDALE MENINGIOMA



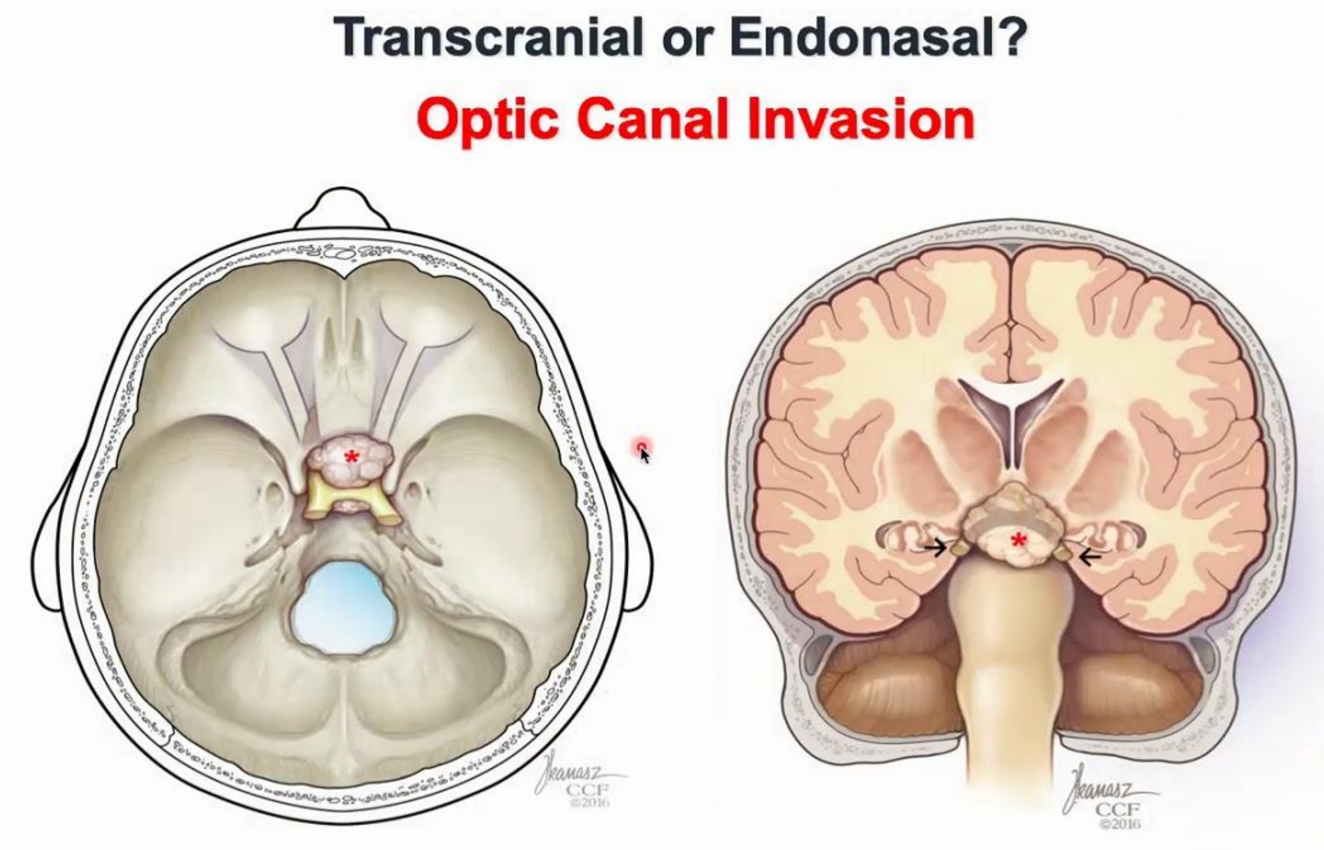
TUBERCULUM SELLAE / ANTERIOR CLINOID REGION MENINGIOMAS



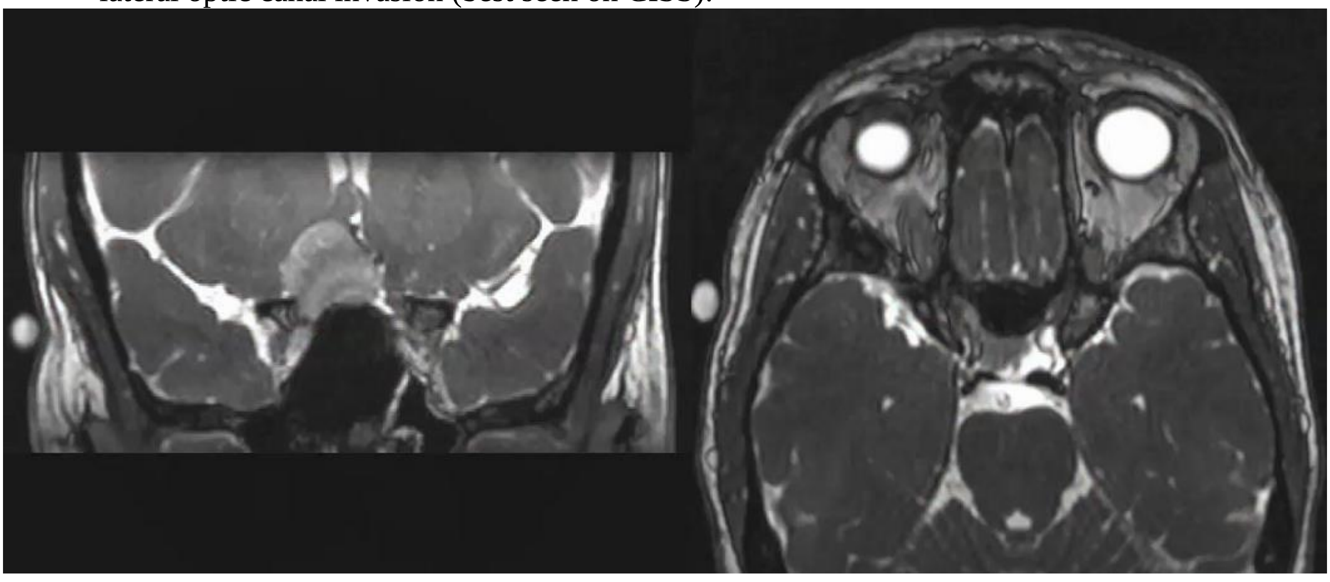
- preoperative imaging of clinoid region meningiomas can accurately predict the presence or absence of tumor involvement of the clinoid in only 75% of cases. In light of the fact that a quarter of patients with radiographically negative clinoids will have tumor present on pathological analysis, recommend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



- small intercarotid distance is contraindication for endoscopic approach



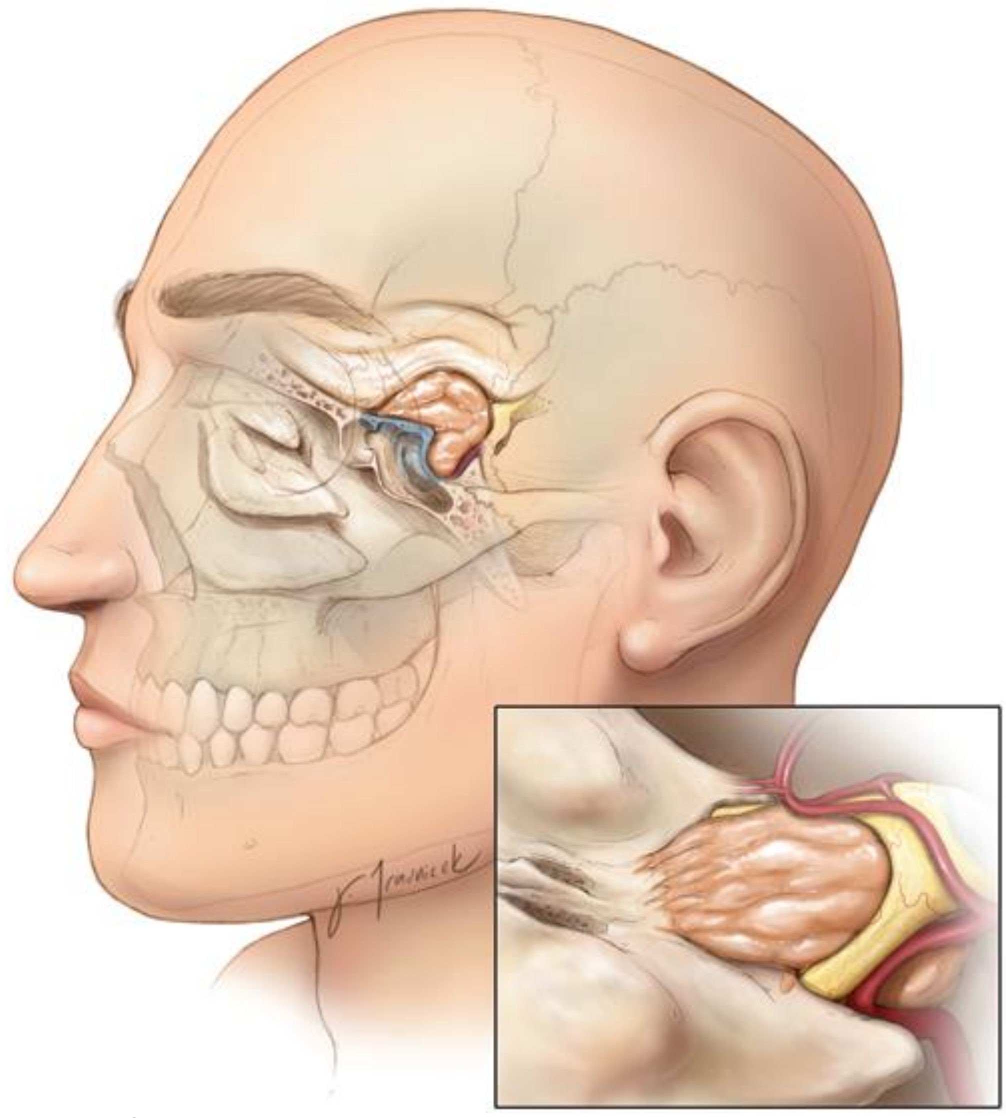
- absence of lateral optic canal invasion is suitable for endoscopic approach.
- lateral optic canal invasion (best seen on CISS):



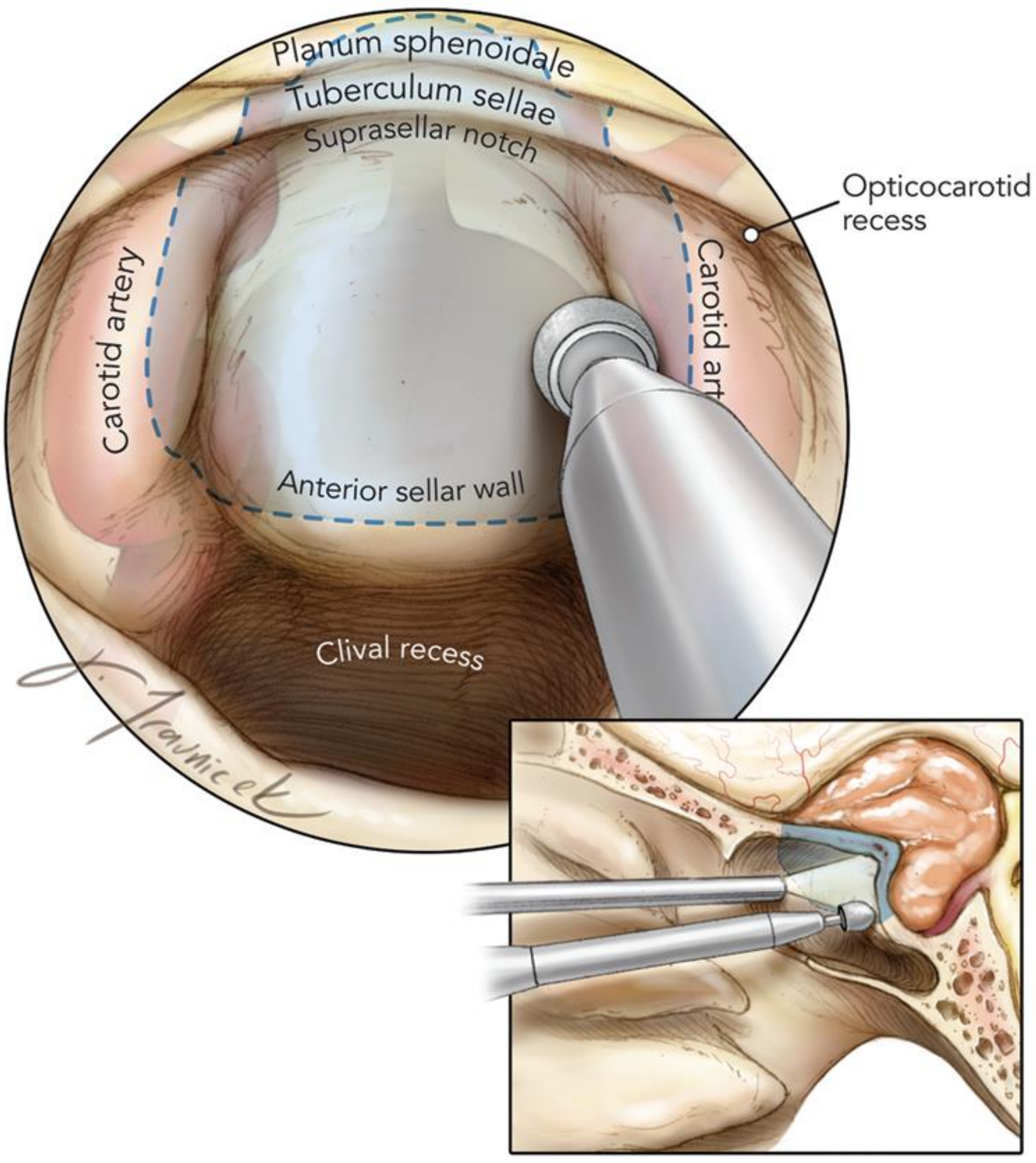
<u>Endoscopic approach</u>:

Charles Kulwin, M.D.,1 Theodore H. Schwartz, M.D.,2 and Aaron A. Cohen-Gadol, M.D., M.Sc. Endoscopic extended transsphenoidal resection of tuberculum sellae meningiomas: nuances of neurosurgical technique. Neurosurg Focus 35 (6):E6, 2013

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: Superolateral view demonstrating the typical planum attachment, optical canal invasion, and displacement of the optic apparatus and surrounding vasculature:



Upper: Anterior endoscopic view of the posterior wall of the sphenoid sinus after removal of the mucosa revealing the relevant bony anatomy. Note the anterior sellar wall centrally, bilateral opticocarotid recesses laterally, and the suprasellar notch superiorly. The area of bone removal is shaded and outlined. Lower: Lateral view demonstrating superoinferior extent of bone removal and trajectory of endoscope and high-speed drill:



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.[13] 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 burring. 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.

- pressure from meningioma can produce marked atrophy of compressed and devitalized cortex; epilepsy may result. Removal of atrophic cortex using techniques ordinarily applied to seizure surgery should be considered.
- perform dural grafting.

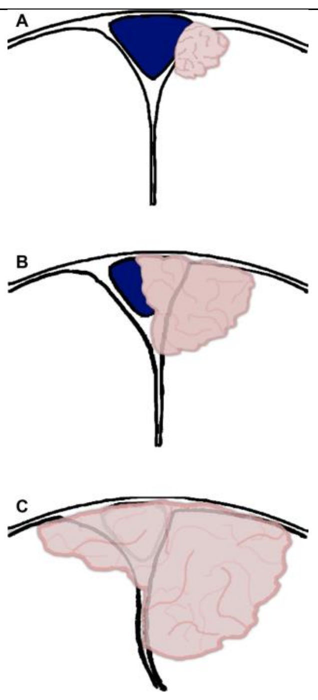
PARASAGITTAL / PARAFALCINE MENINGIOMA

- 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.
        *if SSS is occluded gradually by tumor, venous drainage will be diverted over time through parasagittal veins
    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 sinus and reconstruct it later (either with vein or prosthetic 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.
    N.B. recurrence – MRV – if SSS patent → radiosurgery (resection is contraindicated)

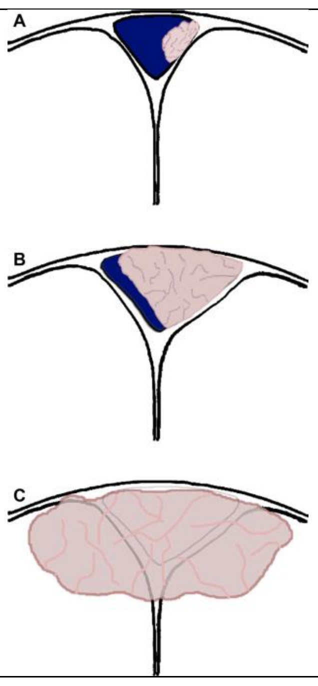
<u>Sindou classification</u> - stages of tumor invasion and the level of blood flow restriction within the SSS:
type I: lesion attached to the outer surface of the sinus wall
type II: tumor fragment inside the lateral recess
type III: invasion of the ipsilateral wall
type IV: invasion of the contralateral 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

<u>Chinese classification</u> *Tengkun 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 wall 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 craniotomy is complicated by tumor's adherence (on its medial aspect) to sylvian veins. Surgical cure is not possible.
    2) middle-third tumors grow into 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 encase 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 presents 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 pterional 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.
- drill 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).

CAVERNOUS SINUS MENINGIOMA

http://www.neurosurgicalatlas.com/grand-rounds/resection-of-cavernous-sinus-meningiomas

- 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 subtemporal 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 meningioma*** - middle third of the tentorial free margin: pterional, subtemporal, and retromastoid approaches.
- ***posteromedial (PM) incisural meningioma*** - posterior third of the tentorial free margin: occipital or supracerebellar infratentorial approaches.