- chlorhexidine is contraindicated at age < 2 months (use Betadine).

DEVELOPMENTAL

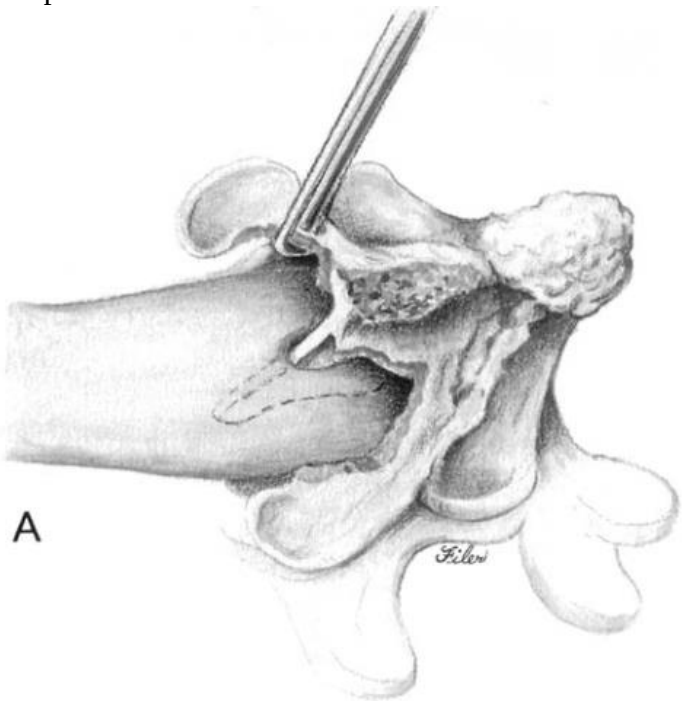
Genetics consult!!!!

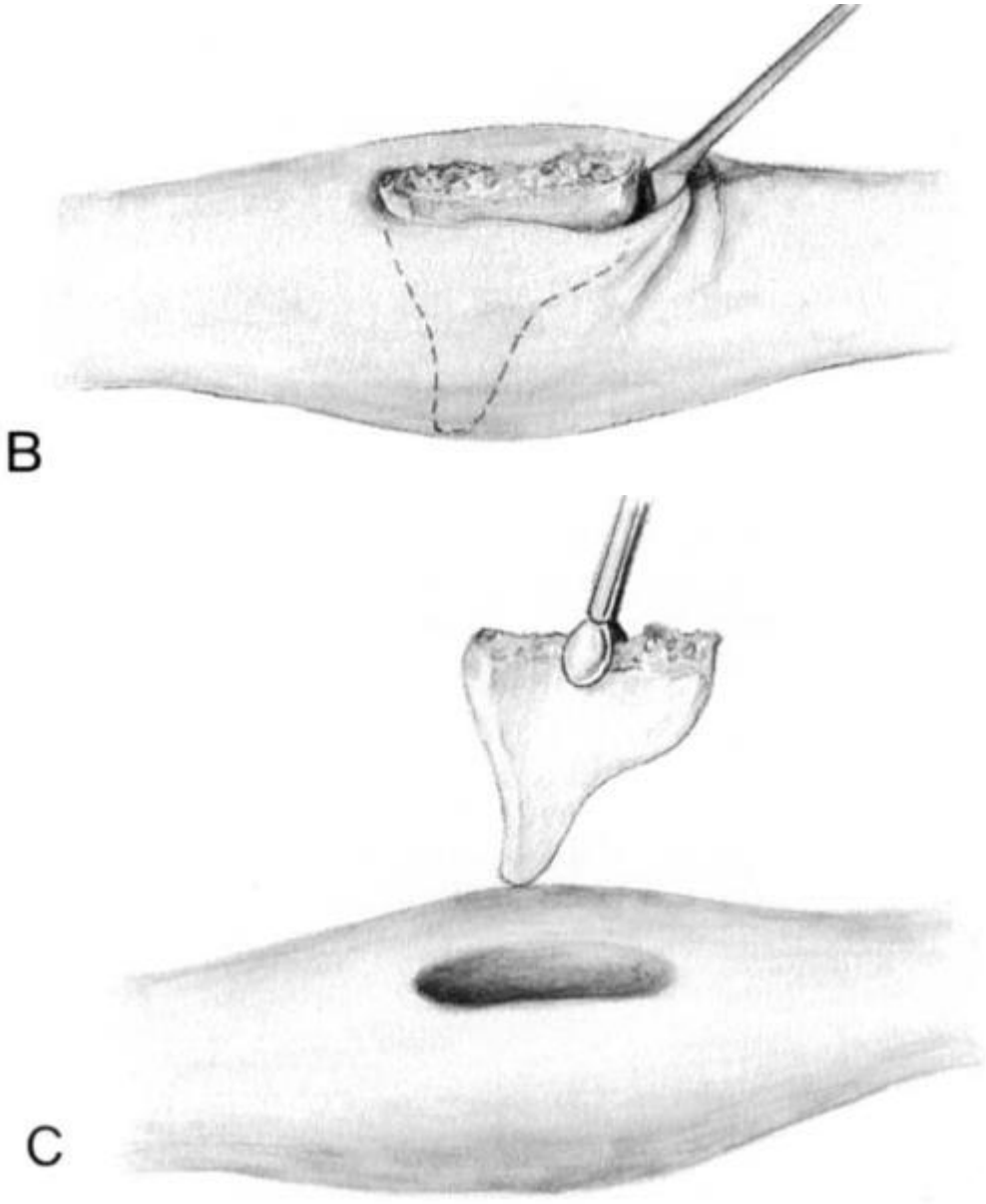
N.B. **palpate anterior fontanelle before proceeding with any other part of physical examination on acutely ill baby**!

ABNORMAL FORMATION OF NOTOCHORD (neurenteric canal disorders):

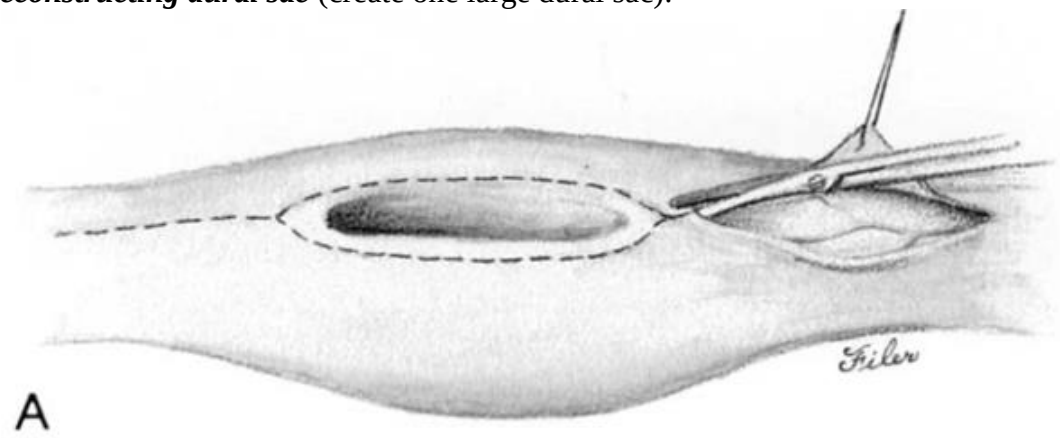
1) **neuro-enteric cyst** (intradural cyst anterior to spinal cord) – due to neurenteric canal persistence.

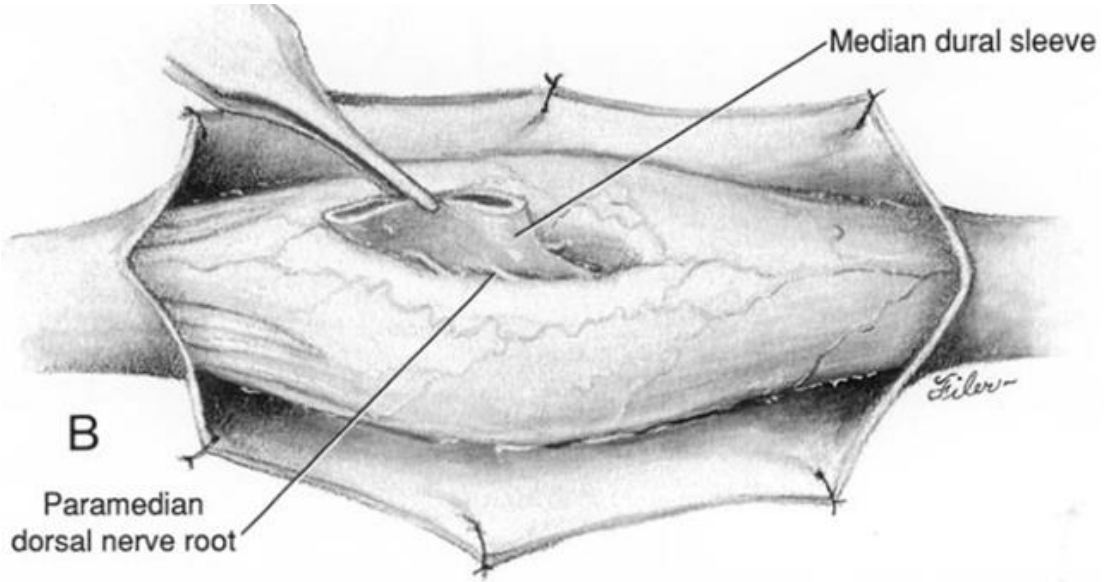
2) **diastematomyelia** (***cleft* in spinal cord**), **diplomyelia** (***duplication* of spinal cord**) – due to adhesions **between *ectoderm* and *endoderm*** → split notochord and secondary splitting of neural plate and vertebral bodies.
    - **mesenchyme** moves into space between hemicords and forms ***spur*** or complete ***septum*** which tethers cord.
    - **skin stigmata** (invariably present, esp. hairy patch – hypertrichosis is a hallmark of split cord!).
    - may be asymptomatic! (but in **children**, eventually from flexion-extension movements impaired innervation to lower extremities - tethering lesions - neurological deterioration is very common and lost function is seldom reclaimable)
        - **adults** - no available data on natural history (evidence to support prophylactic surgery in asymptomatic adults is much less convincing) but it is known that neurological deterioration can be precipitous after a fall or strenuous exercise:
            - asymptomatic adults who are healthy and lead a physically vigorous life → operate.
            - old or infirm, sedentary lifestyle → conservative.
    - preop – MRI + CT myelogram
    - **surgery** (for symptomatic patients): IONM!
        - untethering spinal cord by **removing bony / fibrous septum** (bony septum is always extradural).
        - septum-bearing hypertrophic ***lamina is carefully rongeured*** away piecemeal around attachment of septum until only a small island of lamina is left attached to dorsal end of septum

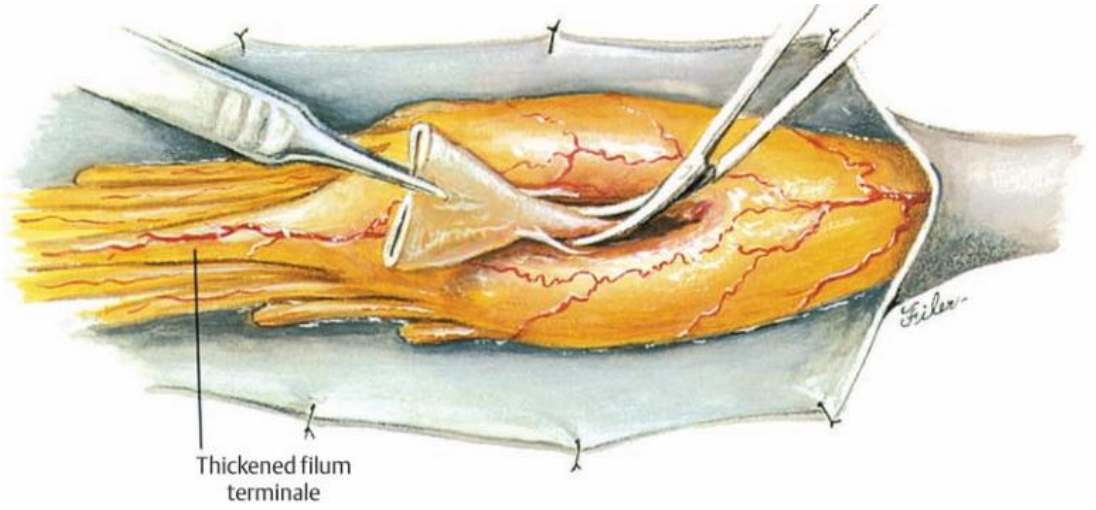




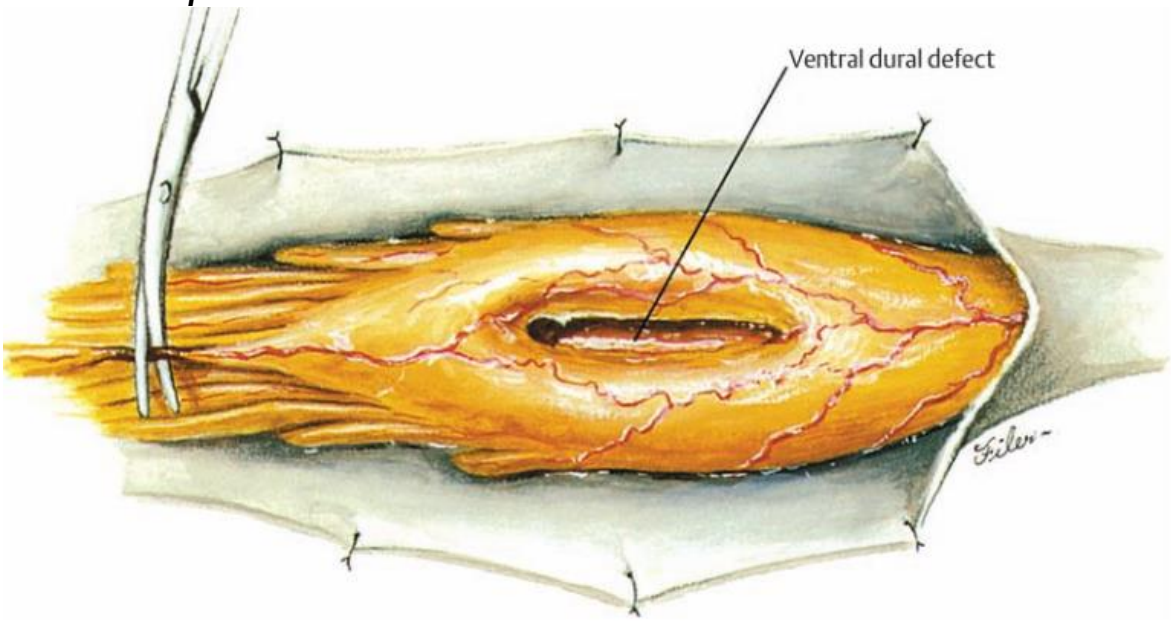
— ***reconstructing dural sac*** (create one large dural sac):







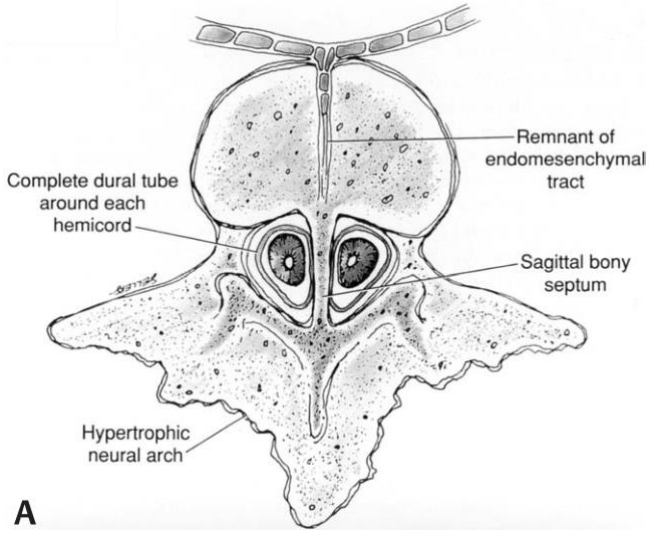
— most *SCMs located in low thoracic or lumbosacral region* have at least one associated lesion tethering tip of conus, which must also be removed later during same procedure; ***cut thickened filum***:



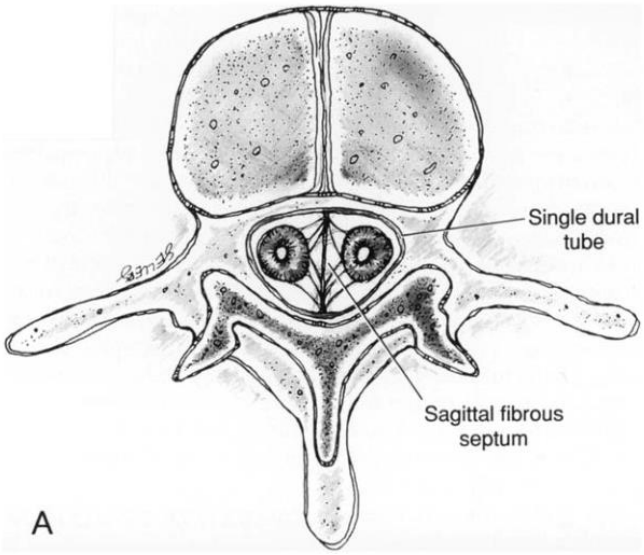
— ***closure of anterior dural defect is unnecessary*** because of abundant adhesions of ventral dura to posterior longitudinal ligament that would naturally prevent CSF leakage

— cords remain separate – do not reunite them!

Type I SCM - bony



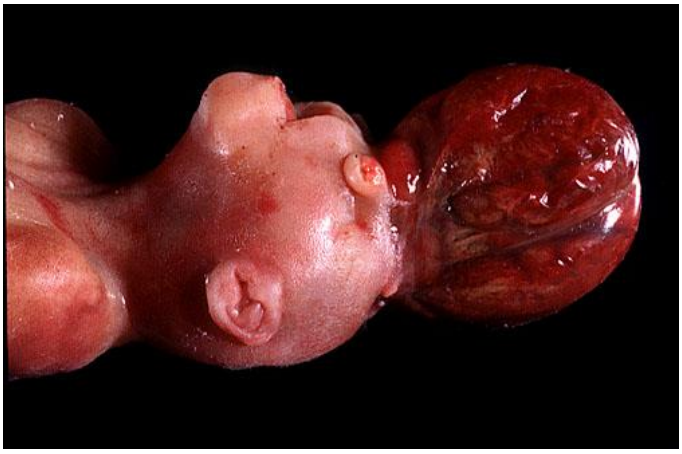
Type II SCM - fibrous



NEURAL TUBE (s. NEURULATION) defects (s. dysraphia, abnormalities of DORSAL induction) - earliest to appear (< 28 days of gestation - *women is frequently unaware that she is pregnant* during this critical time!):

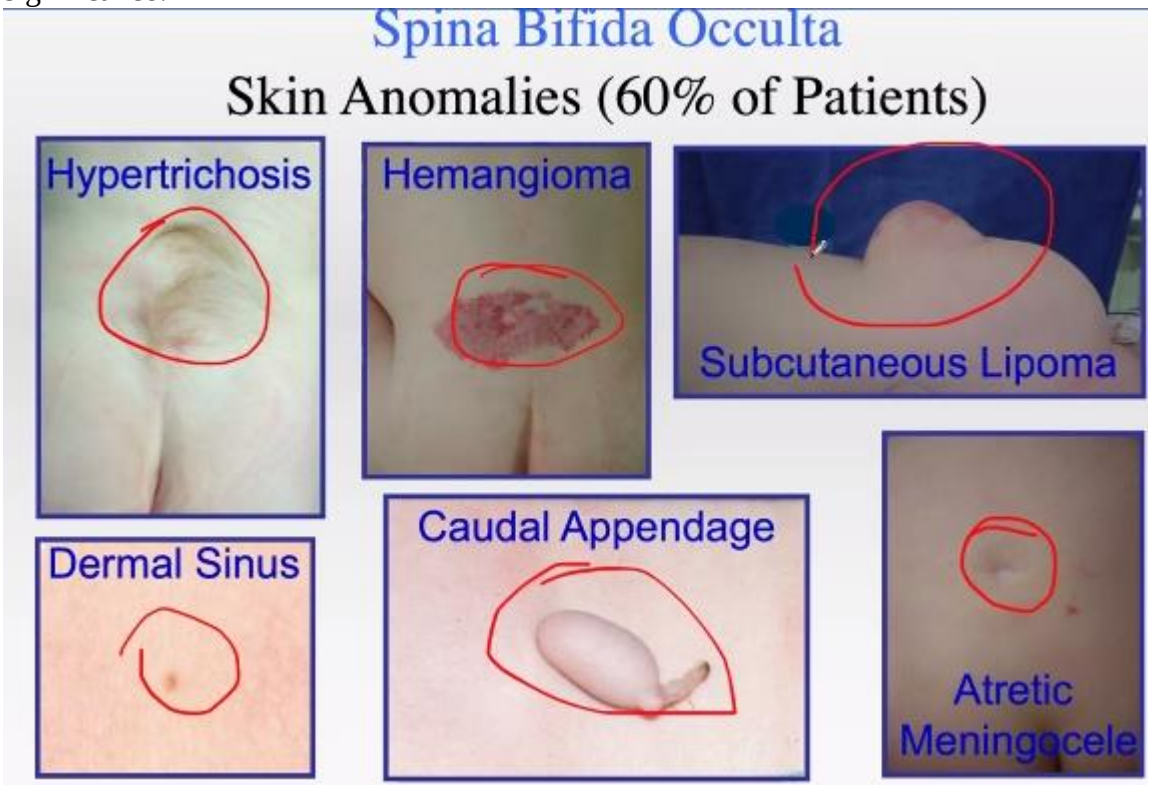
N.B. direct contact with amniotic fluid results in degeneration of neural epithelium

1. **CRANIORACHISCHISIS TOTALIS** - total failure of neural tube closure → brain and spinal cord necrosis secondary to exposure to amniotic fluid.
   - **iniencephaly** = occipital bone defect + cervical dysraphism + head retroflexion.
2. **CRANIOSCHISIS, S. CRANIUM BIFIDUM** (defects of cranial neuropore closure):
   1) **anencephaly** - complete absence of brain and calvarium; no epidermal covering.
   2) **exencephaly** - defect in calvarium (dura, bone, skin):

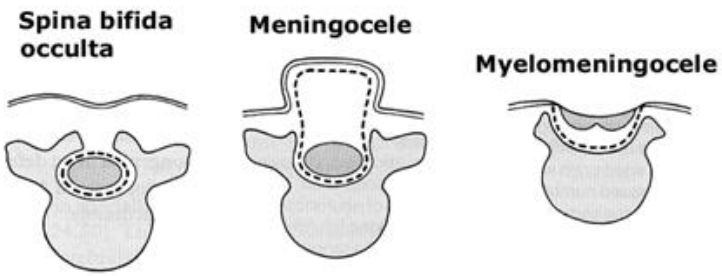


3) **encephaloceles**, **cranial meningoceles**.
   - in few cases portions of ventricles are also included - **ENCEPHALOCYSTOCELE**.

3. **SPINA BIFIDA** - mostly occurs in ***lumbar region***
   A. *Spina bifida occulta* – only defect in vertebral arch (skin is intact but may have **cutaneous markings - tuft of hair**, cutaneous **angioma** or **lipoma**; rarely, sinus tract) - no clinical significance!



   B. *Spina bifida manifesta* (amniotic fluid **AFP↑** + **AChE↑**):
      a) **meningoceles** (neural elements are intact; **surgical repair** – for cosmetic reasons)
      b) **myelomeningoceles***
      c) **myeloceles**
      d) **rachischisis** (myeloschisis + spina bifida).



*associated with Chiari II, hydrocephalus

Spinal dysraphism may be classified pathogenetically:

A) **nondisjunction of neural ectoderm from cutaneous ectoderm**:
   1) **myelomeningocele** (extensive failures of dysjunction)
   2) **dorsal dermal sinus** (punctate failures of dysjunction) - thin communication between *dorsal skin* and *spinal canal*

B) **premature dysjunction of neural ectoderm from cutaneous ectoderm** – various fatty tissue inclusions:
   1) **lipomyelomeningodysplasia** (lipo-myelomeningocele, -myelocele, -myeloschisis).
   2) **subpial lipoma**, **intramedullary lipoma**

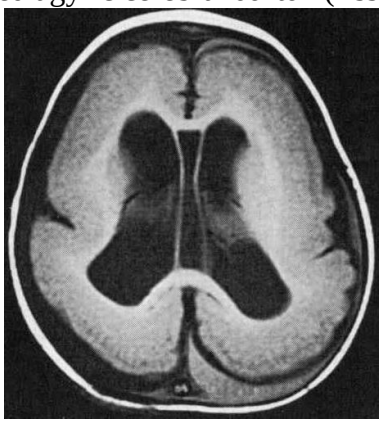
C) **disorders of secondary neurulation** (s. **abnormal retrogressive differentiation**) - occult dysraphic states (commonest malformations diagnosed in adults!):
   1) **tethered filum / tight filum / fatty filum** (failure of fibres in filum terminale to lengthen → tethered spinal cord)
   2) ***caudal regression syndromes*** (**failure to form terminal spinal cord**, **sacral agenesis**)

SEGMENTATION, CLEAVAGE and MIDLINE defects (s. malformations of VENTRAL induction) – appear during 5–8 weeks of gestation - failure of prosencephalon to grow into two symmetrical hemispheres and defects in region of lamina terminalis:

1. **Holoprosencephaly** - failure of prosencephalon to separate into two cerebral hemispheres: severe facial malformations: cyclopia, cyclopia with agnathia; posterior fossa normal.
2. **Septo-optic dysplasia** - absence of **septum pellucidum** + **optic nerve** hypoplasia
3. **Agenesis of corpus callosum** + associated absence of cingulate gyrus; **largely clinically silent** – *disconnection syndrome* only rarely may be discovered.
4. **Arrhinencephaly** - absence of **olfactory bulbs** and **tracts** → *anosmia;* KALLMANN'S syndrome: add *GnRH deficiency*

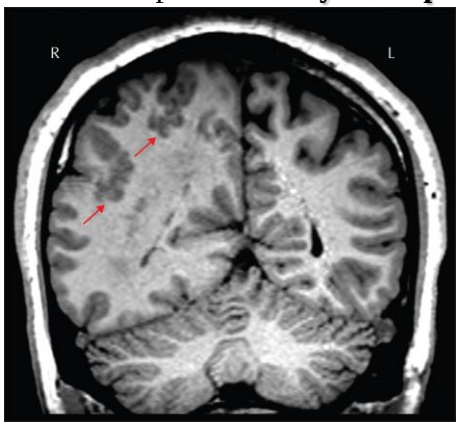
NEURONAL MIGRATION and CORTICAL FORMATION disorders - histogenetic period (2–5 months of gestation) → *seizures* ± *mental retardation*

1. **Lissencephaly** (s. agyria) / **pachygyria** (s. macrogyria – "local lissencephaly") - markedly thickened agyric cerebral ***cortex*** (fissures normal!):



2. **Polymicrogyria**
3. Neuronal **heterotopia** - groups of neurons in inappropriate places (periventricular node, subcortical stripe)
4. Focal **cortical dysplasia** - maloriented neurons in inappropriate layers.
5. **Ulegyria*** - fusion of layer 1 at depths of sulci (gyrus in cross section - *mushroom appearance*)

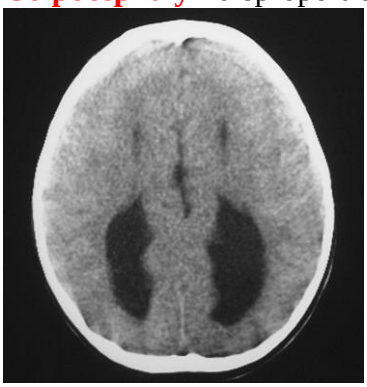
6. **Schizencephaly*** - cleft within cerebral hemisphere lined with gray matter.
7. **Porencephaly*** - cyst lined with white matter that *communicates* with lateral ventricle and / or subarachnoid space (**hydranencephaly -** extreme form of porencephaly - *bilateral occlusion of internal carotid arteries* during early fetal development - cerebral hemispheres are almost totally absent or represented by membranous sacs)
8. **Megalencephaly** - enlarged *brain volume* (white and gray matter volume↑)
9. **Hemimegalencephaly** - abnormally large *one hemisphere* (with ***marked micro and macro disorganization*** → perform **early hemispherectomy**):



10. **Microencephaly**

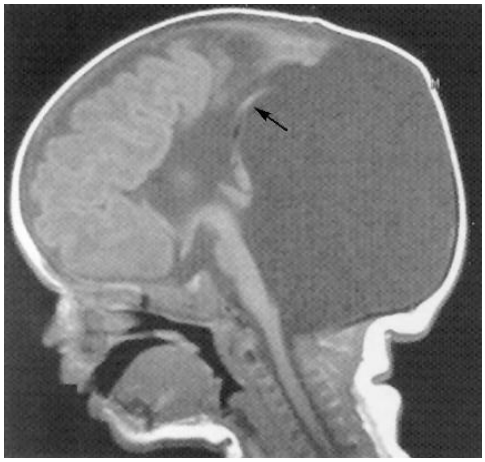
*etiology - perinatal destructive insults (esp. vascular)

Colpocephaly - disproportionate **enlargement of occipital horns** of lateral ventricles:



POSTERIOR FOSSA anomalies (posterior fossa structures are also formed during ventral induction period) – anomalies of **brainstem & cerebellum**:

1. **Chiari malformations**
2. **Dandy–Walker malformation** – imperforation of Magendie and Luschka foramina → cystlike dilation of 4th ventricle ("large posterior fossa cyst" vs. in true cyst – 4th is compressed), enlarged posterior fossa, absent cerebellar vermis, obstructive *hydrocephalus* → **double ventriculoperitoneal and cystoperitoneal shunt**



3. **Mega cisterna magna**
4. **Vermian–cerebellar hypoplasia**
5. **Joubert's syndrome** see Mov50 p.
6. **Mobius' syndrome** see CN7 p.
7. **Marcus Gunn syndrome** see Eye64 p.
8. **Duane syndrome** see Eye64 p.

Abnormalities of CRANIUM

1. **Microcephaly** ← microencephaly, synostosis
   Most intracranial conditions causing microcephaly are untreatable!
   The only treatable cause is craniosynostosis!
2. **Macrocephaly** ← BESS, ICP↑
3. **Craniosynostosis** - **premature fusion** of one or more of 6 cranial sutures → facial and cranial deformity + ICP↑

BESS syndrome (benign enlargement of subarachnoidal space) - no signs of raised ICP; infants develop normally clinically.

- head shows initial rapid growth followed by normal rate (larger than normal head growing at normal pace).
- positive history in one or both parents.
- **imaging** - wider than normal ventricular system and subarachnoid spaces (particularly over frontal lobes); brain is otherwise normal.
- will eventually reduce and become normal in size.

Abnormalities of CRANIOCERVICAL JUNCTION

1. **Basilar impression, basilar invagination, platybasia, convexobasia** - floor of posterior fossa bulges upward → narrowing of foramen magnum.
2. **Atlantoaxial instability** - ADI > 3 mm → acute or chronic **spinal cord compression**
3. **Occipitalization of atlas (s. assimilation of atlas)**
4. **Dens hypoplasia, os odontoideum**
5. **Klippel-Feil anomaly** - congenital fusion of cervical vertebrae

Abnormalities of SPINE

1. **Vertebral fusion anomalies**
2. **Transitional vertebra** - vertebra ***at junction of major divisions of spine*** has CHARACTERISTICS OF BOTH DIVISIONS (e.g. cervical rib)
3. **Hemivertebra** - incomplete development of lateral half of vertebral body → kyphosis / scoliosis

4. **Butterfly vertebrae** - failure to fuse of two lateral centers of chondrification for vertebral body → cleft in midsagittal plane
5. **Failure of fusion of secondary ossification centers** - can be confused with fracture!
6. **Limbus vertebra** - anterior interposition of intravertebrally herniated nuclear material → triangle-shaped bony mass
7. **Pedicle anomalies** (absence or hypoplasia)

ETIOLOGY

A. **Genetic** etiology (e.g. homeotic genes that control body patterning).
B. **Environmental teratogenic insults** to antenatal brain:
   1) infections (most commonly!)
   2) irradiation
   3) toxins (e.g. antiepileptics, alcohol)
   4) metabolic disorders (e.g. phenylketonuria)

Risk factors for neural tube disorders:
1) maternal hyperthermia
2) maternal diabetes
3) anticonvulsants (esp. *VALPROIC ACID*, *CARBAMAZEPINE*)
4) previous fetus with neural tube defect (risk increases 10-fold)

Folate supplementation 4 mg/day before conception and during early pregnancy (until 12th week).
- esp. for women who have had infant / fetus with neural tube defect.

U.S. Public Health Service 1992 recommendation:
1) all women of childbearing age capable of becoming pregnant must take **0.4 mg folate** daily.
2) women who had pregnancy with in neural tube defect must take **4 mg folate** daily (beginning 1 month prior to time pregnancy is planned).

DIAGNOSIS

PRENATAL diagnosis:
1) amniocentesis
2) ultrasonography
3) MRI

- **genetic counseling for parents** (of child with major neurologic abnormality) - *risk of subsequent child's having such defect is high*.

Imaging in SPINAL malformations – rationale is EARLY DETECTION:
- 50% patients have no neurological symptoms in infancy but without neurosurgical treatment 90% will develop neurological deficit!
- repair closed spinal dysraphism as soon as malformation is diagnosed.

1. **Spinal ultrasound** – highly accurate, but cannot completely exclude malformation; if malformation is found, further imaging is still indicated.
2. **MRI** (!!!) - can show most components of malformations.

ENCEPHALOCELE

Pathogenetic theory for acquired cephaloceles in **adults** - associated either with trauma (incl. iatrogenic) or increased ICP (most common locations - where bone is already thin - tegmen tympani, middle cranial fossa pits → into sphenoid sinus).

Basal encephaloceles - the only group that does not produce a visible soft tissue mass; may present as CSF leak or recurrent meningitis

Clinical Features

1) **protuberant mass** that may be pulsatile.
2) **neurological deficits** correlate with extent of ***cortex that is herniated*** into cele: motor deficits, visual defects, psychomotor developmental delay.
3) ***malformed cortex*** (within / adjacent to cele) → **seizures**.
4) frequently associated with *other intracranial abnormalities* (e.g. hydrocephalus!).
5) PROGNOSIS is good for many patients.

N.B. encephaloceles that contain large amount of neural tissue have poor prognosis!

Surgical management – as early as clinical conditions permit (exceptions – very small defects, large defects with associated microcephaly)

1. Encephalocele contents:
   a) **relocation** into cranium
   b) **amputation**
2. Watertight **dural closure**
3. **Bone grafting** to cover calvarial defect.

- **CSF leak** → urgent surgery within 12-24 hours (to prevent meningitis).
- PROGNOSIS is best in sporadic frontal encephaloceles; occipital encephaloceles are more commonly associated with hydrocephalus → worse cognitive outcome.
  - temporal encephalocele has high epileptogenicity.

Basal encephalocele in adult – only for CSF leak / meningitis - combined intracranial approach (with amputation of the extracranial mass) + transnasal approach

Caution: a transnasal approach to a basal encephalocele (even for biopsy alone) may be fraught with intracranial hemorrhage, meningitis, or persistent CSF leak.

NASAL GLIOMA (misleading term - not neoplasm!; better term - **NASAL GLIAL HETEROTOPIA**) - form of **frontonasal encephalocele** with no clear bony defect!!!!

- **intranasal mass** (CSF rhinorrhea following removal of nasal polyp)
- requires immediate imaging and prophylactic antibiotics → surgical repair.

A nasal polypoid mass in a newborn is an encephalocele until proven otherwise!

Finding	Encephalocele	Nasal glioma
pulsatile?	frequently (may not be if small)	no
changes with Valsalva maneuver	swells (Furstenberg sign)	no change
presence of hypertelorism	suggests encephalocele	does not correlate
attachment to CNS	stalk	none, or minimal
probe	can be passed lateral	cannot be passed lateral

CHIARI MALFORMATIONS

- each characterized by displacement of cerebellum

Chiari I - displacement of cerebellar TONSILS (> 5 mm below McCrae's basion-opisthion line) over cervical spinal cord + kink on posterior surface of medulla oblongata ± *syringomyelia*

- manifests in younger adults

Chiari II (s. Arnold-Chiari) – *myelomeningocele* → pull on brainstem → small posterior fossa → downward displacement of brain stem and cerebellum (VERMIS and inferior poles of HEMISPHERES) → *hydrocephalus*; prenatal US – lemon and banana signs.

- manifest in first few months of life.

Chiari III - encephalocele (foramen magnum / high cervical) – ininencephaly?
Chiari IV - cerebellar hypoplasia / aplasia

Associated anomaly	Chiari 0	Chiari I	Chiari 1.5	Chiari II
Hydrocephalus		7-9%	±	+
Supratentorial anomalies*				+
Cerebellar herniation		Tonsills	Tonsills	Vermis, hemispheres
Brainstem herniation			+	+ *"Z" kinking*
Syringomyelia	100%	30-75%	+	40-95%
Myelomeningocele				+

*callosal agenesis, enlarged massa intermedia, *beaked tectum of midbrain, craniolacunia*

- important feature – *disturbed CSF flow across foramen magnum* (***cine MRI***) → *hydromyelia* due to a "water hammer" effect.
  - nondermatomal **neck pain**, **headaches** accentuated by Valsalva
  - medullary compression at level of foramen magnum - *downbeating nystagmus accentuated by lateral downgaze*
  - **lower cranial nerve impairment** (dysphagia, aspiration, sleep apnea, stridor, feeding difficulties)
  - imbalance and **vertigo** with truncal **ataxia**
  - **myelopathy** - upper extremity numbness and loss of pain and temperature sensation, leg spasticity, levoscoliosis* (relatively common manifestation!)

*adolescent idiopathic scoliosis is dextroscoliosis

- Chiari II cases injury to **cerebellum, medulla, and lower cranial nerves** - progressive ataxia, leg weakness, *dysphagia*, *vocal cord paralysis / stridor*, *life-threatening apneic spells*
  - last three are indications for expeditious decompression!

T2 + CINE + CISS (FIESTA) through foramen magnum ± screening neuraxis MRI

N.B. practically, **cervical spine MRI** (vs. brain MRI) is the best – gives sagittal T2, shows entire cervical spinal cord for syrinx screening.

- significance of **low-lying tonsils**:
  - *tonsils normally retract upward with age*, so their location must be interpreted in age-dependent context:

0-10 yrs ≤ 6 mm below level of foramen magnum; 10-30 yrs, ≤ 5 mm; after 30 yrs, ≤ 4 mm.

  - 30% cases with significant displacements (5-10 mm) are asymptomatic.
  - herniations > 12 mm are almost invariably symptomatic.

TREATMENT

- for peds check neuraxis MRI – HCP, tethered cord
- main treatment – only for symptomatic cases – restoring normal CSF dynamics across craniocervical junction.

N.B. if hydrocephalus coexists (e.g. in Chiari II), it should be resolved before consideration of Chiari decompression.
N.B. exclude instability and ventral compression!
Chiari II preop needs - **swallow** study, **vocal cord** visualization by ENT, assessment of **pulmonary function**

Indications for surgery

A. **Syrinx** (however, < 2 mm asymptomatic syringes can be safely followed with serial examinations and imaging q6mos)
B. **Symptoms**:
   a) lifestyle-limiting **occipital Valsalva-induced headaches** refractory to multidisciplinary management.
   b) objective **brainstem dysfunction** (esp. respiratory or cranial nerve dysfunction)
   c) progressive **scoliosis**.

Details

Chiari II surgery is difficult – *confluence of sinuses can be as low as rim of foramen magnum* (good thing - foramen magnum is generally already enlarged), dense arachnoidal adhesions - vermis and medulla difficult to separate (DO NOT attempt to dissect tonsils from underlying medulla)

Postop

- close post-op **respiratory monitoring** for Chiari II (respiratory arrest is the most common cause of mortality)
- MRI q6-12mos for syrinx: if syrinx fails to decrease or syrinx symptoms persist → ***second surgery*** (reexploration is preferred to syringosubarachnoid drainage).

Complications

- **CSF leak**: keep HOB up, suture wound if leak is external → lumbar drain → revision → VP shunt.
- **aseptic meningitis** (from subdural blood) → 7-10 days of high-dose ("burst") **steroids**.
- **reclosure of outlet foramen → redo decompression, resection of tonsil**.
- **persistent syrinx → redo decompression** → still persists → **syrinx shunting**
- **cerebellar slump / ptosis** (results from extending craniectomy too far laterally without elevated bone replacement).
  - can cause headaches (different from typical Chiari I headaches), obstruction of CSF flow with syrinx formation, variety of deficits.
  - H: **cranioplasty** to buttress cerebellum.
- 1-9% pediatric patients develop **hydrocephalus → shunting** (redo decompressions + intradural explorations usually fail).

Obstetric concerns

Retrospective Review

Most pregnant patients with Chiari *should not be treated differently* than women without Chiari—and specifically Chiari malformation is not a contraindication to vaginal delivery or epidural anesthesia! (historical rec: C-section, no epidural)
But have nsgeon on standby for more severe cases!

NEURONAL HETEROTOPIA

- groups of neurons fail to migrate fully to their cortical destination → groups of neurons remain in inappropriate places:

a) **(SUBEPENDYMAL / PERIVENTRICULAR) NODULAR heterotopia** - periventricular (multiple nodules in walls of lateral ventricles).
b) **BAND heterotopia** - subcortical stripe of neurons.
   – "**double cortex**" - islands of subcortical laminar heterotopia separated from malformed cortex by band of white matter.

- cortex is generally well formed grossly (occasionally, overlying cortical malformation) but functionally abnormal (has EEG spikes).
- main presenting feature is **seizures** of various kinds.
- small heterotopias may be **asymptomatic**.

DIAGNOSIS

- extremely high-resolution MRI (7T MRI)
- for proper counseling, mother of child with BAND HETEROTOPIA should undergo MRI even if asymptomatic.
- Italian school ("Claudio Molinari epilepsy center") – DTI is a must – shows connection to the cortex.

TREATMENT

For epileptogenic heterotopias → **surgery** (defining the extent of the EZ with SEEG* appears critical, as more extensive ablations or resections may be needed):

a) isolated heterotopias → **surgical excision / thermoablation** (i.e. if patient has solitary nodule, behavior of it is unpredictable – OK to do LITT without icEEG but prepare patient for potential more than one surgery).
b) diffuse bilateral band heterotopias (→ drop attacks) → **callosotomy**.

*heterotopias connect to:

a) associated cortex (ictal discharges originate in heterotopia or/and associated abnormal cortex)
b) mesial temporal structures (implant it!) – especially posterior nodular heterotopias.

N.B. PVNH is frequently part of a larger epileptogenic network!

N.B. patients can have other heterotopias - most likely going to need to stay on AEDs in the long run.

FOCAL CORTICAL DYSPLASIA (FCD)

- milder end of the spectrum of neuronal migration disorders: disruption in lamination and columnar organization → maloriented neurons in inappropriate layers ± abnormal neuronal elements*
*e.g. **balloon cells** (hallmark of FCD, although they are not present in all patients)

Type I - ***no abnormal cells***.
Type IA - isolated architectural abnormalities, usually laminar or columnar disorganization.
Type IB - + giant cells or immature neurons.
Type II - ***abnormal neurons*** (brain feels firmer on palpation)
Type IIA - dysmorphic cells.
Type IIB - + balloon cells.
Type III – ***associated pathology*** is present.

CLINICAL

- various types of **seizures** in childhood (but can be delayed into adulthood).

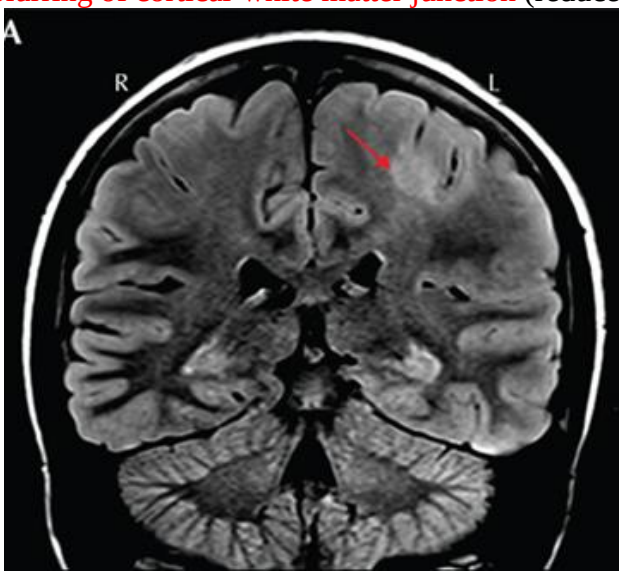
- most frequent (50%) anomaly found in *medically intractable seizures* (EEG - focal very high amplitude rhythmical activity).

Type I FCD can be clinically silent or have **cognitive impairment** instead of epilepsy.

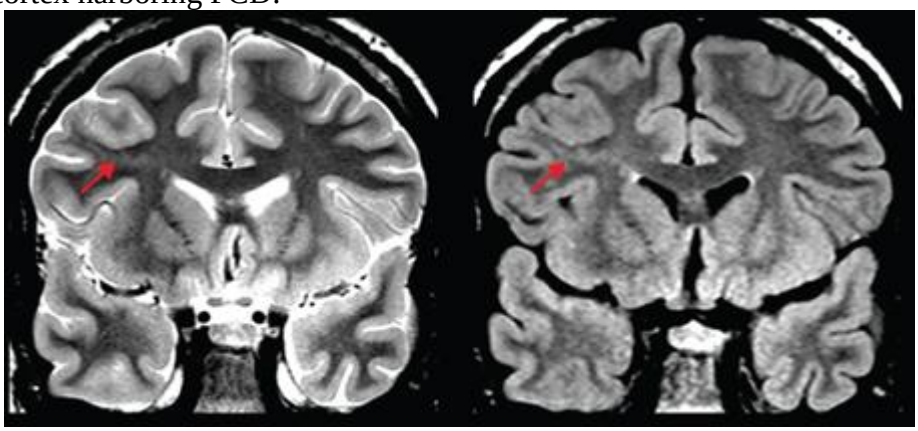
DIAGNOSIS

MRI (MRI looks normal in 1/3 of patients!!!):

1) focal abnormal gyral thickening esp. at the bottom of deep sulci!
2) blurring of cortical-white matter junction (reduced demarcation)



3) transmantle sign – funnel-shaped signal across white matter, from lateral ventricle to cortex harboring FCD:



TREATMENT

- surgical extirpation of epileptogenic lesion **guided by icEEG!**

- ***earlier surgical intervention*** = improved development.
  N.B. regions of histological FCD may extend beyond abnormal MR images – it is paramount to have intracranial ECoG grids to determine extent of resection!
- type 2 FCD (vs. type 1) – **brain feels firmer**!
- if possible, resect all accessible FCD (even if not involved on SEEG or grid recordings) – they tend to activate later after resection of other EZs (e.g. resecting epileptogenic cavernoma).
- role of SEEG (add stimulation to induce seizures to increase certainty):
  - sampling from the difficult to access areas ideally suited for LITT (if patient has solitary FCD – OK to do LITT without icEEG but prepare patient for potential more than one surgery)
  - FCD type 2 – stimulation has large response but no function – can be removed even in Rolandic cortex (else RNS)

Outcomes
- resection achieves 50-70% seizure freedom.

HYPOTHALAMIC HAMARTOMA (HH)

- congenital non-neoplastic lesions in ventral hypothalamus: clusters of normal neurons with abnormal architecture.

CLINICAL

- **gelastic seizures** - burst of mechanical laughter with retained consciousness.
- development of secondary seizure types due to kindling (38% patients).
- progressive encephalopathy.

TREATMENT

- difficult to control with AED alone.

LITT - treatment of choice (SRS 16-20 Gy, open resection – poorer alternatives).
- do not need to remove / ablate the whole HH; enough to disconnect it from the network!
- staged approach for larger hamartomas.

Treatment Complications
short-term memory dysfunction (rarely, permanent)
endocrine dysfunction, incl. hypothalamic obesity, diabetes insipidus

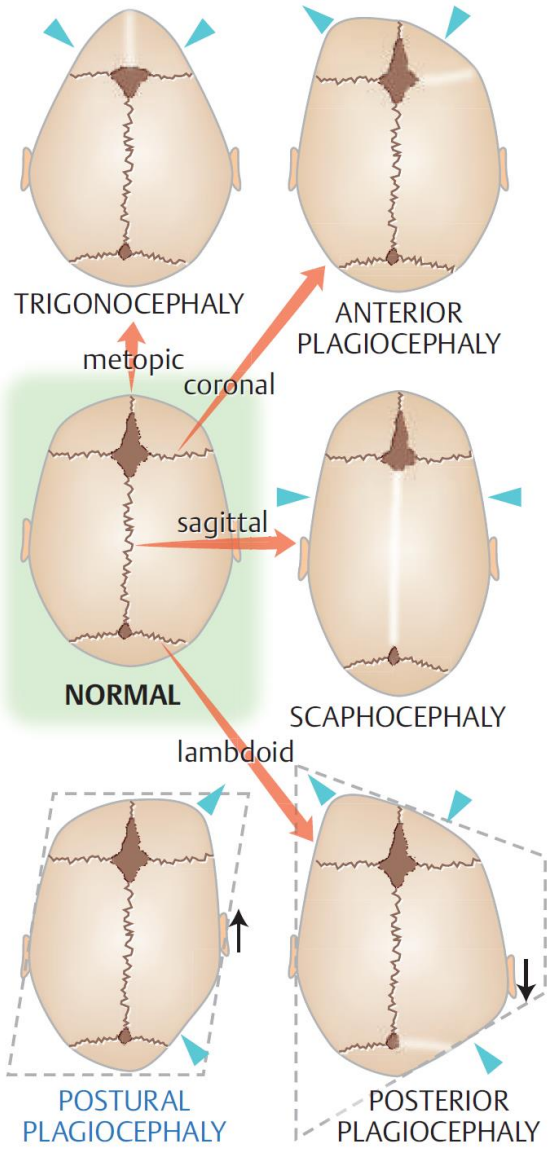
CRANIOSYNOSTOSIS

- **premature fusion** (in utero) of one or more of 6 cranial sutures → worsening facial and cranial deformity in first few months of life
- visible / palpable ridging of closed suture
- skull growth *restricted* - perpendicular to affected suture ("hand grabs and holds skull at suture");
- skull growth *enhanced* - parallel to affected suture.
- **ICP↑** - only when > 1* suture is affected (cause and mechanism is not well understood** – may be present even in cases where absolute intracranial volume is increased) → adverse effects on development!

*esp. in syndromic cases (but also 15% of single suture cases)
**abnormalities of cerebral venous drainage due to maldevelopment of foramina at skull base

N.B. papilledema is rarely seen!
N.B. hydrocephalus is rare!

- **airway problems**
- **vision loss**



CT with 3D reconstruction (method of choice!; 3D reconstruction may be false-positive → check source axial images).

- others say - diagnosis is clinical (CT or XR is unnecessary – radiation exposure)

In questionable cases, a **technetium bone scan**:

a) first weeks of life – normally, little isotope uptake by any sutures
b) prematurely closing suture - increased activity
c) completely closed sutures - no uptake

NORMALLY

Head circumference measurement - **occipital-frontal circumference (OFC)** - is routine part of physical assessment of all children ≤ 2 yrs!

- 90% of adult head size is achieved by age 1 yr; 95% by age 6 yrs.
- growth essentially ceases at age 7 yrs.
- skull is unilaminar at birth → diploë appear by 4th yr and reaches maximum by age 35 yrs (when diploic veins form).

Anterior fontanelle: closes by age 2.5 yrs.
Posterior fontanelle, sphenoid and mastoid fontanelles: close by 2-3 months (mastoid by age 1 year)

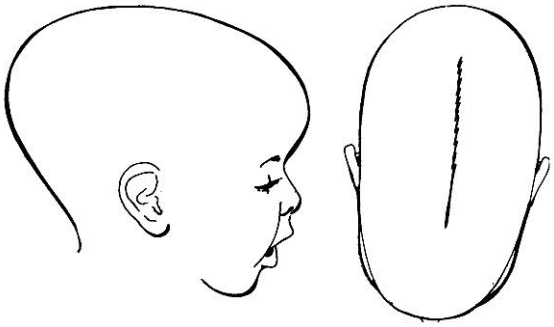
Sutures serve as site of bone deposition in growing calvarium.

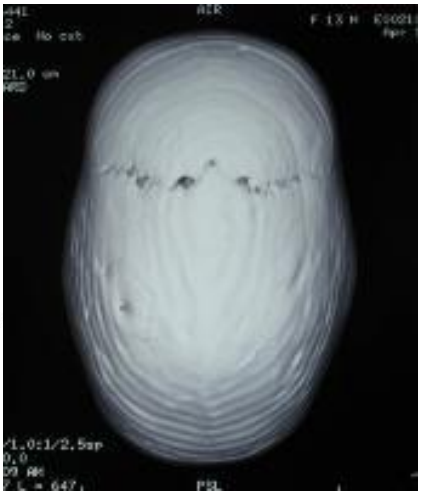
Skull growth occurs perpendicular to suture!

- primary factor that keeps sutures open is ongoing brain growth.
- by end of 2nd yr, bones have interlocked at sutures and further growth occurs by accretion and absorption.
- suture closure occurs by age ≈ 12 years, but completion continues into 3rd decade.

SINGLE-SUTURE synostosis:

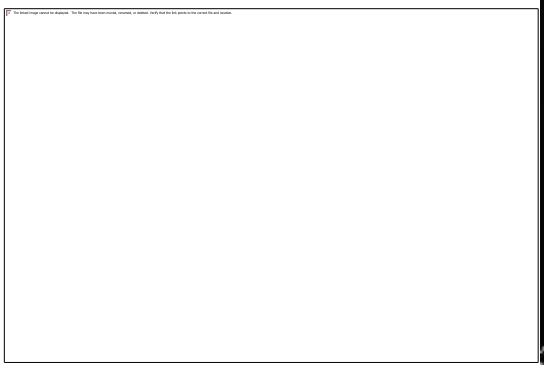
Sagittal suture (55% of all cases!) → **SCAPHOCEPHALY** (vs. dolichocephaly - term is reserved for normal anatomic variant) - **no neurological deficits**!

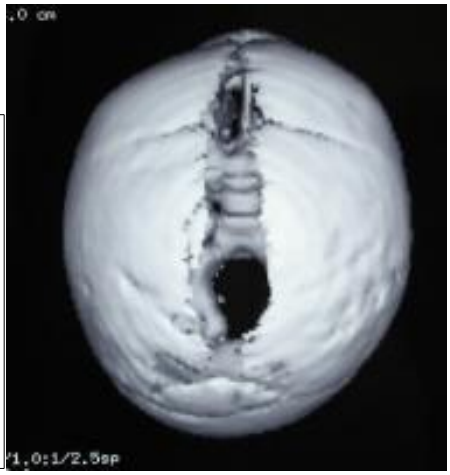




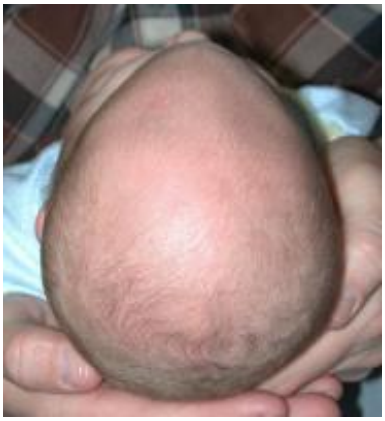
Coronal suture (20-30% of all cases) → **BRACHYCEPHALY** - higher incidence of *neurological complications*: optic atrophy

- supra-orbital margin is higher than the normal side, producing harlequin eye sign; parents often like affected **HARLEQUIN** eye (bigger) more than normal eye ☺
- orbit rotates out on abnormal side → amblyopia





Metopic suture → **TRIGONOCEPHALY** - abnormality is usually mild and requires no surgical intervention (i.e. treat only most severe cases!)

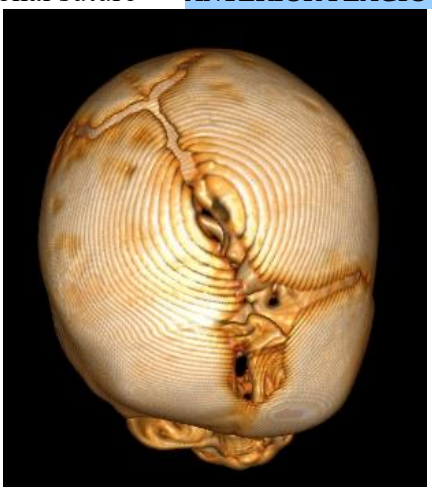


often occurs in syndromic context with mental retardation

UNILATERAL (ASYMMETRIC) synostosis:

lambdoid suture → **POSTERIOR PLAGIOCEPHALY** + *enlargement of ipsilateral MASTOID PROCESS* - pathognomonic for lambdoid synostosis!!!

coronal suture → **ANTERIOR PLAGIOCEPHALY**



COMBINED - strongly suggests craniofacial syndrome!

coronal + sagittal sutures → **OXYCEPHALY** - high, conical head with sharp bossing of anterior fontanelle

coronal + sagittal + lambdoid sutures → **TRIPHYLLOCEPHALY, S. KLEEBLATTSCHÄDEL**

Most severe craniosynostosis! (vision and hearing loss; mental deficiency is rare) – urgent surgical repair!

SYNDROMIC CRANIOSYNOSTOSES

10-20% cases

- **mutation analysis** of FGFR genes!

AUTOSOMAL DOMINANT mutations in **FIBROBLAST GROWTH FACTOR RECEPTORS** *FGFR2 gene*:

CROUZON'S syndrome - **KLEEBLATTSCHÄDEL**

APERT'S syndrome - malformed short cranial base = **BRACHYCEPHALY** + **TURRICEPHALY, S. TURMSCHÄDEL** = short and high skull; prominent forehead and flat occiput.

Skull ≈ as in Crouzon; main differences – hydrocephalus, **syndactyly** (mitten hands and sock feet)

PFEIFFER syndrome – **TURRICEPHALY**, **polydactyly**

TREATMENT

Indications

1. **Cosmetic** (the only consideration in single-suture nonsyndromic synostosis cases!).
2. **Elevated ICP** (routine measurement of ICP in all syndromic cases; may occur in 15% cases of single suture synostosis)
   N.B. if any restriction of brain growth by skull occurs, it is only in first 6 months of life; after infant is > 6 months, effect of craniosynostosis becomes exhausted (burnt out); i.e. *maximum constrictive effect of craniosynostosis occurs at birth*!
3. **Progressive exophthalmos** threatening eyes.

Contraindications

- only absolute contraindication is **microcephaly**, i.e. *secondary craniosynostosis*

Surgery timing

a) **EARLY SURGERY** - soon after birth (minimized risk of mental impairment due to restricted brain growth; bones grow rapidly and easily cover surgical defects - best cosmetic results, but high risk of recurrent deformity).
b) **LATE SURGERY** - at age 12 months.

surgery as soon as can safely tolerate physiological stress of surgery, best – **3÷18 months** (sooner if ICP↑ or severe craniofacial disfigurement)

Do not operate without raised ICP until considering following:

- infants have large head relative to body size - deformity appears more prominent in young infant and may be less obvious with age.
  N.B. do not operate on mild metopic synostosis (just ridge) – sometimes disappears with time
- as child grows and more hair appears, visible abnormality may decrease.
- if head shape does not improve by age 2-4 months, then abnormality is unlikely to resolve with age.

Surgery principles

Single suture involvement → wide (at least 3 cm) linear excision of suture (strip suturectomy) – approach age-dependent:

A. Age ≤ 3-6 months → **minimally invasive (endoscopic) linear craniectomy**
B. Age 6-9 months → **open surgery** (Dr. Ritter prefers 10 mos – better withstands anesthesia stress, has more Hb, no harm with waiting so long).
C. Age > 9 months → **open cranial vault reconstruction**.

- optional separation of bony margins by **implanted matrix / spring distractor**

- optional – **barrel stave osteotomies** → custom-made **molding helmet** for 6-18 months

Main principle – **OVERCORRECT** (as head grows back to original shape)!!!

Complex craniosynostosis (multiple sutures) or coronal synostosis - more complex **cranial expansion & remodeling procedures** (linear craniectomies have been abandoned!) - *combined efforts* of a neurosurgeon and craniofacial surgeon, and may need to be *staged* in some cases.

Dr. Fuhs (Duke University): all anterior synostoses (metopic, coronal) need:

1) bicoronal incision
2) supraorbital bar advancement
3) bifrontal bone flap → cut in half sagittally → rotate and swap pieces and put back together (so metopic edges lay in coronal position)

Surgery

- cranial remodeling - significant blood loss! (transfusion is often required)
  EBL OK < 1/3 of circulating blood volume (70 mL/kg) – keep track of EBL!
  Two large bore IVs + A-line (may not need central line); wax bone edges!
- risk of dura, sinus injury → air embolism: HOB down, flood operative field with saline, if has central line – aspirate air.
- if prone position, face should be lifted and gently massaged every ≈ 30 minutes by the anesthesiologist to prevent face pressure injuries.

PLAGIOCEPHALY - although only one suture is prematurely fused, in fact, deformity is bilateral because normal side is attempting to compensate - ***bilateral correction*** is necessary.

KLEEBLATTSCHÄDEL - **early subtotal craniectomy** is only reasonable attempt at correction.

Postoperative

- PEDIATRIC INTENSIVE CARE unit for 24 hours.
- ***considerable edema*** may be encountered, but it quickly resolves in following days.

N.B. most important – follow at 6 mos of age – if recurrence, reoperate!

SECONDARY CRANIOSYNOSTOSIS

- retarded brain growth / atrophy is primary abnormality, i.e. *secondary craniosynostosis* is frequent with microcephaly - ICP is normal, and surgery seldom is needed.

POSITIONAL POSTERIOR PLAGIOCEPHALY, OCCIPITAL PLAGIOCEPHALY

- flattened posterior part of head; due to *position head takes during sleep (SIDS prevention)*; normal lambdoid sutures

N.B. **OCCIPITAL** (not LAMBDOID) to stress that suture is normal!

N.B. *true lambdoid synostosis is rare* (≈ 2% posterior plagiocephaly cases)!

View from above ("bird's-eye view):

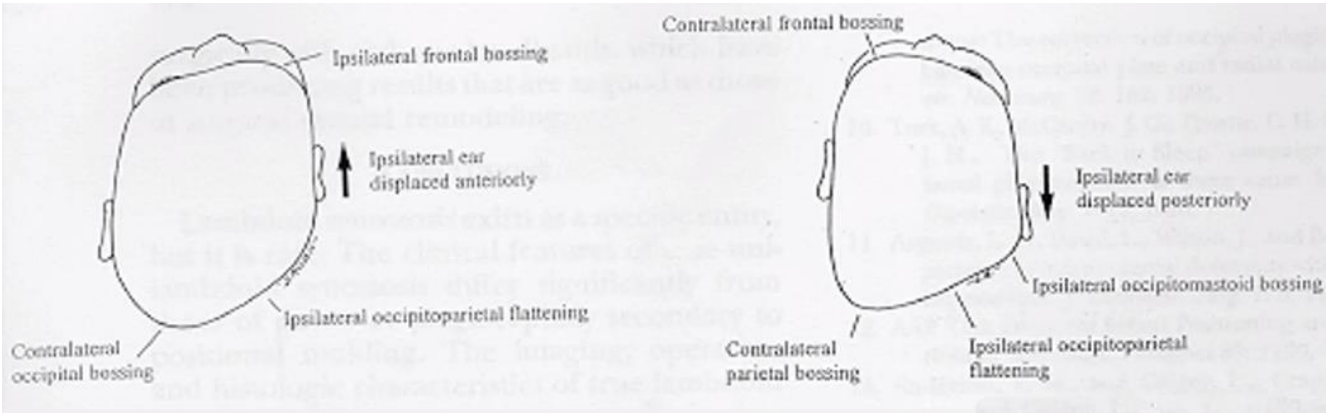
POSITIONAL MOLDING:

1) head shape is parallelogram (rhomboid) - skull is pushed ventrally on one side.

2) ear position is more anterior on side of flattening.
3) frontal bossing is ipsilateral.

TRUE CRANIOSYNOSTOSIS:

1) head shape is trapezoid - growth is restricted on side of fused suture.
2) ear position is more posterior on side of flattening + enlarged mastoid
3) frontal bossing is contralateral (if any).



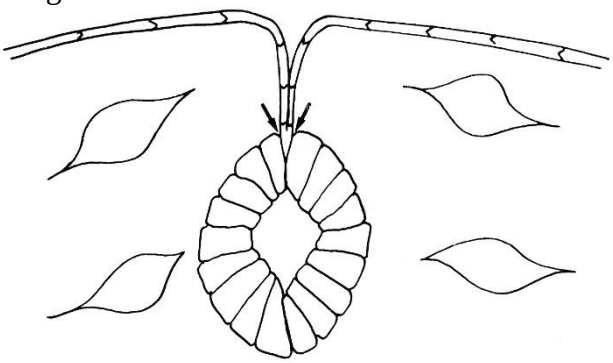
Treatment (only for severe cases):

1) **tummy time**↑ esp. when apnea (SIDS) monitors are now available - recheck in 6–8 weeks: if it was positional, it should be improved! (vs. synostosis will declare itself)
2) ***plastic caps*** (***molding helmets***) worn 23 h/d until age 1 year
3) no surgical treatment!!!!

See Case P2 >>

DORSAL DERMAL SINUS

(punctate failures of dysjunction skin from neural tube) - thin communication between *dorsal skin* and *spinal canal* - **small opening in skin** above* intergluteal crease! → **MRI** to look for dermoid / epidermoid tumors along course of dermal sinus tract



*some experts still would do US to screen for tethered cord

Anything in kid's midline above intergluteal crease is abnormal - needs MRI!!!!!
Most important presentation is devastating **infection** (dermal sinus is serious condition!)
PILONIDAL SINUS - fistula in sacral region (i.e. below gluteal crease), communicating with exterior, containing hair (may act as foreign body → chronic inflammation).

Surgery – excision of *entire* tract ASAP (to prevent infection); follow sinus all the way to the bottom:

1/3 lead to **lamina**
1/3 lead to **dura**
1/3 lead **intradurally** (may cause cord tethering) – need to *excise all fat elements from intradural location* to prevent further intradural lipoma formation and retethering.

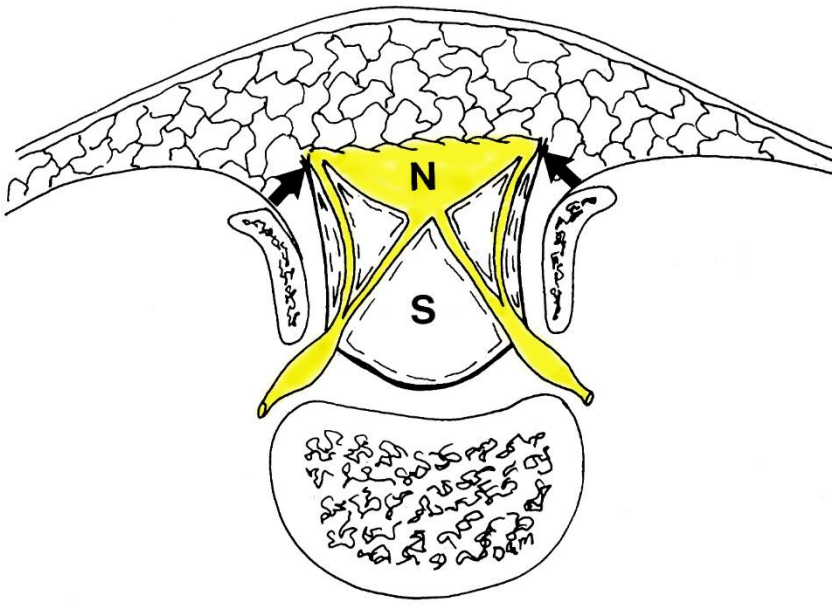
LIPOMYELOMENINGODYSPLASIAS (lipomyelomeningocele, lipomyelocele, lipomyeloschisis)

LIPOMYELOMENINGOCELE – components (MMC covered with lipoma)

1) **myelomeningocele**
2) skin-covered **subcutaneous lipoma** attached to **placode**

- focal PREMATURE DYSJUNCTION of ***neuroectoderm*** from ***cutaneous ectoderm***, allowing migration of mesenchymal tissue into neural tube (via dorsal surface of unclosed neural tube).

- *mesenchyme prevents neurulation*, leaving neural plate in shape of *placode*.
- ectopic mesenchymal cells give rise to fat.
- this intramedullary adipose tissue remains continuous with subcutaneous tissue (i.e. lipoma is attached to dorsal surface of placode and is in continuity with subcutaneous fat) - results in *spinal cord tethering* to lipoma, *vertebral arch nonfusion*.
- ventral surface of placode faces subarachnoid space, where nerve roots exit from placode:

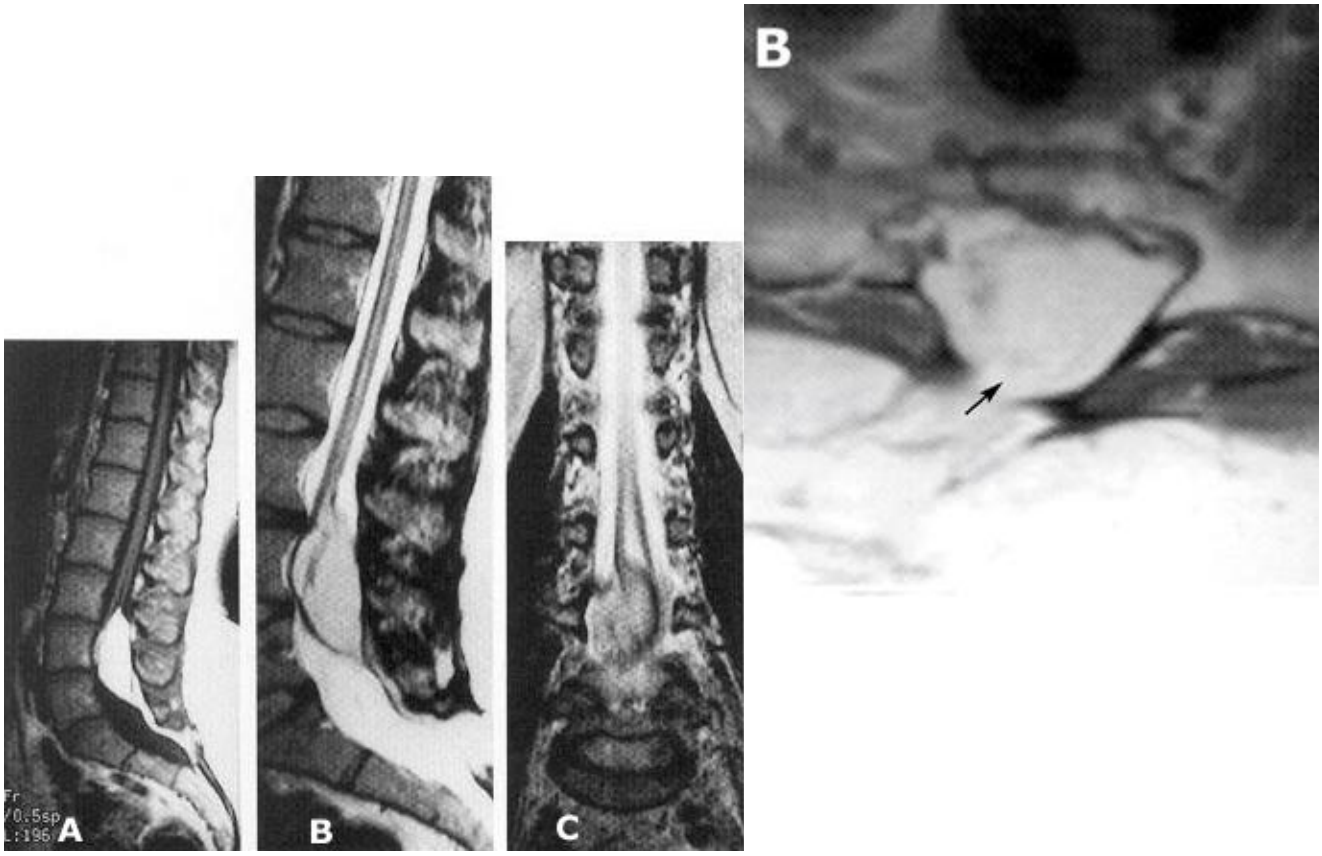


Progressive cord dysfunction may be caused by fixation or by compression:

a) **tethered spinal cord** - fixation by filum terminale on the distal spinal cord.
b) **intramedullary lipomas** - compress cord but do not have a component of fixation.
c) **lipomyelomeningocele** - both cord fixation and compression

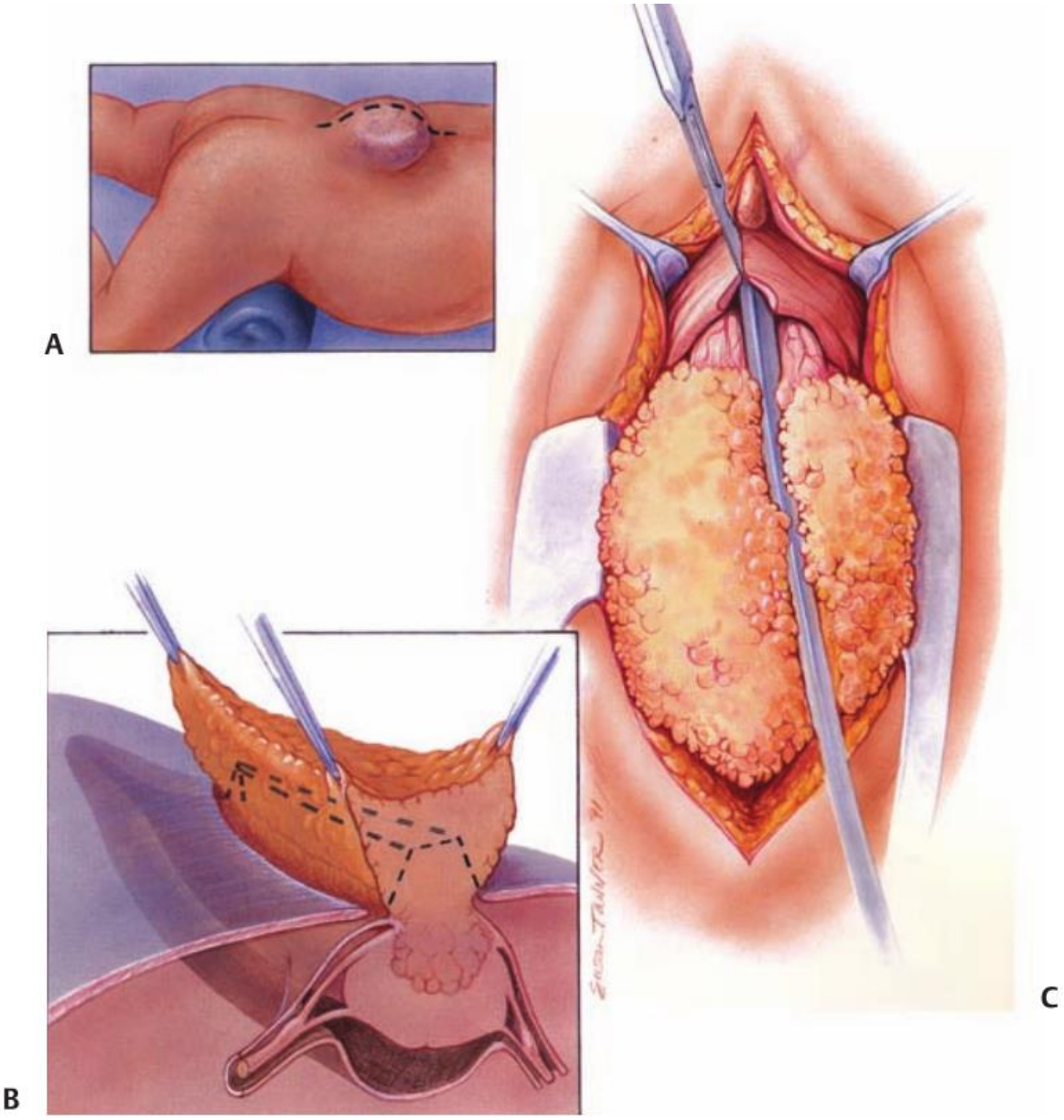
N.B. early aggressive surgery is logical - natural history of lipomyelomeningocele is a progressive loss of neurological function; reversal of bladder dysfunction is unlikely once it is established.

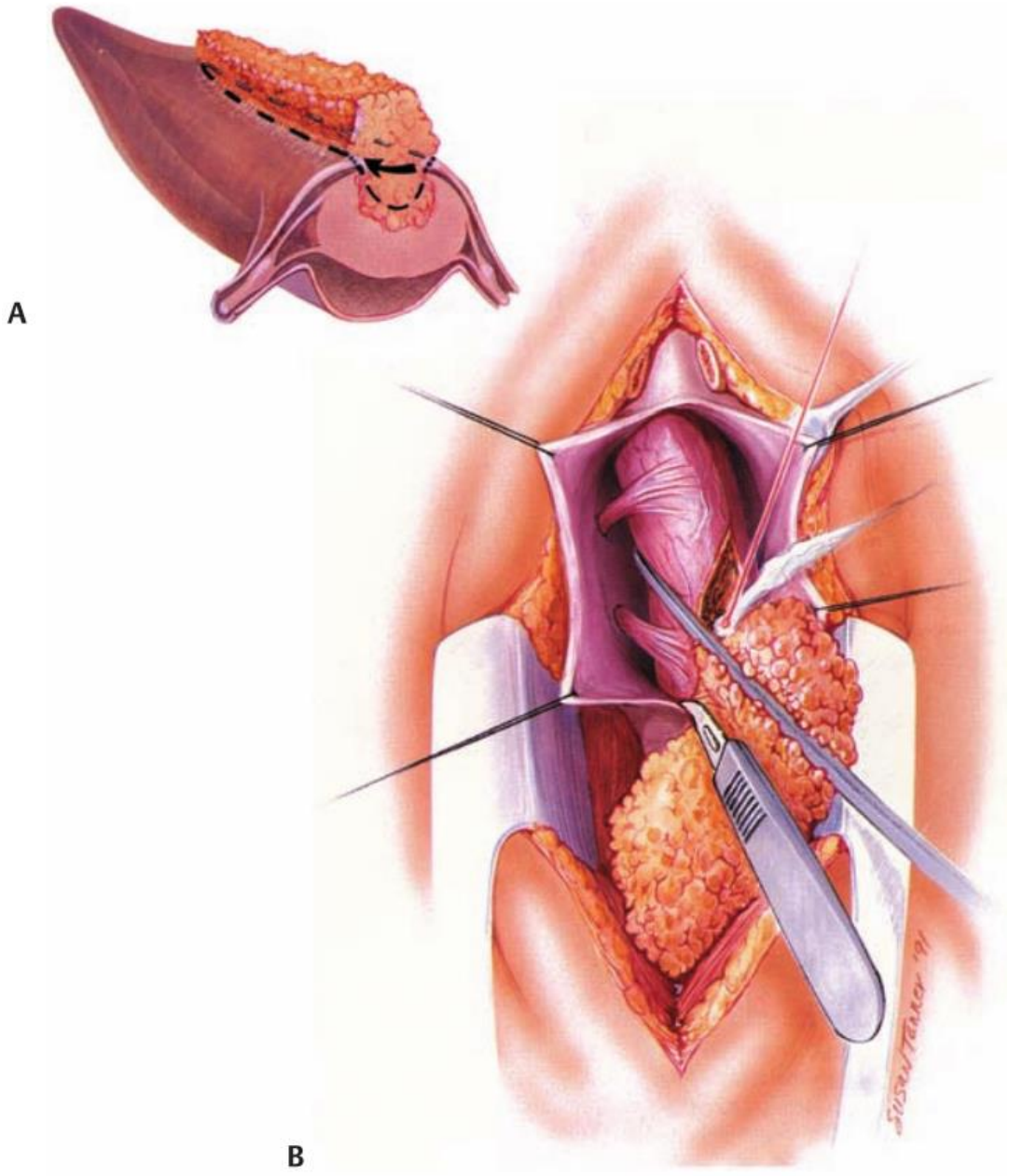
tethered spinal cord → *without treatment, ≈ 90% will develop motor or sensory deficit*

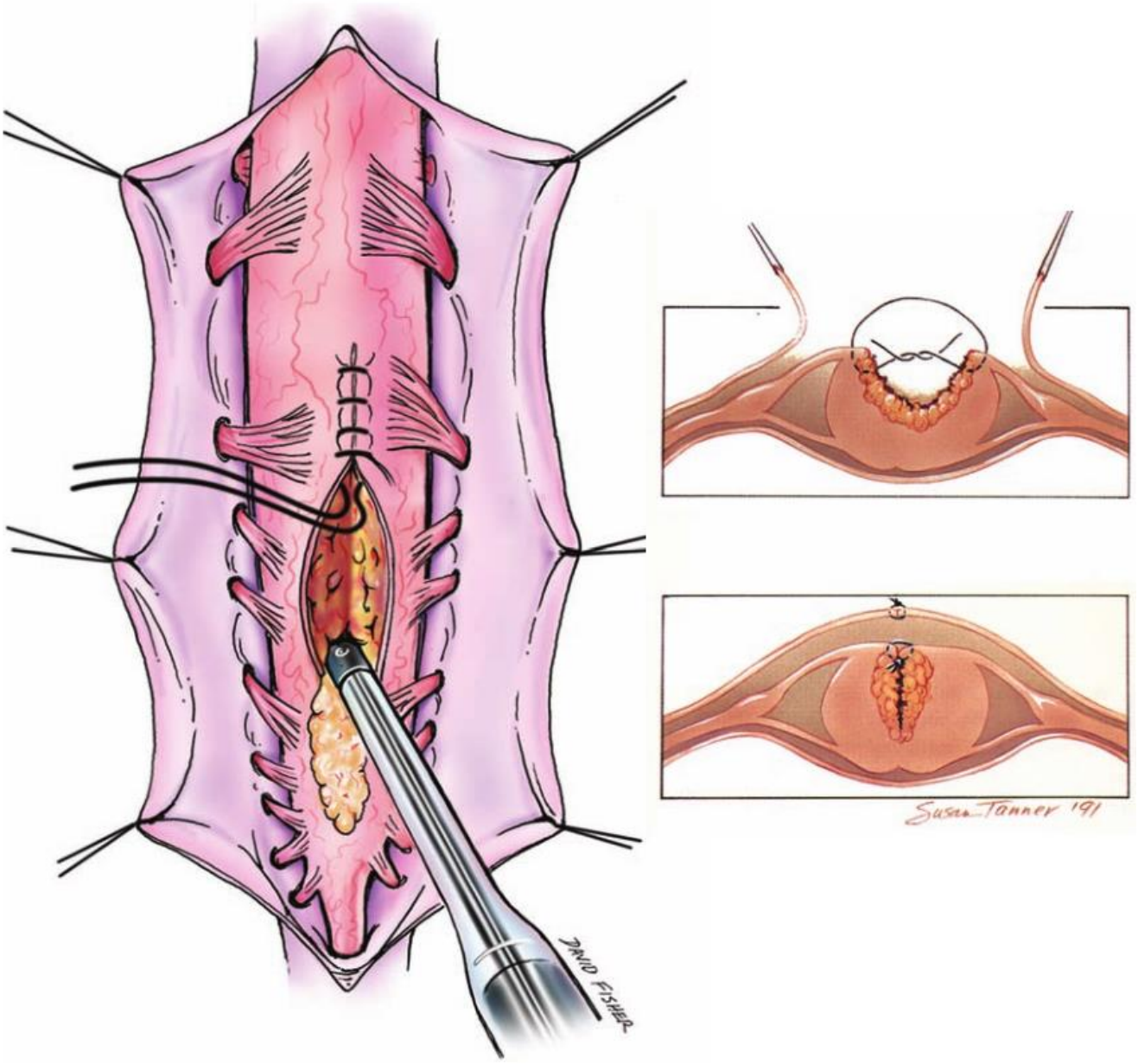


Treatment SSEP and EMG! operative microscope!

1) **releasing tethered cord** - roots are dissected free from fibrolipomatous mass using **Beaver blade**
2) **removal of lipomatous tissue -** using **KTP laser** (up to 5 W continued regimen) as well as **CUSA**
3) **reconstruction of dural sheath** around spinal cord - ***Dura-Guard patch*** leaving ample space for CSF to bathe distal spinal cord (to prevent tethering); distally if no normal dura present - patch is secured to lumbosacral fascia edges → covered with Tisseel and Surgicel in two layers


A
B
C


A
B



- postop place "mudflap" to protect lumbar incision from soiling.
- if lumbar incision closure required undermining of skin flaps, postop keep flat prone or on side (not supine!).

SUBPIAL LIPOMA, INTRAMEDULLARY LIPOMA

PREMATURE DISJUNCTION of neural ectoderm before formation of neural tube is complete → mesenchyme enters open, ependyma-lined central canal from dorsal direction.

- mesenchyme in abnormal location will form fat.

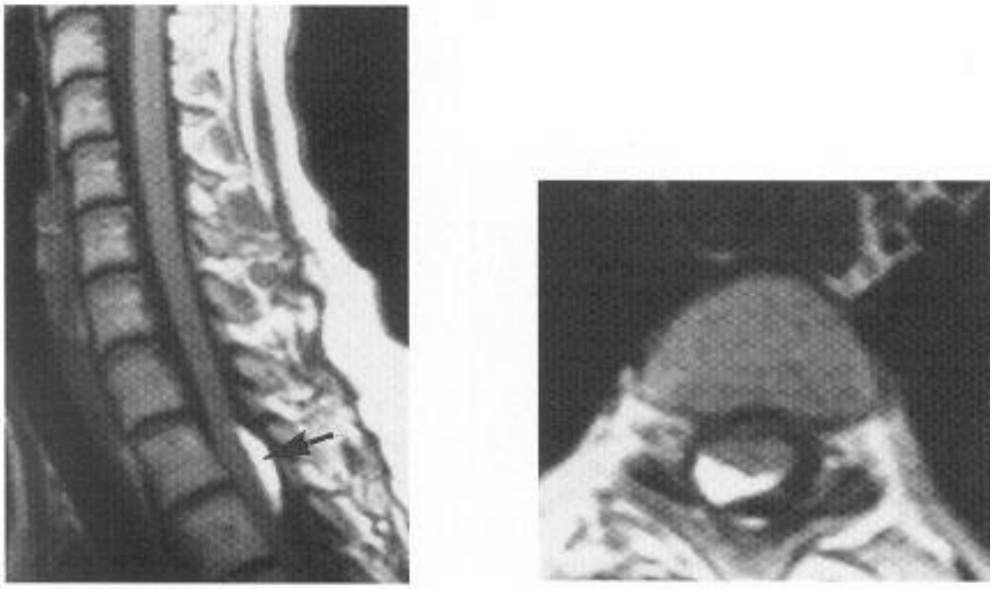
- rare congenital lesions that may lay dormant for many years or decades.
- predilection for involvement of dorsal aspect of cord, but the fat is not connected with a defect of the arachnoid, dura, laminae, or skin - not associated with spina bifida occulta
- **symptomatic lesions** (myelopathy or pain) are approached as any other intramedullary tumor.

Operative Procedure

- goal of the operation is not to remove every pocket of fat but rather to **debulk significant mass** effect leaving interface between cord and lipoma un-manipulated.
- CUSA or CO2 laser at very low wattage
- cord may be reconstructed into a tube
- redundant dura is closed and tented dorsally in effort to prevent adhesion.

SUBPIAL LIPOMA is located *dorsal to spinal cord*.

INTRAMEDULLARY LIPOMA *between posterior columns*.



A B

TETHERED FILUM

Many spinal dysraphic malformations may cause TETHERED SPINAL CORD!

- failure of fibres in filum terminale to lengthen → tethered spinal cord:
  1) **lack of normal ascent** of conus medullaris to L_1.
  2) **ischemic / metabolic** disturbance of caudal spinal cord.

Conus below L2-3 at any age is abnormal!

Filum terminale is abnormal if diameter > 1 mm at L5-S1

- filum terminale is often ***infiltrated with fatty tissue***.

CLINICAL

Symptoms may occur at any age* (typically in **childhood ÷ adolescence** during periods of rapid growth) - flexion and extension of spine → ***repeated trauma & ischemia*** to conus:

*also can present de novo in adults

URO → ORTHO → NEURO

1) back + lower extremity **pain**
2) progressive gait disturbance, lower extremity **spastic weakness**, orthopedic deformities (varus and valgus and cavus changes of foot)
3) **sensory loss** in sacral dermatomes.

4) urinary **incontinence**, impotence

DIAGNOSIS

MRI:

1) *low* **conus medullaris** (below bottom of L_2 vertebral body), absent cauda equina.

   Conus is abnormally low at any age if it is found to end below L_{2-3} disc space

2) *lack* of **intumescentia lumbalis** - conus tapers gradually into thickened filum.
3) *thickened* (> 1-2 mm in diameter at L5-S1 level) and *fat-containing* **filum terminale**.
4) **conus medullaris** *does not move* forward in spinal canal (when MRI is done in prone position).

TREATMENT

Classical - **surgical release** of tethered cord: EMG (± SSEP, MEP - not routine for a simple sectioning of a thickened filum)

1) **transection of thickened filum** (check with intraop bipolar stim probe and EMG before cutting!) – has serpentine vessel running along (vs. nerve roots)
   cut below the point where no EMG responses are obtainable (if activates only anal sphincter, it is OK to cut).
2) **arachnoid adhesions are lysed**.

- young kids - use craniotome (footplate) for laminotomies in one block → reflect entire block (still attached proximally to intact vertebrae) proximally.
- older kids – normal laminectomy.
- obtain absolute hemostasis → blood in thecal sac → arachnoiditis.
- open thecal sac in midline: 15 blade → Potts scissors → dura tacked up using 4-0 silks.
- no drain, flat for 3 days
- if there is diastematomyelia and bone spicule – resect bone first (if opposite, cord bounces against bone upon release and neuro deficits↑)
- if there is dermal sinus, incise lumbar midline in elliptical fashion thus excising skin dimple → dissect it all the way down (needs to be excised in entirety)
- symptom progression is arrested, and symptoms may improve (pain responds best, sphincter dysfunction worst).
- given potential for rapid deterioration with incomplete neurological recovery, even ***prophylactic surgery*** in otherwise asymptomatic child is advisable.
  Treat before symptoms!!! (ischemic damage [cord strokes] does not recover!)

PROGNOSIS

Pediatric cases (vs. adult): no pain, no neuro deficits at presentation, fresh surgical anatomy (vs. scarred in adults), good operative results.

- 20-25% retether (of those, 10-15% retether again after 2nd surgery).
- postop conus ***does not (!) ascend***; recurrence diagnosis – only clinical!
- recurrence prevention:
  — create large dural sac (up to alloplasty)
  — use metal clips for dural closure (less inflammation than silk)

RECURRENCE IN ADULTS

- adult spine stopped growing – symptoms unlikely are related to retethering; greater chances – arachnoiditis (surgery has no real role) – look for:
    1) root clumping, absence of anterior root migration in **prone MRI**
    2) lower motoneuron type **urodynamic study** results (detrusor weakness)
- adult TCS is associated with scarring of spinal cord in intradural space → decreased CSF circulation, rather than mechanical traction of spinal cord - repeat intradural exposure and intradural surgery → further adhesions and scarring, limiting its effectiveness.
- **urinary bladder** may worsen in adults postop (discuss that preop!); rather do 3 months of bladder exercises (double voiding, Credé's maneuver) with urology and medications (cholinergic agonists) (→ re-evaluate with urodynamic study).

Consider (esp. after multiple recurrences in adults) – **spinal column shortening osteotomy**:
- T11-12 – remove half of every vertebral body done MIS from lateral approach.

MYELOMENINGOCELE

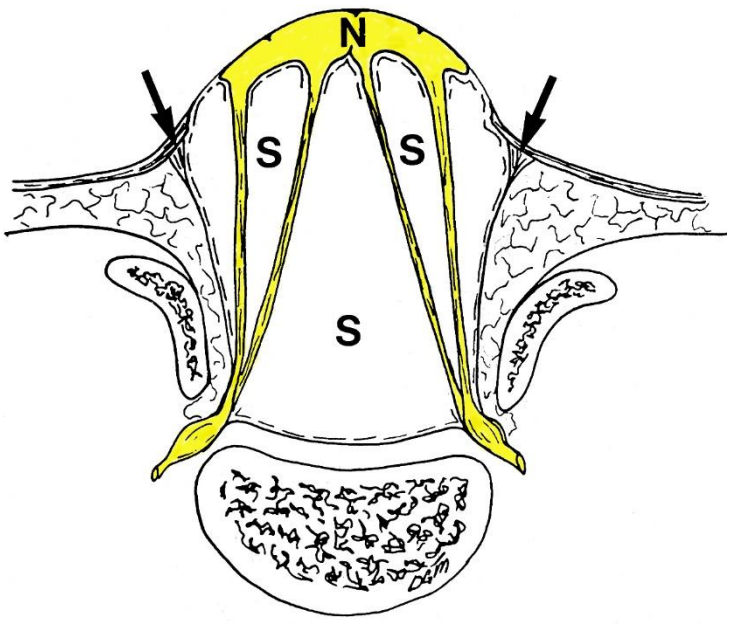
Myelomeningocele – 1 in 1000 live births – most common anomaly of nervous system!

- involves meninges and underlying spinal cord; no skin covering over defect

Greatest disability of spinal dysraphism!

- focal segment of spinal cord fails to roll up and form tube - neural folds persist as flat plate of tissue referred to as *neural placode* - raw, exposed dorsal surface of *neural placode* represents tissue that should have formed ***interior of spinal cord*** (i.e. filleted spinal cord with visibly open central canal).
- CSF exiting from proximally formed central canal floods dorsal surface of placode.
- surrounding *neural placode* is thin layer of skin and arachnoid tissue, below which is subarachnoid space; enlarged ***subarachnoid space*** ventral to placode results in dorsally protruding sac on which neural placode is visible.
- nerve roots lie inferior to neural placode, with ventral roots lying medial to dorsal roots (i.e. dorsal roots exit from anterior surface of spinal cord just lateral to ventral roots).
- spinal cord is always tethered!

neural placode (N); subarachnoid space (S):



1. Saclike **cystic structure** covered by thin layer of partially epithelialized tissue.
   - remnants of neural tissue are visible beneath membrane, which may occasionally rupture and leak CSF.
2. **Spinal cord dysfunction**:
   1) **flaccid paralysis & sensory deficits** below level of lesion:
      defects above L_3 - deficits preclude ambulation (wheelchair dependent);
      defects between S_1 and L_3 - assisting devices may allow ambulation;
      defects below S_1 - unaided ambulation.
   2) **GU tract** (≈ 90%) - constant urinary dribbling, relaxed anal sphincter.
3. Superimposed **infection** (sac rupture → meningitis)
4. 75% patients have **normal intelligence**.
5. Other defects:
   1) **Chiari II** – most common (> 95%) finding associated with MMC! – most common cause of death!
   2) **hydrocephalus** (80-95%).

Late complications:
1. Scoliosis (esp. with lesions above L_3)
2. Traction on cord.
3. Urological complications

N.B. late deterioration is not a natural course of MMC patients – look for cord tethering, shunt malfunction!

PRENATAL DIAGNOSIS

1. **SERUM chemistry** - **α-fetoprotein (AFP)↑ → amniocentesis**

2. **AMNIOTIC FLUID chemistry**:
   1) amniotic fluid **α-fetoprotein (AFP)↑** (in all **open** neural tube defects, but also in gastroschisis, etc).
   2) amniotic fluid **acetylcholinesterase (AChE)↑** (in all **open** neural tube defects).

Amniotic fluid **AFP↑** + amniotic fluid **AChE↑** - sensitivity for open defects ≈ 100% → **detailed (level II) ultrasound**

3. **Ultrasound** - very high sensitivity at even 14-16 weeks' gestation.
   - **lemon sign** - symmetrical bifrontal narrowing of skull – risk of neural tube defects.

Atraumatic delivery (damaged CNS is more vulnerable to perinatal insults) via prelabor **C-section**.

TREATMENT

- imaging is not necessary preoperatively – diagnosis is obvious clinically; however – preop needs **head** US (Chiari II, HCP), **renal** US, **spine** XR (do not operate on lethal anomalies, e.g. anephria)
  - do not overlook *Chiari II*, *tethered spinal cord*.
  - every child must be screened for *hydrocephalus* (daily ***occipital-frontal circumference*** measurements and baseline **trans-fontanel ultrasound**), then monitored postop (after MMC closure)! as > 90% will require ***hydrocephalus*** shunting → later surgical management of ***Chiari malformation*** itself (suboccipital craniectomy & cervical laminectomy) may become necessary!
    N.B. shunting is not needed at time of MMC repair.
    Colpocephaly is not hydrocephalus!
  - ***urological assessment*** plays prominent role - **regularly catheterize** neurogenic bladder!

- ***orthopedic assessment*** **- ambulatory aids**

Prevention of meningitis / ventriculitis is extremely important (intellectual outcome is related!) - **antibiotic prophylaxis** before and around time of surgery (esp. with open defects).

- ***weight-based antibiotics*** (NAFCILLIN + GENTAMICIN), esp. if defect is leaking CSF; continue until clear that shunt is not needed.
- child is kept ***prone*** or in ***lateral*** recumbent position.
- defect is covered with ***warm saline-moistened nonadherent*** Telfa - to prevent injury and desiccation of neural placode.

Surgical management - **closing** all but prognostically worst cases.

- *early treatment is preferable* (no data to support that emergency closure improves outcome) - reduces rate of infectious complications.

Operation within first **24**-48 hours postnatally is standard.

CNS Guidelines For Pediatric Myelomeningocele (2019)
Level I recommendation**:** Prenatal repair of MMC is recommended to reduce risk of developing shunt-dependent hydrocephalus.
Level II recommendation**:** Prenatal repair of MMC improve ambulatory status in short term (at 30 months of age).

- long term benefit for ambulatory status with prenatal closure is unknown.

Level III recommendation**:** Children should be carefully followed for the development of tethered spinal cord (loss of ambulatory function).

N.B. there is evidence that prenatal closure increases risk of recurrent tethered cord vs. postnatal closure

Insufficient evidence that closure of MMC within 48 hours decreases the risk of wound infection.

Level III recommendation**:** if MMC closure is delayed beyond 48 hours, antibiotics should be initiated.

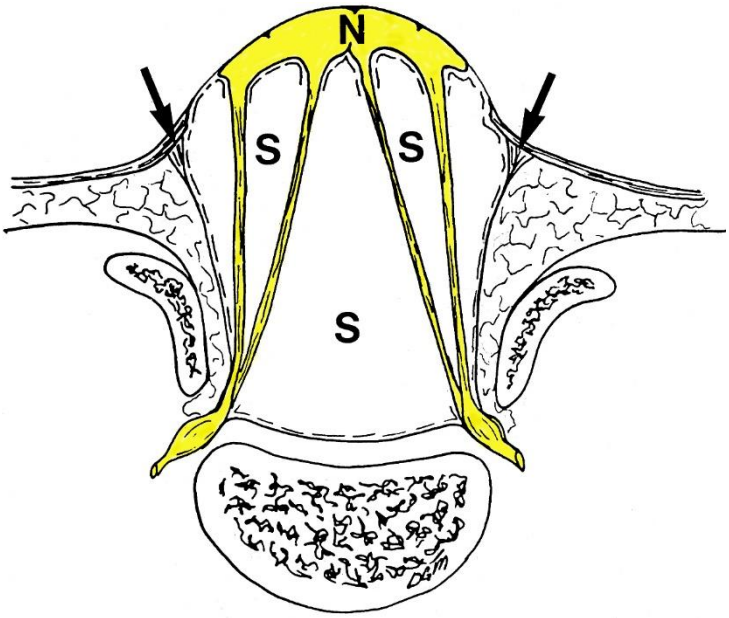
Insufficient evidence that in MMC, persistent enlargement of ventricles adversely impact neurocognitive development.

MOMS trial – intrauterine fetal MMC repair: ↓need for shunting, ↑motor outcomes but ↑preterm labor and uterine dehiscence.

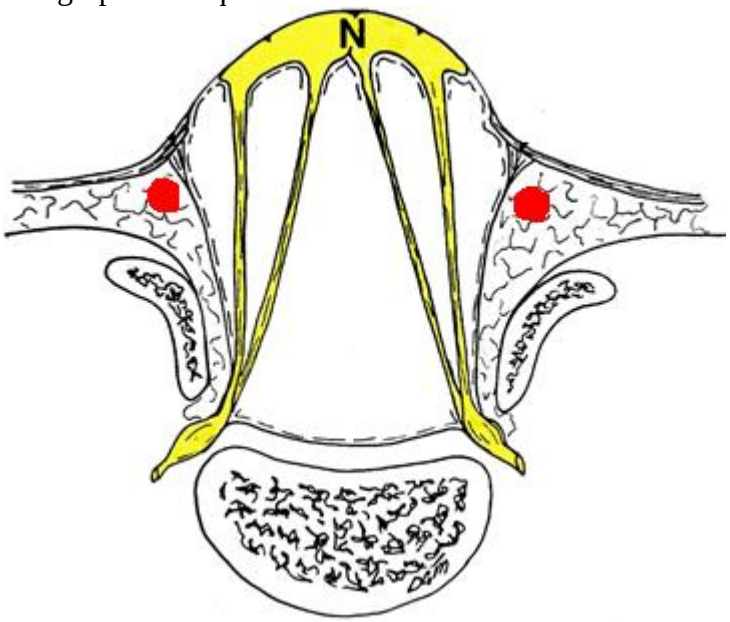
TECHNIQUE

- **transverse rolls** support and suspend chest and pelvis.
- head rotated to side; "doughnut" under head for support, without compression of external ear
- arms at sides
- Mepilex on knees

Transverse section through MMC: arrows demonstrate junction of neural placode (N) with dura mater and skin; subarachnoid space (S):

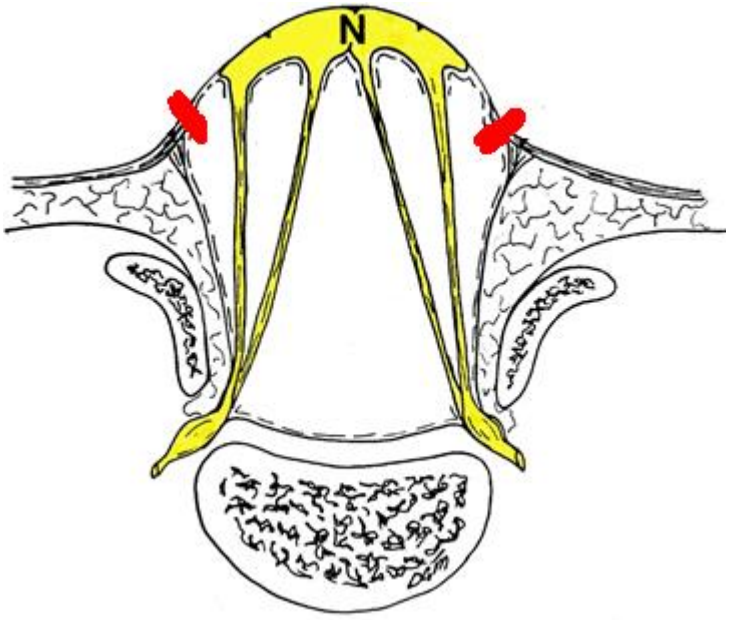


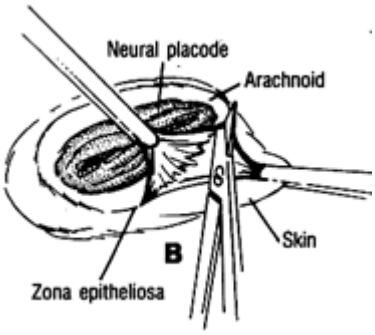
- midline normal skin incision just distal to MMC
- using tip of mosquito find distal dural sac end and tunnel on both sides of dural sac (epidural fat):



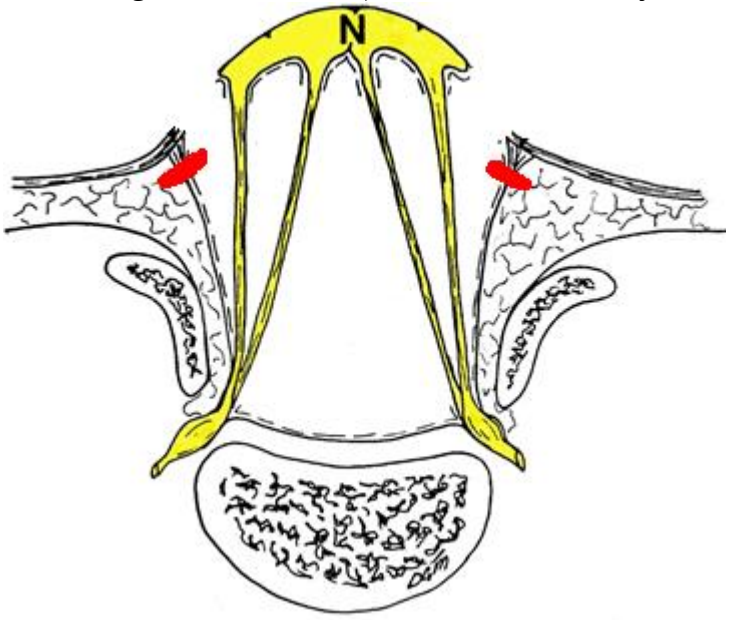
- careful separation of neural placode from surrounding epithelial tissue - open MMC sac with fine scissors and dissect placode circumferentially (both sides, caudally; cranially dissect over spinal cord where it comes to join placode):

  N.B. trim placode sides from any dermal / epidermal remnants (will form **inclusion dermoid** if left in place)!



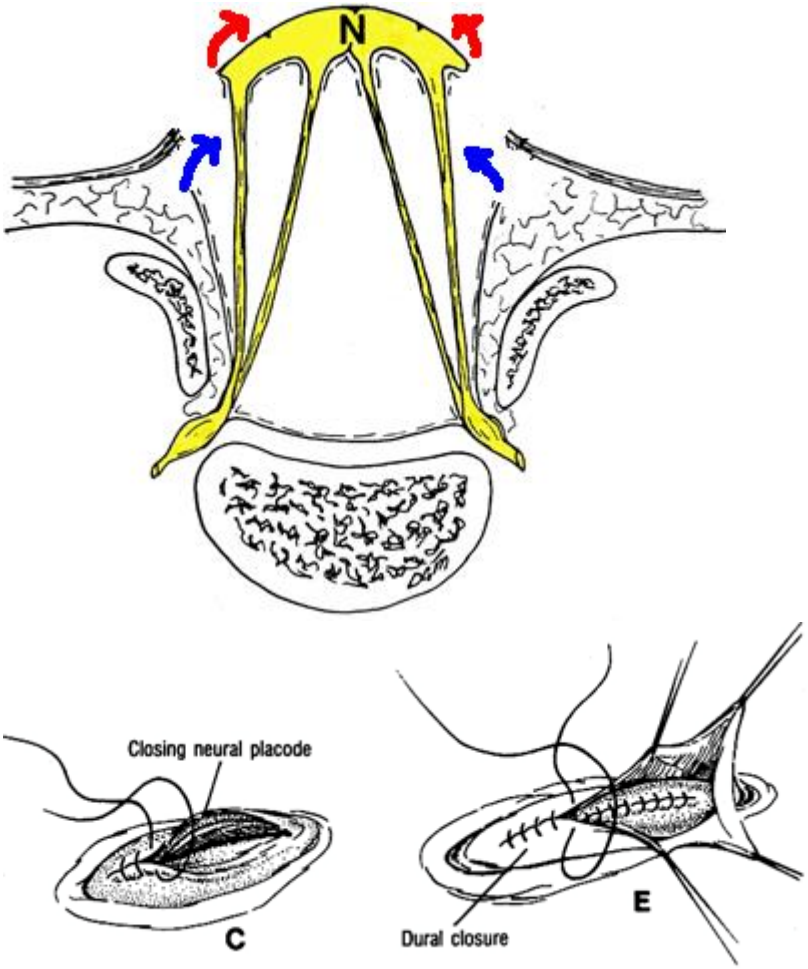


- then disconnect dura from dermis just at junction with it (one leg of scissors in epidural space, another leg on subdural side) - both sides, caudally, and cranially:



- **placode anatomic repair** by formation of tube with fine sutures (imbricate placode with 8-0 Prolene) - creating surface which is covered in pia arachnoid (to prevent retethering in scar tissue when dura is closed); then **close dural sac** over it (cover with Tisseel; occasionally thin dura needs to be reinforced with muscle and fascia):

  great care must be exercised to preserve vessels while mobilizing the dura for closure!



- skin defect needs **plastic surgery closure**: undermine *skin* flaps; best to use ***skin-fascia*** flaps (subfascial dissection - uninterrupted blood supply); ***rotated*** skin flaps and ***relaxing incisions*** may be necessary.

See Case P1 >>

SPINAL MENINGEAL CYSTS

- congenital non-neoplastic extramedullary.
    - cyst size variation may be demonstrable with table tilt or changes in posture.

TYPE I

- extradural meningeal cysts not containing nerve roots

TYPE II (TARLOV)

- extradural meningeal cysts containing nerve roots

- almost always asymptomatic (when large may cause nerve root compression; some have CSF hypotension*, e.g. positional headaches); may grow in size.
    *cyst growth leads to attenuation of its wall, which is associated with CSF leakage
- treatment options:
    1) lumboperitoneal shunts

2) open microsurgery (resection or reduction of cyst with or without correction of the connection between thecal sac and cyst).

TYPE III (ARACHNOID CYST)

- intradural meningeal cysts (s. **arachnoid cysts**).

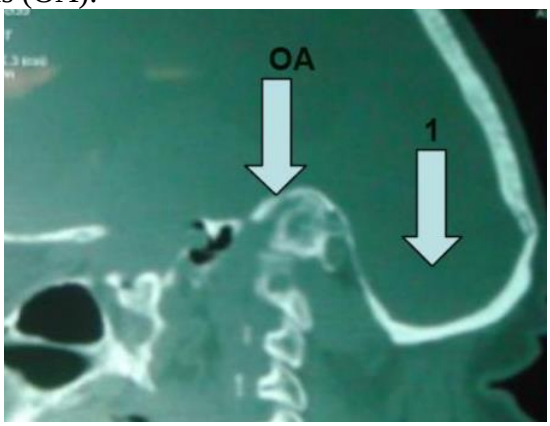
- asymptomatic, but cord or nerve root compression can occur (cyst aspiration → dramatic improvement).
- do not to overdiagnose intradural arachnoid cysts in *thoracic region*:
  - retromedullary subarachnoid space in thoracic spine is commonly wide, and partly loculated by usually incomplete septae;
  - spinal cord usually is closely applied to anterior margin of bony canal, and may have flattened appearance over exaggerated kyphosis.

CRANIOCERVICAL JUNCTION

- primary position ***downbeating nystagmus*** (fast component downward)!
- **cervical myelopathy**, brainstem & lower CN dysfunction, VA compression
- Lhermitte's sign.

1. **BASILAR INVAGINATION** – congenital upward displacement of dens into a normal foramen magnum with normal bone.
   - generally **asymptomatic**

2. **BASILAR IMPRESSION** – similar upward displacement of dens, however, due to acquired softening of skull base bones (Paget disease, osteomalacia / rickets, hyperparathyroidism, RA).
   - floor of posterior fossa bulges upward in region about foramen magnum (i.e. skull base flattened on cervical spine - upward displacement of occipital bone and cervical spine).
   - **PLATYBASIA** - abnormal flattening of skull base.
   - **CONVEXOBASIA** (more extreme form) – cupular shape occipital often with occipitalization of the atlas (OA):



TREATMENT

Preoperative* **halo traction** (to reduce vertical instability + C2 compression neuralgia) for 2-5 days with traction force 5 → 25 lbs. *awake patient reports if something is going wrong

↓ then

Surgical decompression at foramen magnum ± C2-3 laminectomies with **cervico-occipital fusion**

ATLANTOAXIAL INSTABILITY

- anterior arch of atlas - dens interval > 3 mm → acute (immediate death) or chronic **spinal cord compression** H: surgical arthrodesis

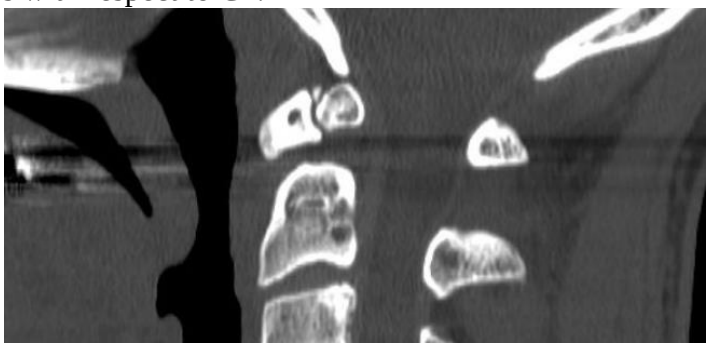
- 70% cases are associated with **os odontoideum**, remainder with **cranial assimilation of atlas**
- dynamic XR
- myelopathy → **surgical arthrodesis** (posterior atlanto-axial fusion).

Etiology
- weakness of structures maintaining stability (e.g. ligament laxity):

1. **Rheumatoid arthritis**!
2. **Mucopolysaccharidoses**
3. 30% Down's syndrome patients

OS ODONTOIDEUM

- smooth, well-corticated ossicle.
- around half the size of a normal dens.
- associated with hypertrophied and rounded anterior arch of the atlas.
- level of mobility is below the transverse band of the cruciform ligament → abnormal mobility of dens with respect to C2.



- dynamic XR, kinematic MRI
- myelopathy → **surgical arthrodesis** (posterior atlanto-axial fusion).

KLIPPEL-FEIL ANOMALY

- congenital fusion of **cervical** vertebrae (**SYNSPONDYLISM**) into one or more separate masses - not of any great clinical importance!

N.B. main neurological complications result from frequently co-existent ***craniocervical instability***!

- *sum in height of congenitally fused bodies* is equal to normal height of two vertebrae plus expected height of intervertebral disc if one were present (vs. fusion due to disease – height is less).
- bony structure of fused vertebra is normal except for fusion.

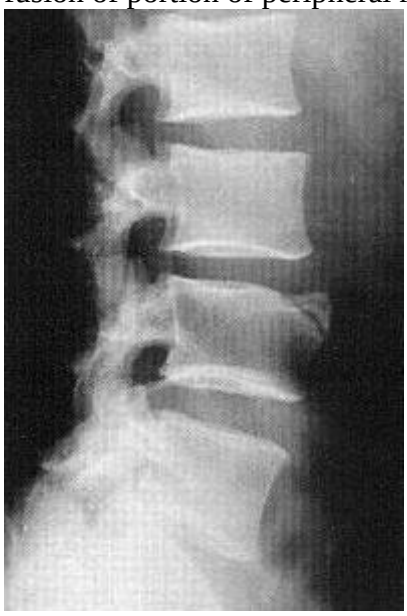
SPINE

HEMIVERTEBRA - incomplete development of half of vertebral body → **scoliosis, kyphosis**

TRANSITIONAL VERTEBRA - vertebra ***at junction of major divisions of spine*** has CHARACTERISTICS OF BOTH DIVISIONS ← level being wrongly identified preoperatively

BUTTERFLY VERTEBRA - failure to fuse of two lateral centers of chondrification for vertebral body → cleft in midsagittal plane

LIMBUS VERTEBRA - ***anterior interposition of intravertebrally herniated nuclear material*** prevents fusion of portion of peripheral ring apophysis: triangle-shaped bony mass along anterosuperior corner:



PEDIATRICS

Stress that medications are administered **weight-based**!

Always ask about VITAL SIGNS, esp. in lethargic patients!

Language:

6 months – beginning of distinct **babbling**.
1 year – **1-word speaker** (language understanding, 1 or more poorly pronounced words; mama/dada (specific)).
2 years – **2-word (telegraphic) phrases**.
3 years – **3 word sentences**.
4 years – close to **adult** speech competence.

Prematurity - born before 37 wk gestation

N.B. neonates < 23-24 weeks' gestation do not have sufficient lung development (absent capillary network adjacent to immature ventilatory units) - cannot survive.

Postmaturity - *failing placental function after 42nd wk* → ***placental insufficiency syndrome***

Small-for-Gestational-Age (Intrauterine Growth Restriction)
= fetal weight ≤ 10th percentile for gestational age.

At term, infant is **low-birth-weight** if < 2500 g (if < 1500 g, **very low-birth-weight**)

N.B. not all brain cells die at once following anoxia; rather, many cells go through reoxygenation and reperfusion period (with neuronal hyperexcitability and intracellular edema)

BRADYCARDIA in distressed child is sign of impending cardiac arrest!!!
Neonates tend to develop bradycardia with hypoxemia!

HYPOXIC-ISCHEMIC ENCEPHALOPATHY

- (sub)acute brain lesions due systemic hypoxemia or cerebral ischemia – i.e. encephalopathy from asphyxia.

BRAIN PATHOLOGY

- depends on brain maturity at time of insult and duration of ischemia:

Total > 20-25 min asphyxia results in *DIFFUSE* lesions rarely compatible with life.

- profound asphyxia lasting < 10 min in otherwise healthy newborn is not thought to cause any permanent brain damage.

Partial asphyxia for minutes ÷ hours results in predominantly supratentorial lesions:

In preterm infants, damage is at *GERMINAL MATRIX* area → periventricular hemorrhages, leukomalacia;

After 36 weeks of gestation, lesions primarily involve:

1. *CEREBRAL CORTEX* (laminar neuronal necrosis in depths of sulci → ulegyria) – diffuse or localized watershed* (e.g. in parasagittal location).
2. *BASAL GANGLIA* (→ status marmoratus** with choreoathetosis and related movement disorders).
3. *BRAIN STEM*.
4. *CEREBELLAR PURKINJE CELLS* (→ cerebellar atrophy).

*especially after fetal hypotension

**marble white discoloration due to patchy neuronal loss, gliosis, and hypermyelination.

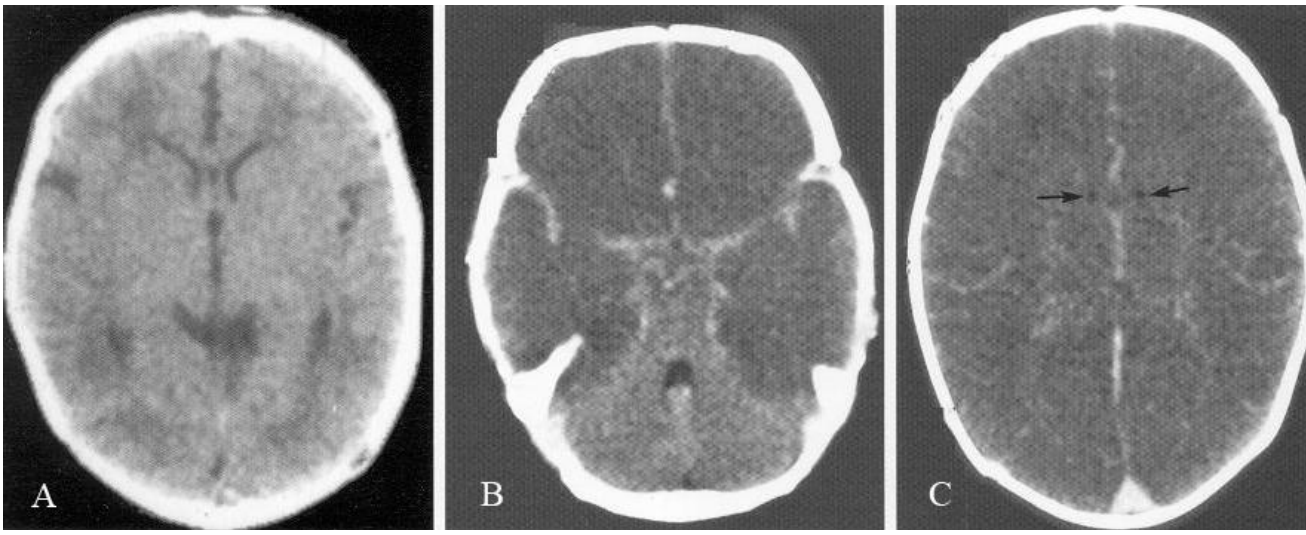
Less severe intrauterine anoxic episodes of undetermined duration may involve neurons *DIFFUSELY* or may preferentially affect *HIPPOCAMPAL AREAS*.

General course: depression → hyperalertness and hyperreflexia → coma.

- **involvement of multiple organs** besides brain is hallmark of HIE.
- diagnosis - primarily clinical!
- neuroimaging
  - **ultrasound**: *cerebral edema*; *ischemic lesions* - diffuse or localized echodensities (→ multicystic encephalomalacia, severe atrophy + ventricular enlargement).
  - **pulsed Doppler** - diastolic velocities↑ with reduced resistive index (< 0.50), sign of **luxury perfusion**.
  - **CT** - *cerebral edema*, *infarction* (areas of reduced density)

A. CT of normal term newborn.
B, C. CT of severe partial hypoxia (12-hour-old term newborn) - no differentiation between white and grey matter; preserved normal tissue attenuation in posterior fossa but lateral ventricles (*arrows* in C) are compressed owing to edema. Since there are already extensive changes at age 12 hours, insult occurred in utero, at least 24 hours before

scan.



  - **MRI** is valuable at 6 months ÷ 1 year - status of *myelination* (e.g. delayed), *white-gray tissue injury*, preexisting *developmental defects*.
- sequelae – microcephaly, mental retardation, epilepsy, cerebral palsy.

Treatment
- current data insufficient to recommend **brain HYPOTHERMIA** for all asphyxias; but it is slowly emerging as useful therapy for mild-to-moderate cases!
- seizures should be treated early with PHENOBARBITAL (drug of choice!!!) or LORAZEPAM (second drug of choice); PHENYTOIN IV (third drug of choice) may be added.

BIRTH TRAUMA

HEAD TRAUMA

Risk factors - primiparas, large infants, preterm delivery, difficult delivery.

Operative delivery (vacuum extraction, forceps, cesarean section) or ***rapid birth*** (esp. in breech presentation - rapid head moulding during final moments of birth) - increased risk of **skull fractures**, **intracranial hemorrhage**!

Slow deformational forces → **tears in tentorium** (less commonly, **in falx**, in junction between falx and tentorium) → ***subdural hematoma***.

Forceps delivery → **'ping-pong' skull fracture** (may require elevation for cosmetic reasons).

Intracranial hemorrhage
- ***gestational age*** is best indicator of probable site of intracranial hemorrhage:
  supratentorial SDH – exclusively ***full-term*** or large infants with difficult deliveries.
  supratentorial SAH of venous origin – ***full-term*** newborns who have focal seizures and benign clinical course.
  periventricular hemorrhage – ***premature*** infants of ≤ 32 weeks gestation.
- diagnosed by **CT** (ultrasound is not good method).
- can be life threatening (esp. if born prematurely).
- prognosis for SAH is generally good; prognosis for SDH is guarded (some infants do well)
- treatment:
  - vitamin K;
  - **symptomatic subdural hematomas** → daily subdural taps.

– **posterior fossa hematoma** - surgical drainage may be lifesaving!

Vaginal delivery may result in:

1) **MOLDING** (bone overlapping at sutures) - disappears within 2 weeks.
2) **CAPUT SUCCEDANEUM** – SWELLING in presenting portion of scalp (*above periosteum*) secondary to compression by cervix; resolves within 2 weeks.
3) **SUBGALEAL HEMATOMA** – *sub-galeal* BLOOD ACCUMULATION.
   – soft fluctuant swelling over entire scalp (i.e. not limited by periosteal insertions).
   – *self-limiting condition*.
   Needle / incisional drainage may result in infection!!!
4) **CEPHALHEMATOMA** – *subperiosteal* BLOOD ACCUMULATION after instrumental delivery.
   – not present at birth, appears within 24 hours
   – fluid-blood collection is limited by periosteal insertion at suture lines, i.e. *does not extend across suture* (vs. caput succedaneum).
   – initially soft, but may develop ***raised bony margin*** within 2-3 days (rapid Ca deposition at edges of raised periosteum).
   – *resorb spontaneously* within few weeks (occasionally calcify and form bony protrusion - *self-correcting* cosmetic deformity before age 1-2 years).

   Needle / incisional drainage may result in infection!!!

CRANIAL NERVE INJURY

Most often - **FACIAL NERVE**:

a) most injuries - pressure on nerve in utero (head lying against shoulder, sacral promontory, or uterine fibroid).
b) forceps pressure.

- injury usually occurs *at or distal to exit from stylomastoid foramen*.
- ***facial asymmetry*** is most apparent during crying (differentiate from mandibular asymmetry resulting from intrauterine pressure - occlusal surfaces are not parallel, vs. facial nerve injury).
- testing or treatment is not needed for peripheral CN7 injuries - resolve by age 2-3 months.

BRACHIAL PLEXUS INJURIES

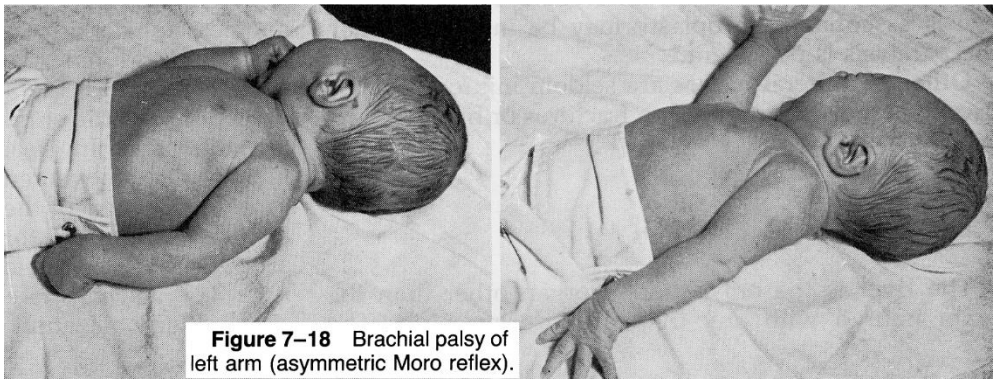


Figure 7–18 Brachial palsy of left arm (asymmetric Moro reflex).

- etiology – stretching by shoulder dystocia.
- upper plexus injuries are most common; pure lower lesions (C7–1) are rare (≈ 2%).
- associated injuries – fractures of clavicle or humerus or subluxations of shoulder or cervical spine – patient may not move arm* because of ortho injuries!

  *either spontaneously or when Moro reflex is elicited
- treatment – hand support, passive range-of-motion exercises.

- usually improve rapidly (esp. if only C5-6 [most common injury in neonates] – spontaneous recovery in 90% cases)
- observe for 3 months → MRI to determine extent of injury → surgical exploration & repair (aim at 3-9 months of age).

N.B. if found neuroma, just excise it (nerve stimulation does not work in babies)

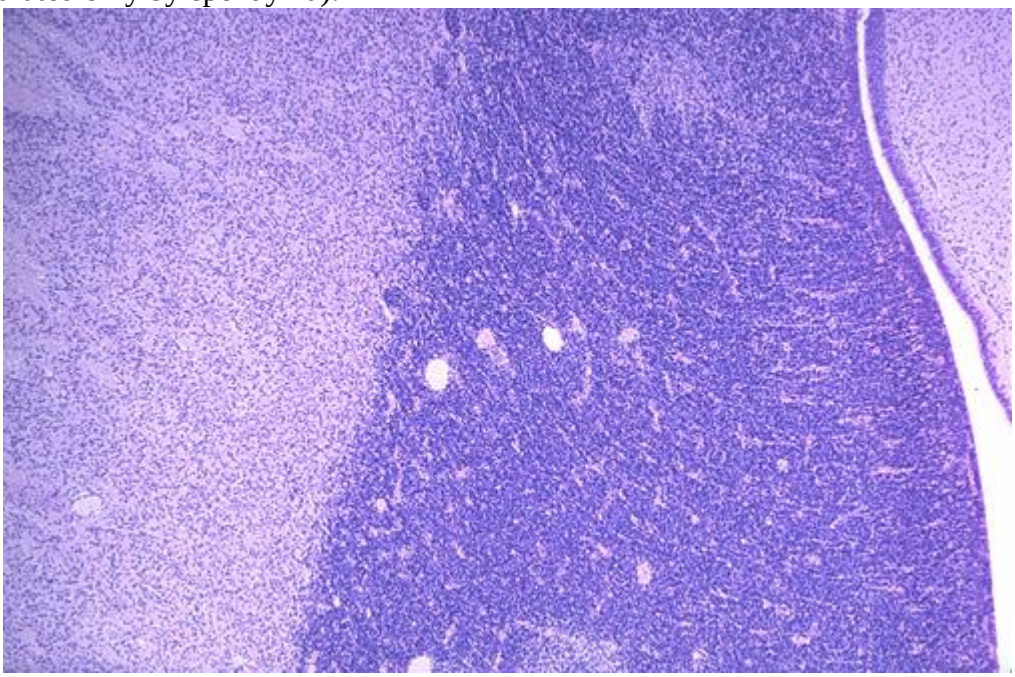
- if *entire brachial plexus* is injured (*flail arm + Horner syndrome*) - prognosis for recovery is 0%; extremity's growth may be impaired; H: nerve transfer* (even at age 3 months).

*Oberlin transfer does not work – need donor from outside brachial plexus!

PERIVENTRICULAR / INTRAVENTRICULAR HEMORRHAGE (PVH-IVH)

- hemorrhage into germinal matrix seen exclusively in PRETERM INFANTS after ***asphyxia***.

- intraventricular hemorrhage in TERM INFANTS – from choroid plexus (or venous sinus thrombosis)
- hemorrhage occurs into subependymal friable, richly vascular germinal matrix (lies on lateral wall of lateral ventricles between thalamus and caudate, near foramina of Monro; from lateral ventricle separated only by ependyma):



- germinal matrix is site of neuronal proliferation as neuroblasts divide and migrate into cerebral parenchyma;
  - by ≈ 20 weeks' gestation, ***neuronal proliferation*** is completed; however, ***glial cell proliferation*** is still ongoing until ≈ 32 weeks' gestation, at which time regression is nearly complete.

N.B. germinal matrix is present only in < 32 weeks!

- metabolically active differentiating cells of germinal matrix are rich in mitochondria (quite sensitive to ischemia).
  - supplying this area is primitive and fragile retelike capillary network.
  - arterial supply - *recurrent artery of Heubner* and *lateral striate arteries*.
  - venous supply - *thalamostriate veins*.
  - immature lungs (*episodes of hypoxemia*) + *fluctuations in cerebral perfusion*, vessels in germinal matrix have tendency to rupture.

N.B. only sites in adult brain where neurons still being produced – **olfactory bulb** and **hippocampus**!

- diagnosis – **ultrasound** (has replaced CT!) – blood is *echogenic material*

American Academy of Neurology recommendation - all infants < 30 weeks must be screened* by cranial US at 7-14 days postnatal life and at 36-40 weeks postmenstrual age.

*PVH can occur without clinical signs

Grade I – confined to germinal matrix, i.e. subependymal (usually asymptomatic - most infants do well!)

Grade II – small blood amount (< 40% of ventricular volume) in ventricles without ventricular enlargement (nonspecific irritability or lethargy - most infants do well!)

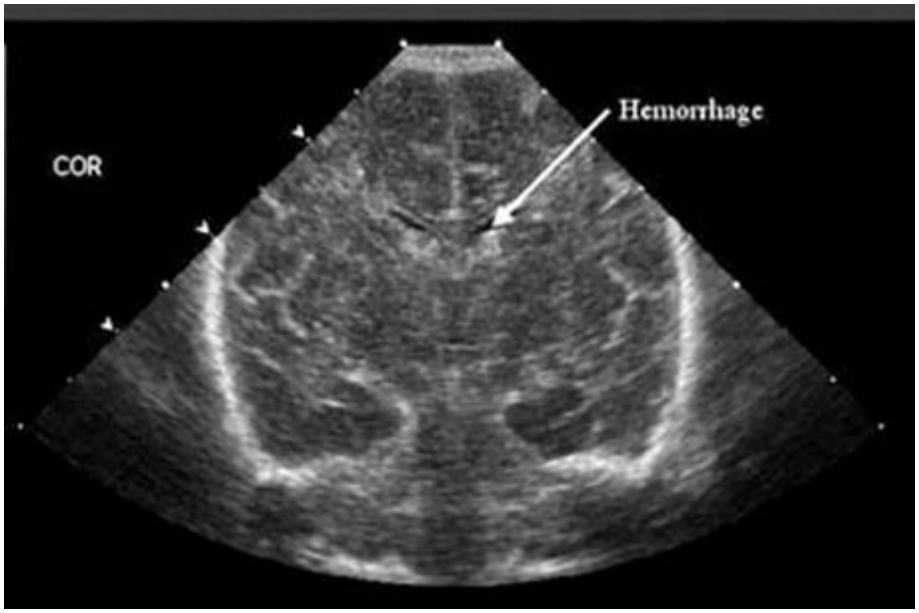
(when clot is small – must be distinguished from *choroid plexus* – colour Doppler may help)

Grade III – blood in ventricles, ventricular dilation (mortality < 10%); sequelae - static or reversible or progressive *posthemorrhagic hydrocephalus* → 30-40% incidence of cerebral palsy and mental retardation.

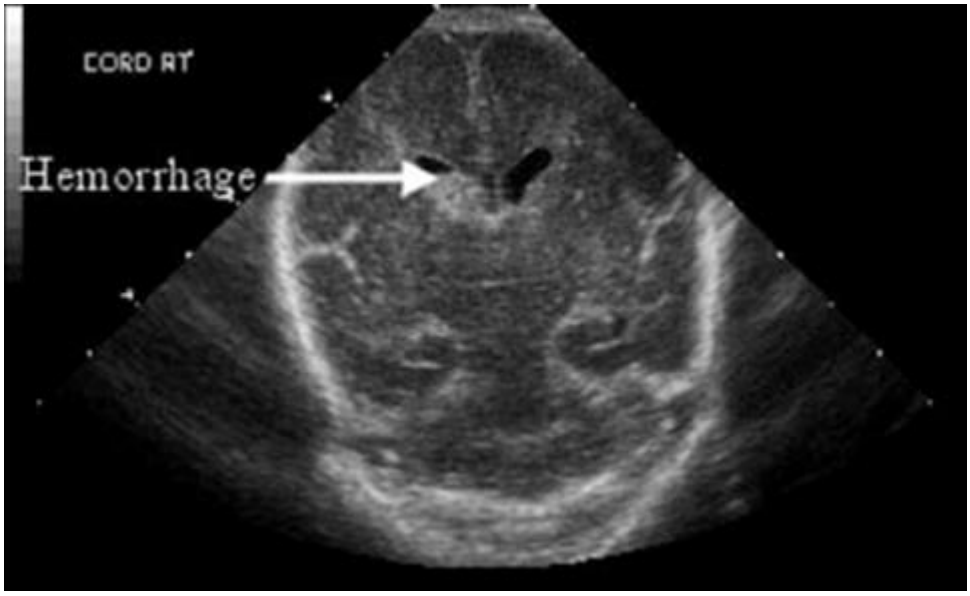
Grade IV (periventricular hemorrhagic venous infarction) – additional hemorrhage into parenchyma which involves periventricular motor tracts (27-80% mortality!; 90% incidence of cerebral palsy and mental retardation); it is ***secondary to grade I-III hemorrhage*** → congestion in periventricular white matter → venous infarction → secondary hemorrhage

N.B. prognosis (of subsequent handicap) is better than in PERIVENTRICULAR LEUKOMALACIA!

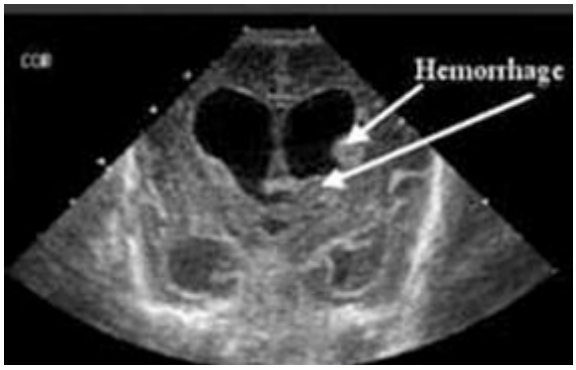
Grade I PVH:



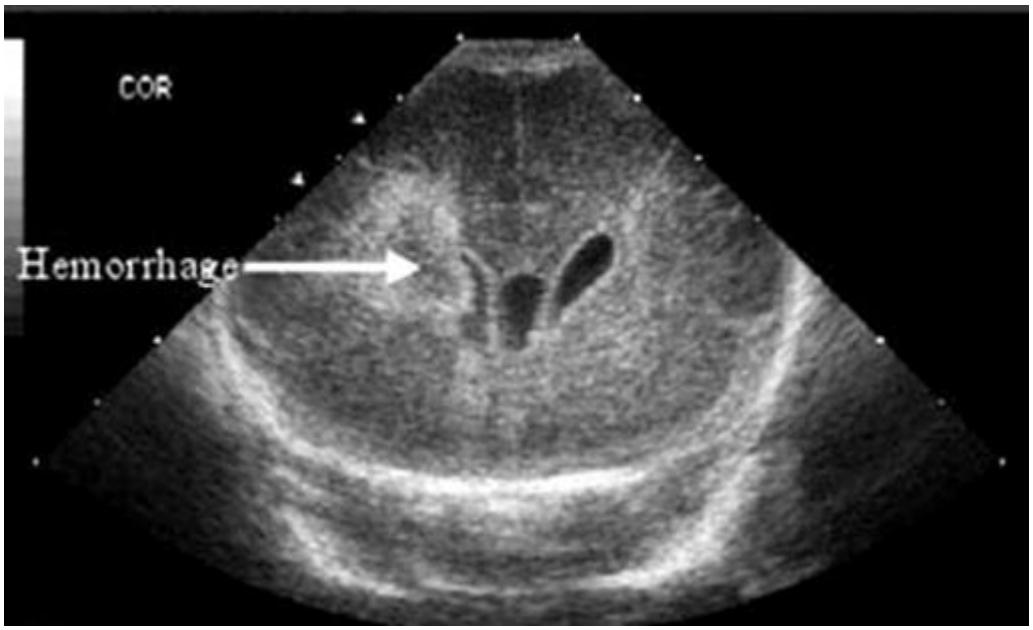
Grade II PVH-IVH:



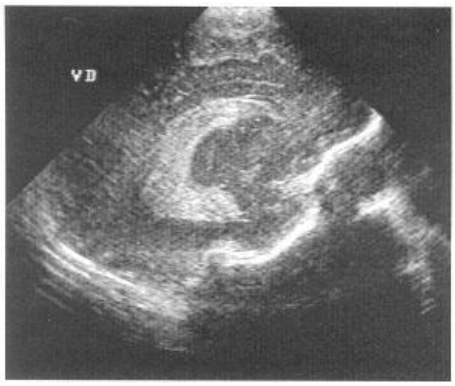
Grade III PVH-IVH:



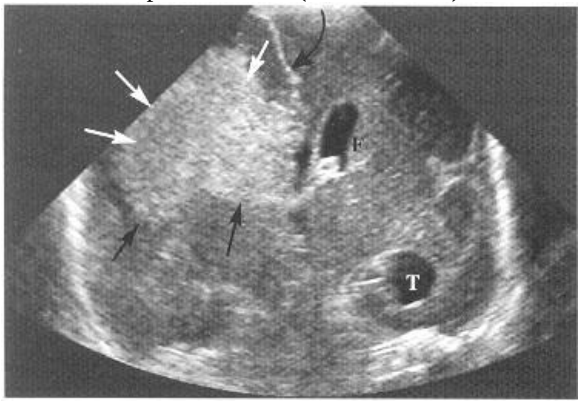
Grade IV PVH-IVH:



Sagittal sonogram (intraventricular hemorrhage): hyperechogenic blood fills lumen of lateral ventricle:



Coronal sonogram - intraventricular hemorrhage with parenchymal hemorrhagic infarction (*straight arrows*), mass effect on interhemispheric fissure (*curved arrow*), dilatation of left ventricle (frontal horn *F*, temporal horn *T*):



Sequelae:

1. Destruction of periventricular cerebral parenchyma (esp. motor tracts) → **cerebral palsy**, mental retardation, seizures.
2. Posthemorrhagic hydrocephalus

Possible concomitant, injury to other portions of brain:

1) GLOBAL HYPOXIC-ISCHEMIC INJURY
2) PERIVENTRICULAR LEUKOMALACIA (PVL) - nonhemorrhagic ischemic necrosis.

Prophylaxis: **INDOMETHACIN**- ***accelerates maturation*** of germinal matrix vasculature;

Greatest risk is first 72 hours of life (50% hemorrhages occur on 1st day) – reduce systemic blood pressure fluctuations (may diminish incidence of hemorrhage and its spread):

PANCURONIUM paralysis while infant is **ventilated**

Avoid rapid **volume expansion**

TREATMENT

Correction of anemia, acidosis, hypotension + ventilatory support.

Daily **head circumference**

Weekly **head US**

No treatment is necessary for grades I - II.

Grade III- IV

- most patients with hydrocephalus demonstrate spontaneous resolution within weeks.
- daily ventricular punctures to drain large CSF volumes (e.g. 10 ml CSF/kg) to prevent hydrocephalus.
- if head growth is double normal rate over 2 weeks or ICP↑ persist → **implant ventriculosubgaleal (VSG) shunt**.

– Dr. Fuhs: ventricle tap based on US; if need taps too often → implant either ventricular access device or ventriculo-subgaleal shunt

CNS Systematic Review and Evidence-Based Guidelines on the Treatment of Pediatric Hydrocephalus (2014) - **TEMPORIZING MEASURES**:
Level 2 recommendation: ventriculosubgaleal (VSG) shunts reduce the need for daily CSF aspiration compared with ventricular access devices (VADs).
Level 1 recommendation: serial LP is not recommended.
Level 1 recommendation: Intraventricular thrombolytic agents are not recommended.
Level 1 recommendation: Acetazolamide and furosemide are not recommended.
CNS Systematic Review and Evidence-Based Guidelines on the Treatment of Pediatric Hydrocephalus (2021 Update):
Level 3 recommendation: neuro-endoscopic lavage is a feasible and safe option for the removal of intraventricular clots and may lower the rate of shunt placement.

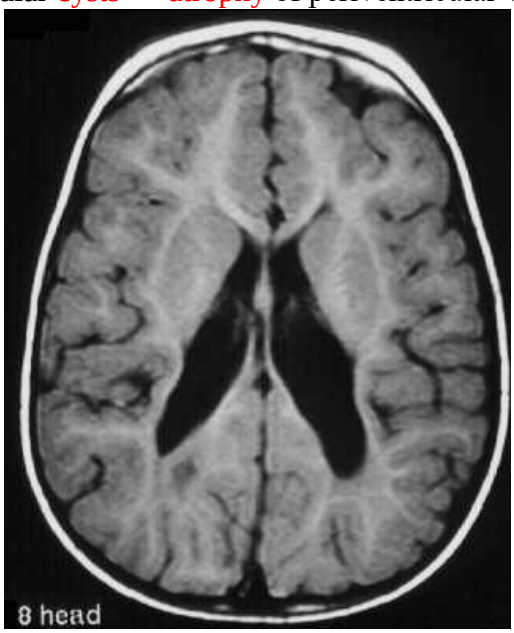
Indications for **ventriculoperitoneal shunt**: head circumference > 1.5 cm above 97th percentile; or head growth > 1.5 cm/week for 2 weeks; and signs of raised ICP
– high complication rate in small infants! – delay shunting until > 1800-2000 g, age > 38 weeks; plus, US shows ↓clot size.
– modern alternative – **ETV with CPC** (choroid plexus coagulation)

CNS Systematic Review and Evidence-Based Guidelines on the Treatment of Pediatric Hydrocephalus (2014):
Insufficient evidence to recommend a specific weight or CSF parameter.
Insufficient evidence to recommend ETV.

PERIVENTRICULAR LEUKOMALACIA (PVL)

- selective loss of oligodendrocytes due to hypotension, ischemia - bilateral white matter lesion of premature infants, esp. mechanically ventilated

- affects **corticospinal tracts**, **visual radiations**, and **acoustic radiations** → *multicystic encephalopathy*
- diagnosis – **ultrasound** N.B. initial exam may be normal! → periventricular edema → periventricular cysts → atrophy of periventricular white matter → secondary ventricular dilatation



- clinically most significant destructive lesion in immature brain - strong relationship to subsequent handicap!

- no treatment currently exists!

CEREBRAL PALSY (CP)

- nonprogressive **motor** disorder (abnormal control of movements or posture) due to intrauterine ÷ early postnatal nonprogressive (static) injury to DEVELOPING brain (cerebrum or cerebellum*), i.e. due to nonprogressive [static] encephalopathy.

N.B. *patients do not lose skills once acquired*! (vs. progressive neurologic disorders!)

*i.e. not spinal cord, peripheral nerves, or muscles

Spastic diparesis (**diplegia**), **LITTLE disease** – most common form (≈ 45%) - leg "scissoring"
Spastic hemiparesis (**hemiplegia**) – commonest form (≈ 34%) in term neonates.

NOT NEUROSURGERY RELATED

Apgar score at 1 and 5 min:

CRITERIA	MNEMONIC	SCORE		
		0	1	2
1) **color**	**A**ppearance	all blue, pale	pink body, blue extremities	all pink
2) **heart rate***	**P**ulse	absent	< 100 / min	> 100 / min
3) **reflex response to nasal catheter / tactile stimulation**	**G**rimace	none	grimace	sneeze, cough
4) **muscle tone**	**A**ctivity	limp	some flexion of extremities	active
5) **respiration**	**R**espiration	absent	irregular, slow	good, crying

Heart rate > 100/min + ***adequate respiratory effort*** + ***cyanosis*** → **O_2 supplement**
Heart rate < 100/min OR ***respiratory distress*** (inadequate respiratory activity) OR ***central cyanosis*** (despite 100% O_2) → **bag-mask ventilation**
Heart rate < 60/min following 30 seconds of effective positive pressure ventilation → **chest compressions;** jei po 30-60 sek. išlieka < 60/min → **intubation & mechanical ventilation**; jei po 30-60 sek. ventiliacijos vis tiek išlieka < 60/min, skiriama **EPINEPHRINE**

Developmental delay
- failure to achieve expected motor and cognitive milestones owing to *ENCEPHALOPATHY*:

Child Abuse – **skeletal X-ray survey** (in < 5 yrs children) ± **radionuclide bone scanning, CT of head / chest, ophthalmologic exam**

Failure to Thrive (inadequate nutrition due to psychosocial / medical causes) - weight < 3rd percentile at age-appropriate norms ± height↓ (head circumference↓ in severe cases)
Recurrent Pain Syndromes - pains occur at least monthly for 3-month period; no organic pathology is found; between episodes, child is well:
Recurrent abdominal pain syndrome
Limb pain ("growing pains")
School phobia, separation anxiety, stranger anxiety
Attention Deficit Hyperactivity Disorder (ADHD) – onset at < 7 yrs: too much attention to too many things, difficulty concentrating, impulsivity, distractibility, excitability, hyperactivity.

Rx – psychostimulants: **METHYLPHENIDATE**, AMPHETAMINES; second-line agent - ATOMOXETINE (selective norepinephrine reuptake inhibitor)

Autistic Spectrum Disorders (s. Pervasive Developmental Disorders) - qualitative impairments in **social interactions** (preoccupation with internal world), delay in, or total lack of, development of **spoken language**, and **repetitive stereotyped patterns of behavior**; **mental retardation** is present in 75% patients; occur before age 3 yrs

Learning Disabilities - subtle CNS dysfunction: dyslexia, dysphasia, dysgraphia, dyscalculia, dysnomia

Discrepancy between *academic potential* and *academic performance*

N.B. by US law, affected children should participate as much as possible in **inclusive classes** with peers who do not have learning disabilities (so called "mainstreaming")

Mental Retardation - global developmental delay:

1) delayed intellectual development (slow progress rather than developmental arrest) → IQ < 70
2) immature behavior
3) limited self-care skills (inability to function independently)

for children < 5 yrs – diagnosis should be **developmental delay**

Trisomy syndromes (Down syndrome, Edwards syndrome, Patau syndrome)

Sex chromosome abnormalities (Turner syndrome, triple X syndrome, Klinefelter syndrome, 47XYY, 48XXXX, 49XXXXX, fragile X syndrome)

Elimination (Toileting) Disorders: enuresis, encopresis – primary / secondary

- when to start toilet training:
  - for bowel control - at age 2-3 yr; incontinence at age ≥ 4 yr is abnormal
  - for urinary control - at age 3-4 yr. incontinence at age ≥ 5 yr is abnormal
- by age 5 yr, average child can go to toilet alone.

Disruptive Behavioral Disorders (oppositional defiant disorder, conduct disorder) - behavior that violates rights of others, hostile behavior directed at authority figures; as adults - antisocial personality disorder.

Feeding: infants < 34 wk gestation *must be fed by NGT*

first 6 months - exclusive breastfeeding – encourage this!!!!

6 mo ÷ 1 year - breastfeeding + solid foods

only acceptable alternative to breastfeeding in 1st yr is formula; wheat, eggs, peanuts, chocolate, honey, *whole cow's milk* should not be used in 1st year

iron-fortified rice cereal is traditionally 1st food introduced

> 1 year - full diet of solid foods and fluids ± breastfeeding

2 yrs, child's diet essentially resemble that of rest of family

Diet supplements:

1) **iron** (if fed by noncommercial formula)
2) **vit. D** (if fed by human milk in areas with little sunshine)
3) **fluoride** (start only after 6 months and only if local water contains fluoride < 0.3 ppm)
4) **calcium** and **phosphorus** (only for preterm infants)

COMMERCIAL FORMULA-FED *INFANTS DO NOT REQUIRE VITAMIN OR MINERAL SUPPLEMENTATION.* If mother's diet is adequate, no dietary supplement is needed for *breast-fed* infant Preterm infants - should routinely receive **multiple-vitamin supplement**

Lactating mother diet: avoid foods that may cause *colic*, extra 600 **kcal**, extra 400 mg **calcium**

Infant colic (paroxysms of crying & irritability, apparent abdominal pain; appetite is good, weight gain is normal) – crying does not harm the child, baby is healthy, do not blame yourself; will improve without intervention (most will disappear after age 3-5 months); most important – soothing skills: use

pacifier, if bottle feeding lasts < 20 mins, use nipple with smaller hole; try different formulas (may be milk intolerant)

N.B. if age > 9 months – it is irritable bowel syndrome!