Infection
- craniocerebral osteomyelitis, subdural empyema, meningitis, brain abscess.
- risk factors – open scalp fractures, violated parasinus sinuses (esp. with CSF leak).

SCALP WOUNDS
- Procedure
- Postoperatively
- Special Situations

TWIST DRILL CRANIECTOMY (FOR CHRONIC SUBDURAL HEMATOMA)
- Procedure
- Postoperatively

ACUTE EPIDURAL HEMATOMA EVACUATION
- Procedure
- Postoperatively

ACUTE SUBDURAL HEMATOMA EVACUATION
- Procedure
- Postoperatively

DECOMPRESSIVE CRANIECTOMIES
- Indications
- Complications

POSTERIOR FOSSA DECOMPRESSIVE CRANIECTOMY
- Procedure

PENETRATING BRAIN INJURIES
- Procedure

MALIGNANT CEREBRAL EDEMA
- Procedure

GENERAL PRINCIPLES
- Indications for Surgery

PREFORREATIVELY
- correct coagulopathy - fresh frozen plasma (for prolonged PT/aPTT), cryoprecipitate (for fibrinogen < 1.5 g/L), thrombocyte transfusions (for platelets < 100,000). 
- add antiepileptic (AED)
- antibiotic prophylaxis.
- tetanus immunization status should be checked and updated (esp. lacerations, contaminated wounds).
- if suspect vascular lesion (e.g. young person with deep bleed):
  1) order CTA (prop
  2) plan cranietomy so will have proximal control (e.g. by dissecting Sylvian fissure).
  3) start evacuating blood clot furthest from suspicious area and may leave small clots.

ANESTHESIA
- even if patient is in coma it is unwise to begin without full anesthetic support (only exception is patient thought likely to expire during time taken to organize these precautions, which can usually be done while theater is prepared).
- if head is rotated for surgery:
  - make sure neck veins are not twisted.
  - head above heart level (if BP permits)
  - E-point head fixation device is useful if unstable C-spine fracture is present but careful with skull fractures.
  - drape to allow extension of surgical incision beyond actual confines of wound, for EVD et drain exit, or to allow possible scalp rotation procedures.
- patients with high ICP are very vulnerable to incidents of respiratory obstruction, hypercarbia, systemic hypotension.
- N.B. once intracranial hematoma begins to be removed blood pressure may fall precipitously (esp. if multiple injury has produced hypovolemia, masked by effects of raised ICP).
- ICP monitor (or venricular drain) usually is placed intraoperatively in patients with GCS ≤ 8.

TECHNIQUE
- whole head is shaved (e.g. for placement of ICP monitor on contralateral side).
- never make small trauma cranietomy (brain may swell and may need to leave bone flap out); big trauma flap is never wrong choice (postoperative brain swelling may strangulate brain against tight cranietomy bone edges).
- Dr. Mathem likes dural tack-up plates before opening dura (if time permits) – place stitch under bone – helps with hemostasis (during the case) and dural closure.
- after evacuating mass lesion, leave ICP monitor in (even if removed bone flap).
- send selected removed blood clots for pathology (may find tumor, vascular lesion).
- malignant cerebral edema – see below >>

POSTOPERATIVE
- CT is obtained ≤ 24 hours postoperatively.

COMPLICATIONS
- Infection (craniocerebral osteomyelitis, subdural empyema, meningitis, brain abscess)
- risk factors – open scalp fractures, violated parasinus sinuses (esp. with CSF leak).
SCALP WOUNDS

SCALP AVISSION
- often contaminated with pieces of dirt - should be thoroughly cleaned and inspected for puncture wounds to ensure removal of unsuspected foreign bodies.

SCALP LACERATIONS
- Require of scalp's rich vascular supply:
  1) scalp lacerations may be source of significant bleeding.
  2) most uncomplicated lacerations can be closed (after cleansing and debridement) and antibiotics are usually not needed.
  3) even very large scalp avulsions can survive:
     - if avulsion remains attached to rest of scalp by tissue bridge, it should be reattached to surrounding tissue.
     - if avulsion is completely detached from scalp it should be treated as any other amputated part and reimplanted ASAP.

- small scalp defect is repaired by rotating portion of scalp.
- large scalp defect requires skin graft or vascularized free flap.

HEMOSTASIS methods:
- 1) direct digital compression of bleeding vessel against skull; skalpo kraujagyslės išsidėstę tarp dviejų tampatų sluoksnių - odos ir aponeurozės (galea):
   a) palpēt tik odą - kraujavimą lengva sustabdyti spaudžiamuoju tvarsčiu.
   b) palpēt tik įgaleją - įžauda placiai žyvį, o iš jos kraštų profilaziką kraujoją ( kartu tepat naménem mūsų didelio kūkio išdėtrą storg tvarą) - kraujavimą galima sustabdyti tik stipriai prasiskupdžiant žiaudos kraitus prie kaulo; to naudoti negalima, jei yra nestabilūs (nedėsminiai) fūzūmas ties įžaudą - tokia atveju prasiskupdžiant prie kaulo a. temporoa (virs arcų zygomaticaus).
- 2) infiltration of wound edges with LIDOCAINE + EPINEPHRINE.
- 3) ligation of identified bleeding vessels (likely futile maneuver except when very large vessels are found to be injured).
- 4) if galea is lacerated, it can be pulled up with clamp and its edges folded over lacerated skin edges to tamponade bleeding vessels.
- 5) Ranney scalp clips (plastic - do not interfere with CT) - easy to apply rapidly to wound edges - useful in unstable patients.
- definitive method - wound closure after proper debridement and irrigation.

Once hemostasis is obtained. wound is copiously irrigated:
- blood clots & debris should be removed (rinsed away).
- careful digital exploration of scalp wound, palpate galea and underlying cranium to detect any remaining debris, disruptions, or bony step offs; if avulsion remains attached to res attached part and reimplanted ASAP.
- if avulsion is completely detached from scalp, it should be treated as any other amputated part and reimplanted ASAP.

- subgaleal emissary vessels drain directly into diploe veins → venous sinuses → potential to intracranial infections.
- N.B. stab lacerations are particularly prone to infection.
- base of laceration must be directly visualized (easy to confuse galea disruption or periosteum tear with skull fracture) - by clipping away small area of hair parallel to edges of wound (alternatively, antibiotic ointment can be applied to hair immediately surrounding wound and used to plaster hair with skull fracture).

- if there has been prolonged exposure to skull, exposed portion of bone should be rongeured until active bleeding stops (nidus of dead bone is source of osteomyelitis).

Closure:
- galea disruption results in wound gaping - large galea lacerations must be closed (interrupted absorbable 2-0 sutures) - to prevent edges of wound from pulling apart as muscles within galea contract.
- Būtina susiūti sužalotą aponeurozę!
- other scalp layers do not require separate suturing - dermis & skin are repaired in single layer with interrupted or vertical mattress sutures of 3-0 nylon or polypropylene.
- N.B. sutures must be tied more tightly than elsewhere, so that hemorrhage is controlled (wound hematomata is particularly undesirable complication in scalp!).
- if galea is not involved, scalp lacerations can be repaired with staples.
- if laceration begins on forehead and extends upward beyond hair line, surrounding hair should not be removed (this would obliterate useful landmark for cosmetic closure → malalignment of two laceration edges).
- when repairing bald scalp, use intradermal suture.
- accidentally embedded hair within repaired laceration delays healing - by interfering with proper granulation (By producing inflammatory reaction or by serving as nidus of infection).
**SKULL FRACTURES**

**DEPRESSED SKULL FRACTURES**

**Used sources:**
- Blankenship et al. demonstrated a 0% infection rate in 31 children with compound depressed cranial fractures treated with primary bone fragment replacement, regardless of the degree of contamination of the wound at the time of surgery.

**Patient Selection**
- The usual presentation of the growing fracture is a progres- sive, often pulsatile, lump on the head. Neurological symp- toms such as seizure, hemiparesis, and mental retardation are less frequent. Often the only sign of neurological sequalae noted inci- dentally by the parents. Usually a growing fracture

**indications** – see p. 7185
- lary "S" or box-shaped incision over depression; biconal incision is preferred for forehead depressions; in open fractures, scalp wound is debrided and incorporated into incision.
- bony fragments are elevated
- bone and is soaked in antibiotic and isotonic saline solution (if wound seems clean and occurred in < 48 hours).
- cultures of wound and bone and devitalized tissue should be sent for later tailoring of antibiotic coverage should an infection develop.

**dural tears are repaired** (thus, entire lacerated dura must be exposed).

**bony fragments are reassembled** (larger pieces may be wired together), titanium mesh is applied to cover larger skull defects, methyl methacrylate can be used as substitute for bone fragments (avoid in children; H: absorbable bone plates and screws).

**No difference in infection rate if bone fragments are replaced (soon after trauma) vs. removed** (used for cranioplasty surgery):

6. Blankenship et al. demonstrated a 0% infection rate in 31 children with compound depressed cranial fractures treated with primary bone fragment replacement, regardless of the degree of contamination of the wound at the time of surgery.

**PING PONG FRACTURE**

- there are reports of using obstetric vacuum extractor at bedside to elevate fracture - works for premature skulls
- make small incision at and perpendicular to the fracture edge
- small suture (with M-S bit) on the normal bone just next to fracture line
- insert Joker periosteal elevator and pop fracture up.

- if that fails – extend incision across entire fracture; make circular craniotomy along fracture line; flip bone flap and secure to skull with small plates.
- postop - no need to restrict anything (likely kid won’t lay on that side anyway because of pain).

**LEPTOMENINGEALE CYST (S. GROWING FRACTURE)**

**CLINICAL PART**
- see p. THS >>

- treatment:
  - cyst excision – dural closure – cranioplasty
  - occasionally, shunt surgery is performed to decompress cyst and treat localized dilatation of ventricles.

**From Goodrich (2008)**

Growing fracture is a rare complication of skull fracture occurring in infancy and early childhood. This late compli- cation of skull fracture is also known as a leptomeningeal cyst. “Growing” fracture is somewhat of a misnomer, but it is characterized by progressive diastatic enlargement of the fracture line. Although skull fracture is a common occurrence in the pediatric age groups, the incidence of growing fracture is only 0.05 to 1% among skull fractures in childhood.

**Patient Selection**

The usual presentation of the growing fracture is a progres- sive, often pulsatile, lump on the head. Neurological symp- toms such as seizure, hemiparesis, and mental retardation are less frequent. Often these patients are perfectly asymp- tomatic, and a palpable mass or widening of the fracture line is the sole sign of neurological sequelae noted inci- dentally by the parents. Usually a growing fracture de velops within a few months following the initial skull frac- ture, but it may not be recognized for many years. Growing skull fractures usually occur during the fi st 3 years of life (most often during infancy), and almost never occur after 8 years of age. Although fractures may form in any part of the skull, the most common site for growing fracture is over the skull vault in the parietal region. Dural laceration is always present along the fracture line, and it is an essential factor for the development of a

**DEPRESSED SKULL FRACTURES**

- compression dressing over large lacerations (collodion dressing to small ones)
  - when compression dressing is applied, ears must be padded with cotton to prevent pressure necrosis of auricular cartilage
autologous bone cranioplasty. If initial skull fractures are noted in the same patient, healing of the fracture in one area may be noted as opposed to a linear fracture extending from the depressed fracture can usually reveal significant hemorrhage or contusion subjacent to the skull. Radiological Studies

The ipsilateral ventricle tends to show focal porencephalic dilatation with ipsilateral shift of the midline structure. This phenomenon may be due not only to lack of dural resistance but also to cerebral atrophy.

Meningoencephalocele

Surgical intervention is indicated with a growing fracture line, seizure disorder, or progressive neurologic deficits. A progressive cystic degeneration in the brain that has herniated through the dural and cranial defect is accompanied by a cerebrospinal fluid (CSF) pulse wave of the int

the cranial defect. These flaps are separated from the inner table of the skull toward the defect (Fig. 7

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The ipsilateral ventricle tends to show focal porencephalic dilatation with ipsilateral shift of the midline structure. This phenomenon may be due not only to lack of dural resistance but also to cerebral atrophy.
Figure 7-2 (A) After the craniotomy, the intact dura mater is exposed around the dural defect, which is covered by the periosteum. Underneath the overgrowing periosteum is a cerebromeningeal cicatrix that is removed using bipolar cautery and sharp dissection until healthy white matter is exposed. (B) After all pathological tissues have been removed, the edge of the surrounding dura is separated from the intact cortical surface. (C) The previously removed periosteum is used to repair the dural defect. A watertight closure is achieved with 4-0 sutures. (D) The bone grafts are split at the diploic space between the inner and outer tables by means of an osteotome. (E) The obtained split bone flaps are used to repair the cranial defect. The bone flaps are secured to each other and to the edge of the cranial defect with nylon sutures or stainless steel wires.

Specific Considerations
The growing fracture may extend toward a dural venous sinus such as the superior sagittal or lateral sinus. Although these venous sinuses were spared from direct injury at the initial trauma, direct exposure of them is not advised or necessary. When the fracture line extends perpendicularly to these sinuses, the closest end to the sinus does not need dural repair. However, if the growing fracture is parallel and near to the sinus, dural repair may be difficult due to the lack of enough dural edge next to the sinus. In these cases, one may repair the dural defect with a periosteal graft sutured to the periosteum of the skull above the sinus.

Postoperative Management
Including Possible Complications CSF diversion shunting has been recommended for persistent postoperative CSF leakage from the craniotomy wound. It is justified if coexisting hydrocephalus is evident, or if CSF leakage occurs despite adequate repair of the growing fracture. A lumbo-peritoneal shunt or temporary lumbar CSF drainage is to be considered under these circumstances.
TWIST DRILL CRANIOSTOMY (FOR CHRONIC SUBDURAL HEMATOMA)

- hole is drilled at 45° angle to skull over thickest part of hematoma (unless this lies over motor strip); possible under local anesthesia at bedside.
- twist drill is used to perforate dura and to release subdural hematoma.
- thin rubber catheter is gently guided into subdural space, tunneled under scalp, and brought out through stab incision (connect to closed drainage system without suction for 24-72 hours).
- postop – see below >>

BURR HOLE WASHOUT (BHW0), s. CRANIOSTOMY (FOR CHRONIC SUBDURAL HEMATOMA)

Principles of chronic SDH treatment (incl. indications, surgery types) – see p. TrH13 >>

**INDICATIONS**
- Subacute/chronic SDH – BHWO is the procedure of choice. – see p. TrH13 >>
- sometimes even acute SDH can be evacuated through burr holes (e.g. unstable patient with low IHB – nonclotting hematoma); but usually, if patient is minimally symptomatic (e.g. headaches), – may wait until hematoma liquefies (usually 10-14 days).

**PROCEDURE**

**Position**
- supine position: towel roll under ipsilateral shoulder.
- head on gel donut / horseshoe / subdural head holder slightly rotated to the contralateral side.
- Dr. Graham likes subdural head holder – keeps head straight vertical (helps with drainage during procedure) and permits access to posterior region.

**Anesthesia**
- local anesthesia at bedside
- monitored local anesthesia or general anesthesia in OR (best results!)

**Procedure**
- burr holes: see placed over thickest aspects of hematoma; ideally, at superior temporal line (just above temporalis muscle; if needed, OK to go through muscle)
- make 2 (1-3) burr holes:
  - e.g. frontal and parietal burr holes - if needed, can be incorporated into craniotomy;
  - studies show that patients do well with just 1 burr hole but difficult to irrigate through 1 hole!
  - if holes are placed too near extremes of hematoma, drainage may be blocked by expanding brain (H. depress surface of brain with patty or spatula)
- coagulate dura with bipolar cautery
- incise dura in cruciform manner* with a #15 or #11 blade (*do not cut to the edge of bone – leave some dura – easier to stop bleeding if it happens) – watch for motor color thin fluid
- cut with Bovie to completely open up burr holes.
  - if clearly see blood through dura, may open dura with Bovie (avoiding bipolar & blade stop)
  - if thick dark clot is found → thorough copious washout; attempt to scrape (mobilize) clot with Penfield #3, #4, hockey-stick
  - may need additional bur holes or even mini craniotomy; alternative – if significant part of clot was evacuated and brain reexpanded, – may finish and follow with CT (repeat BHWO if needed – less morbidity than craniotomy)
- attempt to fenestrate (with bipolar) visible pathologic membranes (but they may ooze blood nonstop?)
- irrigate with sterile saline via Becker catheter inserted subdurally in all directions (except superiorly towards sagittal suture – not to disrupt bridging veins)
  - irrigate until returning fluid is clear and free of old clot fragments.
- see for brain re-expansion; often, brain does not re-expand right away → drain

**Drain** reduces 2-3-fold subdural hematoma recurrence (8-9% vs. 20-24% without drain) and mortality:

| Recurrence | 9.3% | 24% | p = 0.003 |
| Mortality at 6 months | 0.6% | 1.8% | p = 0.042 |


**Drain location**

A. Subdural drain
- ventriculostomy catheter (Dr. Graham, Holloway use round 7F JP drain – it is more traumatic than EVD catheter).
- insert through posterior (parietal)* or anterior (frontal)* bur hole and advance anteriorly (i.e. direct drain towards frontal pole – when brain reexpands postop, last
fluid to disappear is frontal; if drain sits posteriorly, it becomes blocked early by reexpanding brain

*studies show no difference

– do not force drain (stop with slightest resistance encounter – drain goes to parenchyma very easily), if brain reexpanded, do not place subdural drain, rather place drain under galea and running over bur holes.
– drain complications: puncturing cortex*, causing hematoma, subdural empyema
  
*H: Becker catheter is used after the stylet is bent in shape of hockey stick – so that catheter slide not into the brain!

B. Subgaleal drain – not positioned in direct contact to cortical structures, bridging veins, or hematoma membranes

– use flat 10F JP drain; make sure holes are over bur holes (sometimes difficult as flat 10F JP drain has long tapering part that has no holes; alternative – use fluted / channelled 10F drain).
– tunnel drain under galea from anterior bur hole to posterior and the further posterior.

N.B. there is no difference in recurrence rates (7.7-8.4%)* and outcomes with subdural and subgaleal drains but subdural drains have reduced risk of infection, intracranial hemorrhage, brain injury, empyema, and epilepsy.

**SPECIAL SITUATIONS POSTOPERATIVELY**

**Risk factors**

– Alcoholism, seizure disorders, coagulopathy, ventriculoperitoneal shunt.

**Patient factors**

– Postoperative seizures

**Drain complications**

– subdural empyema
– subdural fluid leak
– scalp hematomas
– meningitis

**Drainage**

– use sterile saline


Sohaad Solomon et al. Subperiosteal vs Subdural Drain After Burr Hole Drainage of Chronic Subdural Hematoma. A Randomized Clinical Trial (rCDH-Drain Trial). Neurosurgery. 0:1–10, Oct 2019

*there are studies that show even lower recurrence rate (8.3% vs. 12%) with subgaleal than subdural drain.

Sohaad Solomon et al. Subperiosteal vs Subdural Drain After Burr Hole Drainage of Chronic Subdural Hematoma. A Randomized Clinical Trial (rCDH-Drain Trial). Neurosurgery. 0:1–10, Oct 2019

**POSTOPERATIVELY**

• postoperative seizures are reported in 3-10% patients (many surgeons use prophylactic anticonvulsants for 7-30 days after operation).

• CT next day – CT often (<92%) shows residual subdural collection – should be left alone (unless it continues to exert significant mass effect); thus, recommendation is not to do postop head CT until >3 days postop (unless patient deteriorates)

• flat bed regimen as long as subdural drain is present (to prevent sucking air intracranially++) + adequate IV hydration (to promote brain re-expansion).

• *alternatively, subdural drain may be connected to JP bulb (with minimal suction – “dimple on bulb”) – patient may sit up to 30 degrees - much better tolerated

• keep drain 1-3* days; studies show that patients do best if drain is left for ≥ 72 hours and patient remains flat at all that time; Dr. Graham keeps longer (with daily stripping of JP drain) if on CT brain is not reexpanding.

*N.B. there is no difference in recurrence rates (6.8-4.8%) or outcomes with drainage for 1 or 2 days.

• if drainage is sub-optimal (< 50%) JP can be instilled through drain.

• if intracranial pressure is elevated (e.g., HCT)

**SPECIAL CIRCUMSTANCES**

If SDH recurs after burr hole drainage

Rate of 2-3%. 

Risk factors:

1. Patient factors: alcoholism, seizure disorders, coagulopathy, ventriculoperitoneal shunt.

2. Radiologic factors: poor brain reexpansion postoperatively, significant subdural air, greater midline shift, heterogeneous hematomas (layered or multi-localized), and higher-density hematomas.

3. Surgical factors: lack of or poor postoperative drainage.

Further workup:

1) MRI, CTA of brain – for vascular abnormalities

2) MRI of spine, myelogram – for occult CSF leak (Dr. Holloway would do blood patch even if spine looks unremarkable)

Treatment:

1) correct cause

2) repeat bur hole washout.

3) medications (TXA, APOTIPSIN, DEX, etc) → see p. TrH13

– cranioamyotropy with partial removal of enveloping membranes (membranectomy*) or shunting of subdural cavity into the frontal or peritoneal cavity. 

Reoperation Rates (for hematoma reaccumulation) = 12-22%.
**Bilateral Chronic SDH**

- many experts do bilateral BHWO
- modern Japanese (and now also UPMC) – do MRI prep with intention to BHWO on one side only: if hematoma on the "conservative" side looks iso- or hypodense on T1, there is 25-fold increased chance that the second side will also need BHWO.

## ACUTE EPIDURAL HEMATOMA EVACUATION

### IMMEDIATE EXPLORATORY BUR HOLES

**INDICATION**

- conservatively uncontrollable ICP↑ with rapid patient deterioration in ED (consciousness ↓ + asymmetric findings) → think of brain compression* → emergency Burr Holes.

* if skull fracture is present – most commonly epidural hematoma.

It is life-saving procedure – unless burr hole is done patient will die or be damaged: you and patient have nothing to lose and everything to gain - inelegant burr hole now will do much more good than elegant operation one hour or more later.

**STRATEGY**

If CT is unavailable – side of burr hole is chosen:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Hematoma Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>First (or only) dilated pupil</td>
<td>Ipsilateral 94%</td>
</tr>
<tr>
<td>Most abnormal motor response</td>
<td>Contralateral 92%</td>
</tr>
<tr>
<td>Skull fracture</td>
<td>Ipsilateral 66%</td>
</tr>
</tbody>
</table>

- also can be helpful - scalp wound side, M-echo signal dislocation, pineal gland dislocation (on X-ray).

<table>
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<td>Ipsilateral 66%</td>
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<tr>
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</tr>
</tbody>
</table>

- position patient supine – allows approach to both skull sides.

1. **First burr hole** - low in temporal region, just above zygoma (one finger’s breadth anterior to tragus and one finger’s breadth above zygomatic process).

- skin incision is started perpendicular to zygomatic process and curved so it can be incorporated into scalp flap.
- inexperienced surgeons often make this burr hole too high, near temporal crest (this may fail to disclose hematoma in temporal region and is also difficult to incorporate into suitable bone flap).
- superficial temporal artery will likely be transected (cauterize or pick up with hemostat & tie).
2. If initial temporal burr hole is negative, other openings are made:
   a) close to fracture-line
   b) in region of any scalp wound (in absence of fracture)
   c) frontal (1 cm anterior to coronal suture [still behind hairline] and 3 cm from midline; skin incision is parallel to midline; periosteum here is directly beneath galea) and parietal (at parietal boss – most prominent point in parietal bone).

   N.B. incision & burr holes should, if possible, be made in such sites that can be incorporated into “question mark” flap; burr hole must be adjacent to, but not over, skull fracture.

3. If no hematoma is found on one side — proceed in analogous order on other skull side.

4. If no hematoma is found on supratentorially ± occipital fracture — bilateral occipital burr holes.
   • if epidural hematoma is not found – consider subdural hematoma. see p. TdH13 >>

TECHNIQUE

- on occasion, procedure may be performed in ED (under sterile conditions!)
- shave entire scalp (if time permits).
- usually no local anaesthetic is necessary.
- 3-4 cm scalp incision, incise right down to bone (if available, cutting cautery is used to incise galea and temporals muscle); do not stop to stop scalp bleeding.
- scrape back pericranium (periosteum) using periosteal elevator (or similar instrument, e.g. handle of scalpel) to expose skull.
- insert self-retaining retractor - this will stop all bleeding.
  - persisting bleeding (from skin or muscle) must be controlled before proceeding.


- perforate bone using perforator - do no more than just perforate skull - this will create conical hole - dark clot will ooze out; dura will not be seen as it is stripped away by clot.

- enlarge perforation using burr (hole becomes nearly cylindrical); clot will immediately ooze out:

- suck clot away by applying sucker to burr hole:
  N.B. do not insert sucker into cavity - that will cause more bleeding and might damage brain.

  to remove clot adequately, it may be necessary to enlarge hole with rongeur (i.e. to do craniectomy).
  be ready to cope with BP drop (as Cushing reflex is relieved).
  middle meningeal artery (if identified to be torn) is cauterized, waxed into bone, or secured in some manner.
  bone edges are waxed.
  Gelfoam is placed in opening to prevent blood from subgaleal space from entering cranial cavity.
  it is now safe to transfer patient for definite neurosurgical help.
  - leave scalp retractor in with voluminous sterile dressing (but some surgeons suture scalp before transfer).
  - leave in endotracheal tube and leave drip up.
  - send CT scans and any blood that has been cross matched with patient.

**CRANIECTOMY**

- unusual (method best suited for non-neurosurgeons)
CRANIAL TRAUMA PROCEDURES

CRANIOTOMY

INDICATIONS
see p. 313/11 >

APPROACH
- body is supine, head is placed on donut.
- careful with head head clamps - may propagate existing skull fractures.
- calvarium is opened over site of hemorrhage; if patient presents with clinical signs of herniation, rapid Burr hole is made over hematoma - hematoma is partially evacuated (pressure relief until entire epidural blood clot can be evacuated).

“Question Mark” skin flap (frontotemporoparietal craniotomy) - best for classical anterior temporal hematoma:
- incision is started at zygoma, 1 cm anterior to auricle; continued parietally upward and backward (“question mark”); finished frontally not far from midline at hairline.
- initial burr hole is made over zygoma.

“Horse Shoe” skin flap - for more posterior hematoma:

PROCEDURE
- hematoma evacuation.
- inspection of dura → bleeding control:
  - arterial sites - coagulation/ligation/clipping; it may be necessary to follow middle meningeal artery to foramen spinosum, where it can be controlled by plugging foramen with cotton, bone wax, or swab stick.
  - dural venous sinus - tamponade with muscle + head-of-the-bed elevation;
  - diploic vein - bleeding is controlled with bone waxing.
- if dark subdural hematoma shines through dura (or preoperative CT demonstrated contusions beneath EDH) → open dura to explore subdural space.
- epidural tack-up sutures are placed from dura to craniotomy bone edge ± to center of craniotomy flap - to tamponade epidural bleeding from areas beyond craniotomy edges and to prevent recurrence.
- occasionally, epidural Jackson-Pratt drains are employed for as long as 24 hours.

POSTOPERATIVELY
ACUTE SUBDURAL HEMATOMA EVACUATION

Indications for surgery – see p. THI13 >>

**IMMEDIATE EXPLORATORY BUR HOLES**

- durum at burr hole is centered and cut in cruciate manner (using SMALL SCALPELS).
  - cutting dura in cruciate manner produces four corners of dura that may be shrunk using cautery to expose what lies beneath.
  - if only outer dural layer is incised initially, inner layer is placed between dural leaves – dura is elevated away from brain → inner dural layer is incised (avoid injury to underlying brain but brain is supposed be separated by subdural clot).
  - if subdural hematoma has been present for some time, there will be membrane (just deep to dura) that must also be incised carefully.
  - solid subdural blood is cautiously aspirated (liquid blood is allowed to escape).
  - burr hole may be enlarged with rongeur, but craniotomy is required to adequately remove fresh subdural blood (pressure release via burr holes serves only as temporizing treatment).
  - cautious irrigation (with saline) to rinse out blood clots.

**CRANIOTOMY**

- may facilitate dura in mesh-like fashion rather than opening it (to prevent brain herniation through wound).
- remove blood (biopsy forceps, Penfield 3, gentle suction, irrigation) and surrounding "subdural membranes".
  - organized hematoma peels off surface of brain.
  - segments of hematoma, not directly exposed, can be irrigated and gently loosened with suction and Penfield #3.
  - explore areas under dura along entire perimeter by depressing brain gently* with widest ribbon (narrow ribbon cuts into brain).
- stop any active bleeding.
  1) arterial bleeding → bipolar electrocoagulation.
  2) venous oozing → Gelfoam, Surgicel, bridging veins → tamponade with muscle pieces.
- intraoperative ultrasound may locate INTRACRANIAL MEMBRANES (also may require evacuation).
- if associated brain injury and edema are present → place ICP monitor, consider bone flap removal.
- bone flap management.
  a) bone flap is replaced.
  b) bone flap is replaced loosely ("hinge craniotomy").
- leave bone flap out (craniotomy)
  - **NB**: craniotomy is never wrong with slightest anticipation of (postoperative) brain swelling.
- subgaleal (subdural) drain is placed.

**MALIGNANT CEREBRAL EDEMA**

See below >>

**POSTOPERATIVELY**

- obtain CT within 24 hours of removing acute SDH (symptomatic recurrent / residual hematoma → repeat operative intervention).

**DECOMPRESSIVE CRANIOTOMIES**

- allow brain to swell → reduced ICP → prevention of cerebral herniation and death.


Suggested further readings:
INDICATIONS

1. **Primary decompression** – prophylactic measure during emergency evacuation of traumatic subdural or epidural mass lesion when bone is not replaced in anticipation of postoperative elevated ICP.

2. **Secondary decompression** – therapeutic to elevated ICP refractory to medical treatment (e.g. in severe TBI, malignant MCA stroke, some nontraumatic pediatric cases with refractory ICP such as Reyes syndrome) – surgery is lifesaving but not restorative (of what is lost?)

some experts do not include age in making the decision whether to proceed with decompressive craniectomy, however, on the basis of data suggesting that old age does correlate with poor outcomes after decompressive craniectomy for TBI, they temper the expectations of outcomes in older patients.

**Benefits & Disadvantages, Trials**

- When performed correctly, decompressive craniectomy can reduce ICP, increase cerebral blood flow and oxygenation, and reduce therapeutic intensity levels, potentially preventing cerebral herniation and death.
- Decompressive craniectomy decreases mortality but does not improve good outcomes!

**RescueICP (Randomized Evaluation of Surgery with Craniectomy for Uncontrollable Elevation of Intracranial Pressure) trial**

- 408 patients (10-65 yrs).
- Refractory ICP > 25 mm Hg for 1-12 hours.
- Surgery was associated with better ICP control, reduced mortality, and higher rates of worse functional outcomes at 6 months (although this improved at 12 months)
- Lifesaving procedures may not restore normal functions. Maximal medical therapy may not be adequate in ICP control.

**Two issues to talk to family**

1) primary brain injury is so severe that, if patients survive, they are most likely to remain severely disabled.
2) How do people feel about surgical intervention that may leave some experts feel about surgical intervention that may leave severely disabled?

- It is important for family members to know dire prognosis to avoid unrealistic expectations (older patients, patients with limited brainstem reflexes and low GCS from time of injury are at greatest risk for poor outcome).

**Maximal medical therapy may not be adequate in ICP control.**

Australian & New Zealand & Saudi Arabia multicenter trial: randomly assigned 155 patients (15-59 yo) with severe diffuse TBI (Marshall class III CT-moderate diffuse injury) and intracranial hypertension refractory to first-tier therapies:

- a) early (within 72 hrs) decompressive bifrontotemporoparietal craniectomy
- b) standard medical management.

**outcome at 6 months** (evaluated by telephone by trained assessors who were unaware of study-group assignments):

- craniectomy led to lower ICPs and shorter ICU stays (no significant between-group difference in the total time in the hospital): 

- rates of death were similar in the craniectomy group (19%) and the standard-care group (18%).

- craniectomy led to neurological outcomes worse than with standard medical therapy (70% vs. 51%: N.B. cannot be explained by more patients surviving in vegetative state as death rate was similar):  

  Such difference disappeared after post hoc adjustment for pupil reactivity at baseline (i.e. harmful effect of craniectomy was no longer significant).

- benefit provided by lowering ICP was likely offset by surgical morbidity.

**Intracranial Pressure (ICP)** was calculated using a semiconductor ICP-EVD combination. It was measured every 4 hours, 24 hours a day, until death or for 14 days after craniectomy, whichever came first.

**ICP** was defined as a value greater than or equal to 20 mm Hg for more than 15 minutes (continuously or intermittently, i.e. cumulative) within a 1-hour period.

**second-tier options**: mild hypothermia (to 35°C), barbiturates.

**exclusion criteria**: not deemed suitable for full active treatment, dilated unreactive pupils, mass lesions (unless too small to require surgery), SCI, cardiac arrest at the scene of the injury.

**parameters monitored at 6 months** (evaluated by telephone by trained assessors who were unaware of study-group assignments):

- craniectomy led to neurological outcomes worse than with standard medical therapy (70% vs. 51%: N.B. cannot be explained by more patients surviving in vegetative state as death rate was similar):

- benefit provided by lowering ICP was likely offset by surgical morbidity.
PRINCIPLES

4. Cushing’s subtemporal decompression, temporal lobectomy (debridement of contused brain)
   - complete temporal lobectomy performed within 2 hours of the development of clinical signs of transtentorial herniation in 10 patients with unilateral hemispheric swelling and a GCS < 7 + 46 resulting in 40% functional independence.
   - all patients had displacement of the brainstem, compression of the contralateral peduncle, and progressive obliteration of the parasellar and interpeduncular cisterns on CT, along with fixed papillary dilation.

BONE FLAP MANAGEMENT

a) wash with bacitracin irrigation, saturate with sterile solution (e.g. RPMI medium 1640 www.invitrogen.com/GIBCO), sterile wrap and double bagged (e.g. intestinal bags which are then double bagged.
   - store at –80° Celsius)
   - implant into subcutaneous pocket in abdominal left lower quadrant to avoid contamination by feeding tube placement and to decrease confusion with abdominal incision scar
b) place back (if bone is fragmented or grossly contaminated)
   - “No bone flap”.

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   - “No bone flap”.

POSTOP

- head CT ASAP
- after decompressive craniectomy, the new ICP treatment threshold is > 15 mmHg
- patient need protective helmet if out of bed and a sign at the bedside “No bone flap”, precautionary order

TREATMENT

- aggressive brain debridement and watertight dural closure in World War I to minimal brain debridement with maximal surrounding bone removal instituted by Israeli physicians during the Lebanon War of 1982 with improvement in long-term seizure outcomes.
COMPLICATIONS

DECOMPRESSIVE PROCEDURES

1. Previous cranial surgery

2. Precipitous external herniation (malignant cerebral edema) intraoperatively (soon after decompression) – see below

POSTOP COMPLICATIONS

(up to 30.55%)


– In one study, hemicraniectomy lowered ICP but resulted in significantly greater cerebral edema (attributed to reduction in the interstitial pressure within the brain after decompression, resulting in a greater hydrostastic pressure gradient between the intravascular and interstitial spaces).

– “Kinking” of cortical veins against bone edges (when bone flap is too small) may lead to further engorgement and venous ischemia.

2) Expansion of hematomas after decompression.

- skull fracture contralateral to side of decompression is significant risk factor for postoperative EDH - routine early postop CT should be considered in cases with skull fracture remote to site of decompression, esp. if no ICP monitor was placed.

3) Wound complications are most common source of surgical morbidity:

a) Traumatic injury to skin incision – reimplantation, dehiscence

b) Infection

c) CSF leak (open dural tear + CSF absorption problems [CSF is absorbed passively due to pressure gradient, at least 5 mmHg across arachnoidal granulations, which is lost after craniectomy])

4) Abnormalities in CSF absorption (subdural hygroma and hydrocephalus) – due to ruptured arachnoid creating a one-way valve for CSF flow, pressure gradients between hemispheres due to reduction of ICP and decompression of one hemisphere, and alterations in the brain’s shape as a result of surgery.

- CSF absorption is disturbed after craniectomy if CSF is normally absorbed passively due to pressure gradient, at least 5 mmHg across arachnoidal granulations, which is lost after craniectomy.

- Definitive treatment is cranioplasty; VPS may not be successful due to low ICPs.

5) Syndrome of the trephined

- Fatigue, headache, mood disturbances, seizures, and even motor weakness.

- Mechanism underlying this syndrome is unknown (CBF or CSF flow abnormalities, direct atmospheric pressure on the brain).

- Symptoms improve in recumbency.

- Often resolves with replacement of the bone flap.

- No evidence that it is harmful or that delay of cranioplasty can result in long-term consequences.

Intracranial Pressure changes


- Telemetric ICP sensors (Neurovent-P/te, Raumedic, Heimburg, Germany) were implanted in 16 patients (traumatic brain injury: 7, stroke: 9) – scheduled weekly ICP monitoring sessions

- Mean ICP gradually decreased from 7.8 ± 2.0 mmHg to 1.8 ± 3.3 mmHg (P = .02) during the first month.

- Normal postural ICP change was abolished for the entire follow-up period, ie, there was no difference between ICP in supine and sitting position (P = .67).

- Normally ICP drops by 5–10 mmHg going from supine to standing

- Intracranial pulse wave amplitude (PWA) was markedly reduced and decreased from initially 1.2 ± 0.7 mm Hg to 0.4 ± 0.3 mm Hg (P = .05).

- Pulse wave propagation is believed to be an important driver of CSF flow and emerging evidence also supports its role in other intracranial fluid movements, such as glymphatic flow, hence, the reduced intracranial PWA may contribute to development of complications related to CSF flow (hydrogroma, hydrocephalus, “syndrome of the trephined”) occurring after DC.

Subsequent cranioplasty also carries the risk of infection, cerebral swelling, and resorption of the bone flap.

DECOMPRESSIVE HEMICRANIECTOMY (“TRAUMA FLAP”) / FRONTOTEMPORPARIETAL CRANIECTOMY

PLANNING

- Patient is positioned supine.

- Towel roll under ipsilateral shoulder.

- Head turned to contralateral side (do not compress jugular veins!).

- N.B. In setting of trauma, it is important to position patient with cervical spine precautions (if cervical spine fracture – position patient on bean bag)

HEAD SUPPORT

A) Head on foam headrest / gel donut - allows for repositioning of head intraoperatively if venous outflow obstruction is suspected, but pinning in Mayfield frame is most convenient.

N.B. It is very important to make large craniectomy but not to damage venous sinuses – draw midline and transverse sinus projection on scalp (thus, highly recommended to shave the scalp to have good landmarks, if leaving hair on (e.g. in less emergent cases, such as MCA stroke), mark scalp and incision before pinning the patient and while keeping head in neutral position)
B) Dr. JRC likes to pin the patient – greater access and stability (e.g. do not need assistant to stabilize head when cutting with footplate or elevating bone flap).

- AP axis of head is placed horizontal to floor (unless C-spine not cleared or if neck too immobile – one may compensate for this by rotating table)

N.B. pins are contraindicated in skull fractures (skull fractures parallel to the plane of CT imaging can be missed)

N.B. mark incision (esp. midline) before pinning the patient (see above) or else it is difficult to see midline.

Pin just below equator:

Draping

- it is easy to get off midline in emergency setting (especially if head is not pinned); H: mark skin in midline → place drapes up to midline so that you are always oriented to midline; watch for sagittal suture intra-operatively.

- prepping contralateral Kocher point for EVD can save some time after case.

PROCEDURE

SKIN INCISION

- protect superficial temporal artery - to preserve blood supply to flap.
- incorporate scalp lacerations if feasible.

In rapidly deteriorating patient with acute SDH/EDH, immediate temporal decompression is performed by incising skin and temporalis muscle down to bone just anterior to ear and above zygoma → burr hole and, if necessary, small craniectomy are created to partially decompress temporal lobe, before entire skin incision is completed.

A. Large (REVERSE) QUESTION MARK:

- starts 1-2 cm anterior to tragus at temporal root of zygoma, curves posteriorly above and gently behind ear (or just superior to pinna) to asterion;
- posterior extent of the incision should be more than 15 cm behind the keyhole;
- sweeps around parietal boss to few centimeters lateral* to sagittal suture and forward to widow's peak;
- may cross over to opposite frontal region in curvilinear fashion along hairline for 3-4 cm.

* N.B. one wants scalp incision away from craniotomy edge – postop scalp shrinks and drags scar over dura (cranioplasty is easier if scalp scar is over the bon). Plus, it is safer to mark / make incision paramedian and not in midline (to leave margin of error if midline was not clearly marked, plus, during surgery it may be difficult to visualize sagittal suture); posterior corner may hug the lambdoid suture.
B. Ludwig G. Kempe hemispherectomy incision (midline sagittal incision with “T-bar” extension)
- spares STA, posterior auricular and occipital arteries, unlike large reverse question mark incision:
  - starts at widow’s peak and is carried posteriorly along the sagittal suture to inion;
  - “T-bar” extension is started 2 cm anterior to tragus at temporal root of zygoma, curving slightly above ear and then incised superiority to meet midline sagittal suture (approximately 1 cm behind the coronal suture)
  - advantages over “?” craniotomy - much better healing (preserved vascular supply, no pressure on posterior incision), also allows for easy surgical access to contralateral side by placing second “T-bar” extension if bilateral surgical access is needed.


MUSCLE AND SOFT TISSUE DISSECTION

- skin incision is carried down to cranium; incise temporalis muscle with Bovie along skin incision.
- expose superior portion of temporalis fascia (along temporal line) and make incision leaving fascial cuff for reconstruction (only if planning to place the bone flap back at the end of procedure; otherwise elevate full thickness myocutaneous flap leaving naked bone).
- musculocutaneous flap is reflected anteriorly (i.e. temporalis muscle is elevated off bone using periosteal / Bovie) and fixed with scalp hooks/towel clamps.
- ideally, muscle dissection extends down to root of zygoma and as far below keyhole as possible, to maximize temporal decompression achieved.
BURR HOLES AND BONE FLAP

- Several burr holes (at least three) are made to create a bone flap that is at least 12 cm × 15 cm (smaller bone flaps would not sufficiently decompress the brain but may be sufficient for EDH or SDH evacuation when brain edema is not expected) – use ruler to measure back from keyhole to ensure anteroposterior extent of bone flap is 15 cm.
- Large burr hole is placed in temporal squamosa at zygoma root; additional burr holes can be placed posterior (parietal) and 1.5 cm off midline (frontal).

- Flap should extend 1.5 cm from midline, 1-2 cm above transverse sinus – to decompress vein of Labbé, parasagittal bridging veins.
- in especially urgent cases (recent anisocoria and underlying SDH), making cruciate opening in dura through first burr hole may provide some relief of intracranial hypertension.
- dura over anterior frontal lobe is commonly torn (typically in emergencies and older patients) - it is good practice to assume that dura may be incompetent in frontal area and to begin to strip dura and elevate bone flap away from this site.
- Dr. Villanueva makes parasagittal bone cut from front to back (rationale – dura is more commonly is damaged at the beginning of cut – so better to tear SSS anteriorly).
- fate of bone flap - see above >>

TEMPORAL FLOOR
- after removal of bone flap, remaining TEMPORAL BONE must be cut with rongeur down to floor of middle cranial fossa (subtemporal craniectomy) to provide maximal decompression of lateral brainstem.

N.B. BITE with rongeur (not twist or torque) during bone removal low in middle fossa; aggressive maneuvers with rongeur can open or displace skull base fractures → uncontrolled bleeding.

- sphenoid wing is removed with rongeurs or high-speed drill
- wax bone edges.
- line cranial edges with hemostatic material (e.g. Surgicel) and Cottonoids.
large amounts of bleeding arising from the middle cranial fossa warrant further attention and usually come from the middle meningeal artery or the sphenoid wing. In this situation, a slightly more conservative temporal craniectomy can provide bone to which the dura can be tacked to help tamponade such bleeding.

**Dural Opening**
- Several choices:
  a) Only vertical slit incisions (“pie cutting”)—if expect malignant cerebral edema (e.g. in GSW) so will be difficult to close even scalp flap, slide brain ribbon through slit and then suction tip over brain ribbon—evacuate clot, if brain looks collapsed after clot evacuation, may connect cuts by horizontal dural cut (so result is H).
  b) C flap
  c) Shaped with spoke-wheel relief cuts 1-cm short of the craniotomy edge with dural releasing incisions made at intervals up to the bone margin to avoid strangulation of the brain on the dural edge.
  d) Multiple radial incisions (in stellate fashion) to provide maximal cerebral decompression:

**Open Dura slowly (**!!!**—risk of sudden cardiovascular collapse; H: adequate resuscitation by anesthesia & central line is a must).

**Postop**

**Closure**
- Using dural substitute (DuraGuard, SepraFilm).

**Options**

A. Duraplasty—suturing graft to dural edges.

B. Leave durotomy open to permit brain expansion (“rapid-closure DC”); cover brain with onlay dural substitute to protect brain surface and reduce adhesions to scalp flap—leaves of dura are folded over dural substitute (do not suture patch to dura!)

- Epidural tack-up sutures to bone edge.

- Subgaleal drains are placed over surface of dural substitute and tunneled externally; at least two Jackson-Pratt drains (patients often do not clot properly, and without tamponading effect provided by bone flap, risk of EDH is high).

N.B. Routine prolonged use of drains is needed!?

- Galea is closed with numerous, closely spaced interrupted 2-0 absorbable braided sutures.

- Skin is closed with running 4-0 absorbable monofilament suture / staples—to prevent CSF leak.

N.B. To ensure watertight closure, sutures are placed very close together!

- Sterile head wrap (not tight if bone removed + label side of head without bone)

**Postop**

Head CT ASAP; Decompressive hemicraniectomy. Note the extensive boney decompression from the frontal bone to the occiput and the remaining interhemispheric subdural hematoma. The brain parenchyma on the left can be seen protruding beyond the previous boney boundary indicating how severe the intracranial hypertension was. The hyperdensity seen above the left frontal lobe is part of the Jackson-Pratt subgaleal drain.
INDICATIONS

Level II A recommendation
- bifrontal DC is not recommended to improve outcomes (as measured by GOS-E score at 6 months post-injury in severe TBI patients with diffuse injury and with ICP > 20 mm Hg for > 15 minutes within a 1-hour period that are refractory to first-tier therapies).
- demonstrated to reduce ICP and to minimize days in ICU.

PROCEDURE
- supine position with the head in 15-30 degrees of flexion.

INCISION
- bicoronal (Souttar) incision - starts at root of zygoma, 1-2 cm anterior to tragus, extends superiorly to or just behind coronal suture, and ends at root of opposite zygoma, 1-2 cm anterior to tragus.
- Dr. Villanueva uses wavy (vs. straight) incision – scar does not interfere with chewing.

- myocutaneous flap is brought forward over the orbital rim.
  - dissect out the supraorbital nerves from the supraorbital notch on either side (if the supraorbital notch is closed, a small osteotome can be used to open it so that the supraorbital nerve can be freed) - allows further advancement of the myocutaneous flap.

HOLEs
- bur holes are placed in:
  1) pterion (keyhole)
  2) root of zygoma
Cranial Trauma Procedures

3) just below superior temporal line
4) over superior sagittal sinus (last bur hole to make) – if a large single bone flap is planned
   * posteriorly – behind coronal suture
   ** (Dr. Villanueva extends even further to parietal bossings – the adequate decompression of sagittal sinus)
   ** alternatively, strip of bone can be left over sagittal sinus for protection.

- bilateral frontal and subtemporal craniectomies are performed, exposing frontal and anterior temporal lobes.
- anteriorly, drill passes just above the orbital rims and nasal bridge.
- additional (optional) removal of squamous portion of temporal bone and greater wing of sphenoid bone is accomplished with rongeur, removing bone to floor of middle fossa.
- immediately after removing bone put lap pad with H2O on entire dura – air embolism prophylaxis (in case SSS was damaged) plus hemostatic.
- if frontal sinus is entered, it must be cranialized (dissect the flap of pericranium to cover it).

A. One bone flap:

N.B. cross the superior sagittal sinus with the footplate last!

B. Two bone flaps:

N.B. if midline bone strip is too wide, it can damage the brain!

Variant without temporal decompression (avoiding zygomatic bur hole):


Dura

- some experts insist, that the division of the anterior superior sagittal sinus and falx is crucial.

Dural cuts:

a) standard Kjellberg open fish-mouth cut: made along floor of anterior fossa with release of inferior aspect of interhemispheric falx and then curved up (along posterior bone edge) towards SSS
b) mitral valve-type dural incisions - parallel to superior sagittal and parallel to posterior bone edge (some recommend connecting bilateral incisions along floor of anterior fossa with release of inferior aspect of falx)
c) bifrontal cruciate incisions

POSTERIOR FOSSA DECOMPRESSIVE CRANIECTOMY

- incision: midline skin incision from above inion to ≈ C2 spinous process.
- bone opening: laterally to sigmoid sinuses, superiorly to transverse sinus.
- C1 laminectomy is typically performed as well.
- dural opening: "Y" shaped incision.

PENETRATING BRAIN INJURIES

- systemic antibiotics + tetanus prophylaxis + seizure prophylaxis
- rapid local debridement - clean from bone fragments, necrotic brain, debris, foreign objects.
  - debridement of devitalized brain is gentle (use combination of suction and irrigation).
- exploration for hemorrhage and necrotic tissue (recent data question practice of pursuing bone chips spread deeply into brain).

- retained fragments have not been associated strongly with infection, most authors remove fragments only if they are accessible. (secondary removal is performed only for unusually large retained fragments - complication rate for repeat exploration may exceed rate of complications of retained fragments)
- watertight closure - after hemostasis, all layers of wound are closed tightly (drains are added when hemostasis is not absolute).

Options (class III) for penetrating TBI:

a) small entrance bullet wounds → local wound care and closure.

b) extensive wounds with nonviable (devitalized) scalp, bone, dura → more extensive debridement before primary closure or grafting to secure a watertight wound.

c) significant fragmentation of the skull → debridement with either craniectomy or craniotomy.

d) significant* mass effect → debridement of necrotic brain tissue and safely accessible bone fragments, evacuation of intracranial hematomas.

- N.B. in the ABSENCE OF SIGNIFICANT MASS EFFECT, surgical debridement of the missile track in the brain is not recommended (class III evidence - outcomes are not measurably worse in patients who do not have aggressive debridement); routine surgical removal of fragments lodged distant from the entry site and reoperation solely to remove retained bone or missile fragments are not recommended.**

e) open air sinus injury → watertight dura closure

- the question of timing of surgery has not been adequately studied to make evidence-based recommendations but general practice is to operate promptly.

- N.B. CSF leak is the variable most highly correlated with intracranial infection after PBI (CSF leak increases risk of infection 10-20 fold).

- Highest risk of CSF leak - transventricular trajectories (suggesting a course of CSF drainage in such cases), trajectories through air sinuses (suggesting sinus craniolization in such cases).

**significant - displacement of the midline > 5 mm, compression of basilar cisterns from edema or hematoma, deteriorating clinical condition.
Current standard is debridement of first few centimeters of tract — water tight dural closure

Vigorous debridement and pursuit of intracranial fragments are not necessary to prevent infection, has no obvious efficacy in preventing epilepsy, and is associated with morbidity and mortality without resulting in any clear advantage in mortality.

**GUNSHOT WOUNDS**

Military vs. civilian penetrating brain injury (PBIs)

- Most PBIs incurred on the battlefield are from shrapnel, not bullets, like most civilian PBIs.
- Most PBIs on the battlefield by a high-velocity bullet never make it to medical care - extremely damaging cerebral injuries that these bullets inflict. (Field usage under battle conditions requires the corpsman to identify the injured who have a low probability of surviving and to not prioritize them for rapid transport).
- Wounds are much more likely to be contaminated on the battlefield.
- Suicides are much less frequent.
- Battlefield care conditions are inferior and evacuation times are much longer (mean evacuation time in the military setting is 2.5 hours vs. 30-45 minutes in civilian injuries).
- In the military situation, severe CSF leaks may occur from entry to exit wounds, caused by fractures and dural rents resulting from the concussive effect of the projectile.
- Injuries in the military setting occur primarily in young men in otherwise excellent physical condition; vs. civilians, 70% are older age range.
- Literature reports a mortality under wartime conditions in the 20% range (8-43%: military gunshot wounds have 2.5-4 times higher mortality than from shrapnel wounds) vs. 94% for civilian cases.

- Fast surgery: often represents “damage control” surgery - quick removal of mass lesions, thorough debridement of intracranial bone and metal fragments, removal of necrotic brain, and deep depressed skull fractures is helpful in finding retained fragments or hematomas, and quick decision with respect to decompressive craniectomy.
- Deeply impaled bone fragments and foreign bodies are not chased.
- Scalp incision (during primary craniotomy) is better to locate away from penetration wound so that least possible scarring will overlie site of any future cranioplasty.

- Traumatic CSF leaks are delayed for 1 year (when patient is medically stable and risk of infection is low).

**STAB INJURY**

a) jej irgusas pateko sau įžūdus šalmačiai priemonė, jei sužeidimas vykės prieš +12 valandų, žiaudu nėra stipriai užteršta jei ligonis pateko jau hard to control bleeding, ligation is dangerous.

b) Sąveikaukite su neįtikėtinais žaizdais: jei sužeidimas išėmęs žalojančią priemonę, pašalinimas atliekamas atkartojant ginklo trajektoriją retrogradiškai.

... • vigorous debridement of intracranial fragments and CSF fistula...

DURAL VENOUS SINUS INJURIES

Traumatic dural venous sinus injuries carry high mortality (vs. slow sinus occlusions by tumor) - hard to control bleeding, ligation is dangerous.

- may be caused by depressed skull fractures overlying any of major intracranial venous sinuses.
- maintain hydration to prevent thrombosis.
- if major venous sinus injury is suspected: approach by exposing intact sinus above and below, open dura on both sides so that sinus can be clamped; ETOMATE for neuroprotection.
- anterior 1/3 of superior sagittal sinus can be ligated without any clinical sequelae; tears of posterior 2/3 of sinus need repair• (primary repair or patching with galea or pericranium, alternatively, piece of muscle or Gelfoam may be sutured over sinus).

*because ligation may cause lethal venous congestion...
Cranial Trauma Procedures

MALIGNANT CEREBRAL EDEMA

- ominous sign!
- may happen if patient had period of hypotension / hypoxia – maximally dilated and brain vessels with paralyzed autoregulation.
- may happen precipitously intraoperatively (soon after decompression) → external herniation

MANAGEMENT

- make sure no venous outflow obstruction, make sure no tapes around neck.
- elevate HOB.
- avoid high SBP
- increase depth of anesthesia
- hyperventilate
- additional transtentorial
- place EVD
- suspect contralateral hematoma - empiric surgical exploration on other side without interim CT (esp. in setting of contralateral skull fracture)
- avoid venous compression at sharp bone edges by making a gap in the bone above draining veins using a bone rongeur.
- subtotal temporal and/or frontal lobectomies may be necessary
- primary scalp closure maybe difficult (if this possibility is suspected in advance, it is wise to obtain hemostasis and be prepared to close before dura is opened); plus:
  - if head damp (Mayfield, Sugita) was used, it should be released to give the scalp laxity to be mobilized toward the incision.
  - dissection of the galea from the neighboring skull may be performed to provide more laxity.
  - make incisions in the galea from the underside of the scalp without cutting the epidermis (relaxing incisions).