Pediatric Head Injury:
Part I – Basic Principles

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Introduction

- **Second most common neoplasm**
- **Most common solid malignancy**
- **Derive from intrinsic/parenchymal elements of CNS**
- **Majority are in midline**
- **Classify by site or histology**

Introduction

- **Trauma leading cause of death in children.**
- **More deaths than all other diseases combined!**
- **Often occurs after-hours, requires intense and immediate interventions.**

Introduction

- **500,000 admissions per year**
- **3000 - 4000 deaths per year**
- **20,000 prolonged hospitalization**
- **Decreased M/M in recent decades.**
- **Better understanding of pathophysiology**

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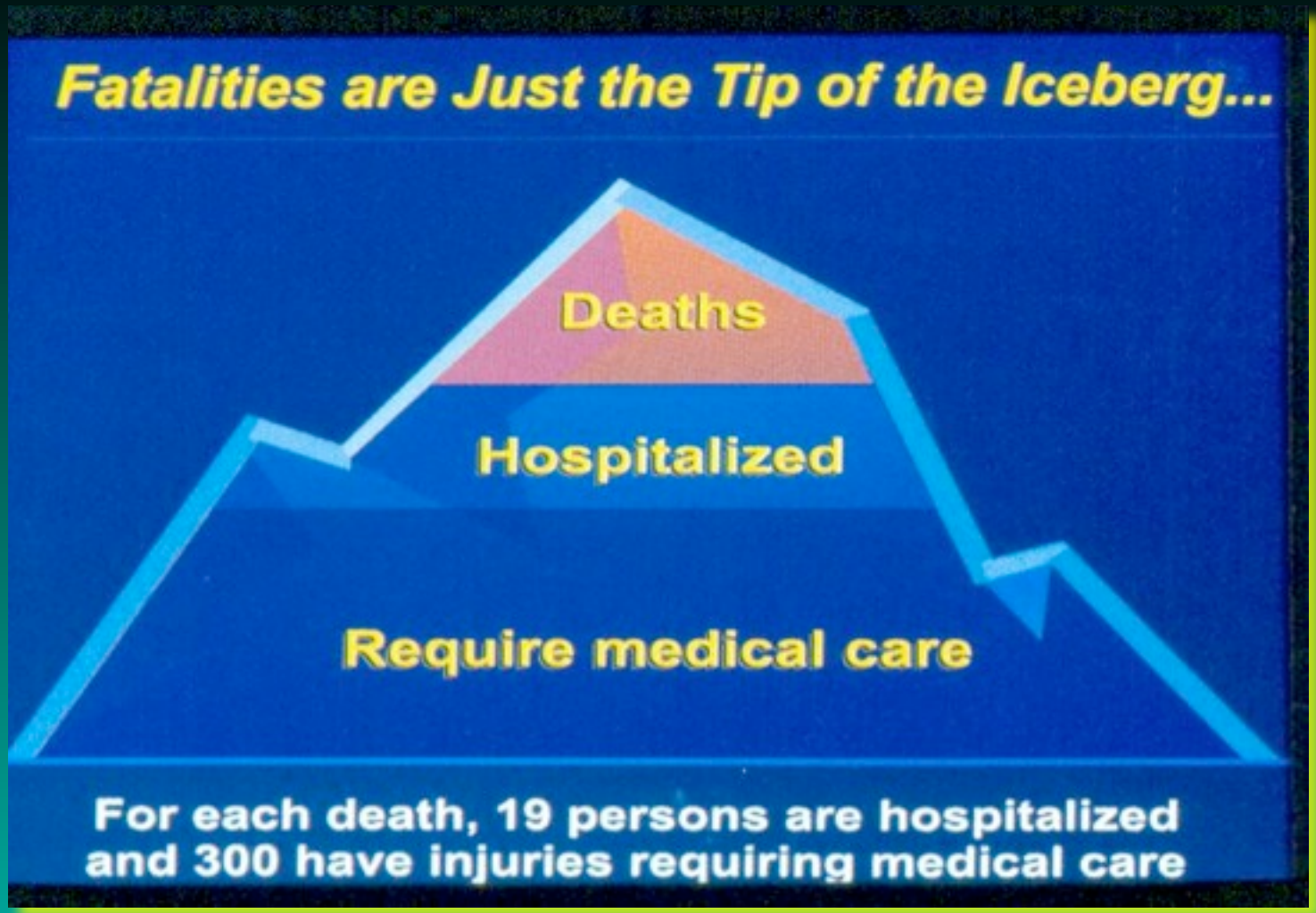
Introduction



Algorithim

Derivation of the children's head injury algorithm for the prediction of important clinical events decision rule for head injury in children

Dunning J, Daly JP, Lomas J-P, et al on behalf of the children's head injury algorithm for the prediction of important clinical events (CHALICE) study group

Sensitivity 98%. Scan rate 14%

Arch Dis Child 2006; 91:885-891

The children's head injury algorithm for the prediction of important clinical events rule

A computed tomography scan is required if any of the following criteria are present.

- *History*
  - Witnessed loss of consciousness of >5 min duration
  - History of amnesia (either antegrade or retrograde) of >5 min duration
  - Abnormal drowsiness (defined as drowsiness in excess of that expected by the examining doctor)
  - ⩾3 vomits after head injury (a vomit is defined as a single discrete episode of vomiting)
  - Suspicion of non-accidental injury (NAI, defined as any suspicion of NAI by the examining doctor)
  - Seizure after head injury in a patient who has no history of epilepsy
- *Examination*
  - Glasgow Coma Score (GCS)<14, or GCS<15 if <1 year old
  - Suspicion of penetrating or depressed skull injury or tense fontanelle
  - Signs of a basal skull fracture (defined as evidence of blood or cerebrospinal fluid from ear or nose, panda eyes, Battles sign, haematympanum, facial crepitus or serious facial injury)
  - Positive focal neurology (defined as any focal neurology, including motor, sensory, coordination or reflex abnormality)
  - Presence of bruise, swelling or laceration >5 cm if <1 year old
- *Mechanism*
  - High-speed road traffic accident either as pedestrian, cyclist or occupant (defined as accident with speed >40 m/h)
  - Fall of >3 m in height
  - High-speed injury from a projectile or an object

If none of the above variables are present, the patient is at low risk of intracranial pathology.

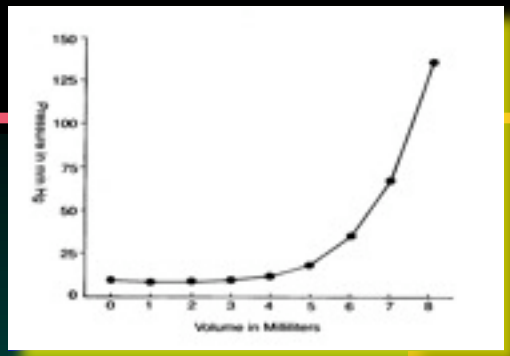
Etiology

- **Falls < 10 y.o.**
- **MVA > 10 y.o.**
- **NAT < 2 y.o.**
- **Sports > 4 y.o.**
- **50% with associated injuries**
- **GCS correlates with outcomes**
- **80% mild, 10% mod., 10% severe**

Pathophysiology

- **Brain 15% at birth, 3% as adult**
- **Skull / brain relationships vary**
- **Increased water content in children**
- **Diffuse injury more common**
- **Less operative trauma**
- **Plasticity of neurologic return**

Monro-Kellie Doctrine

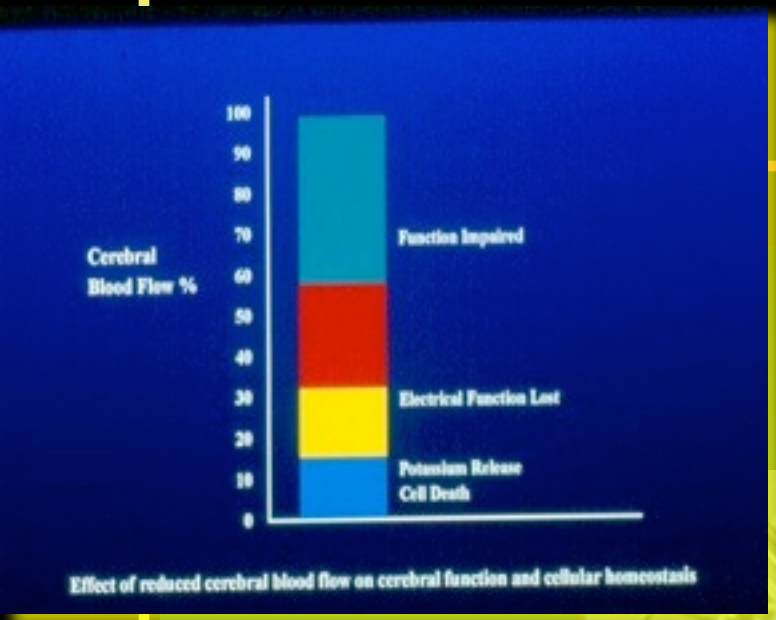


- $V_{blood} + V_{CSF} + V_{brain} = V_{total}$
- **Intracranial space is limited!**
- **Hypothesis proposed in 1783**
- **Cushing popularized concept in 1902**
- **CPP = MAP - ICP**
- **~ 50 mm Hg adequate in children**
- **Ultimate goal = adequate CPP**

Cerebral Blood Flow

- **Adult human brain weighs 1500gm**
- **2% body wt. & receives 15% C.O.**
- **Measured by xenon and TCD**
- **Need continuos O_2 & glucose supply**
- **Cerebral edema causes CBF**
- **Increased with loss of autoregulation**

Cerebral Blood Flow



Glascow Coma Scale

Glasgow Coma Scale	Modified Coma Scale for Infants	Point Value
Eye opening		
Spontaneous	Spontaneous	4
To speech	To speech	3
To pain	To pain	2
None	None	1
Verbal		
Oriented	Coos, babbles	5
Confused	Irritable	4
Inappropriate words	Cries to pain	3
Grunting	Moans to pain	2
None	None	1
Motor		
Follows commands	Normal spontaneous movements	6
Localizes pain	Withdraws to touch	5
Withdraws to pain	Withdraws to pain	4
Abnormal flexion	Abnormal flexion	3
Abnormal extension	Abnormal extension	2
Flaccid	Flaccid	1

Associated Injuries

- **50% BTAT**
- **3-5% spine**
- **15-20% ortho**
- **Increase severity**

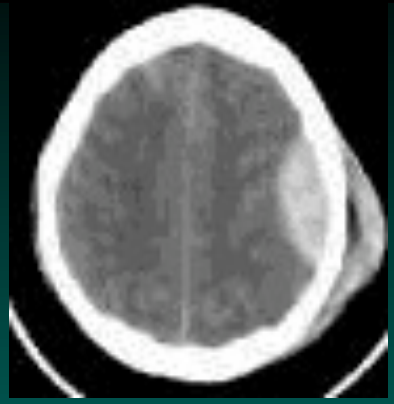
Skull Fractures

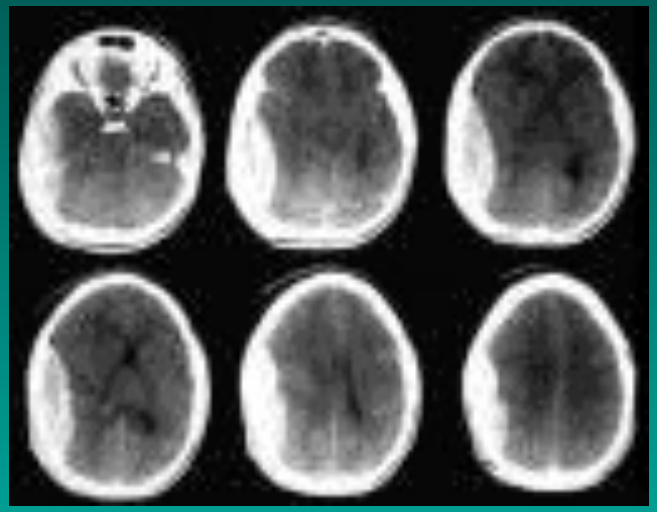
- **5 - 15% of mild head injuries**
- **30 - 70% in child abuse cases**
- **History usually reliable**
- **Often with focal scalp injury**
- **Increases suspicion of brain inv.**
- **Usually require observation**

Skull Fractures

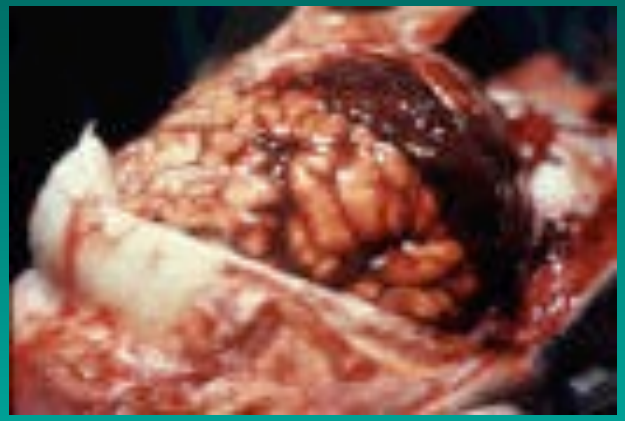
…takes much force to fracture a skull!

Epidural Hematoma



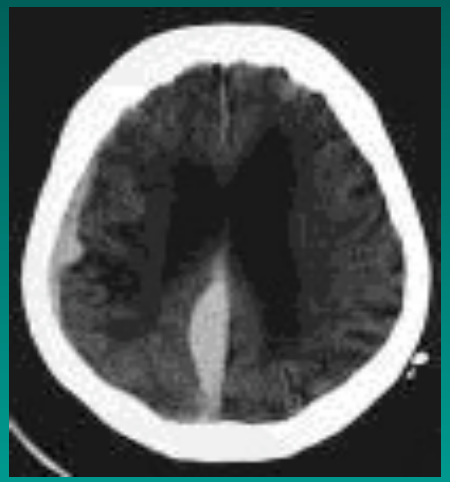


Subdural Hematoma



Non-accidental Trauma

- Interhemispheric falx hemmorhage
- Sub-dural hemorrhage
- Large, non-acute extra-axial fluid collection
- Basal ganglia edema



p<0.05 for above per Hymel et al, Pediatr Radiol; (1997 Sep) v27 n9 p743-7.

Cerebral Concussion

- **Most frequent head injury**
- **Loss of neurologic function**
- **Temporary paralysis of function**
- **Altered cerebral blood flow**
- **No structural abnormality**
- **Outcome uniformly excellent**

Cerebral Concussion

- **Variable level of consciousness**
- **Loss of tone, reflexes, resp. control**
- **Pupil abn., cortical blindness**
- **Pallor, heart rate abn., vomiting**
- **Lethargy, slurred speech**
- **Confusion, amnesia of events**

Admission Criteria

- **Decreasing consciousness**
- **Persistent confusion / lethargy**
- **Excessive headache / vomiting**
- **Uncertain history of trauma**
- **Focal neurologic signs**
- **Seizures / skull fracture**

Observation

OCTOPUS – observation or computed tomography of mild head injury in Sweden: a randomized clinical trial concerning effects and costs

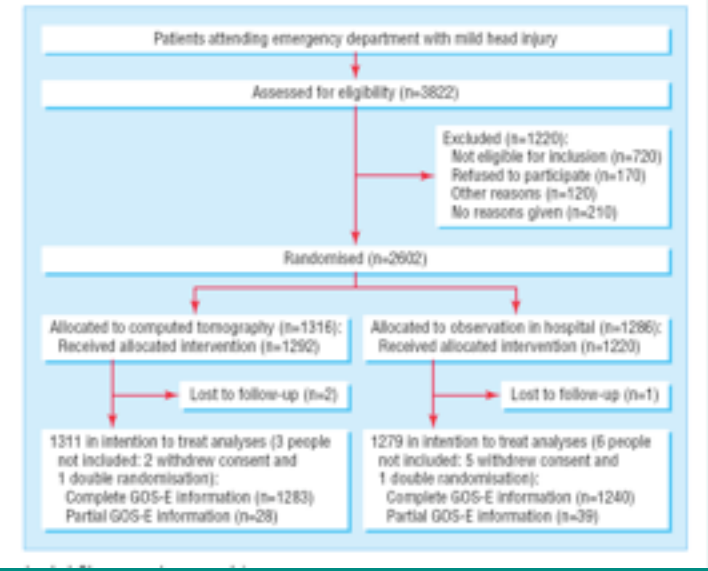


Table 3 Death and complications according to final evaluation by blinded external and internal reviewers

	Computed tomography (n=1316)	Observation in hospital (n=1286)	Total
Deaths:			
Caused by head injury	1	1	2
Possibly related to head injury	1	0	1
Other causes	2	4	6
Total	4	5	9
Admission to ICU/neurosurgical ward during acute phase	2	3	5
Neurosurgical operations:			
-During acute phase	0	0	0
During three month follow-up	1	3	4
Readmissions:			
Readmission due to symptoms of head injury	1	1	2

ICU=intensive care unit.

Table 5 Cost per patient (€) for computed tomography *v* observation in hospital (€)

	Computed tomography	Observation in hospital	P value
Mean cost during acute stage and complications (1st and 3rd quartile)	461 (354-490)	677 (543-688)	<0.001
Mean cost during follow-up	257	237	
Total	718	914	<0.001

Gierjersta JL, et al: BMJ 2006; 465 and 469

Infants - recommendations

- **High Risk: CT scan**
  Skull fracture, seizure, bulging fontanel, LOC > 1 min, decrecased mental status, focal neurologic deficit
- **Intermediate Risk: CT scan**
  LOC < 1 min, nonacute skull fx, vomiting, caretaker concern, High energy mechanism, large scalp hematoma, unwitnessed injury
- **Low Risk: Observe and Discharge**
  Low energy mechanism, (fall < 3 ft), asymptomatic, Over 2 hours from injury, older age (> 12 mo)

Schutzman SA, et al: Pediatrics (2001) 107: 983-993

Post-concussive Syndrome

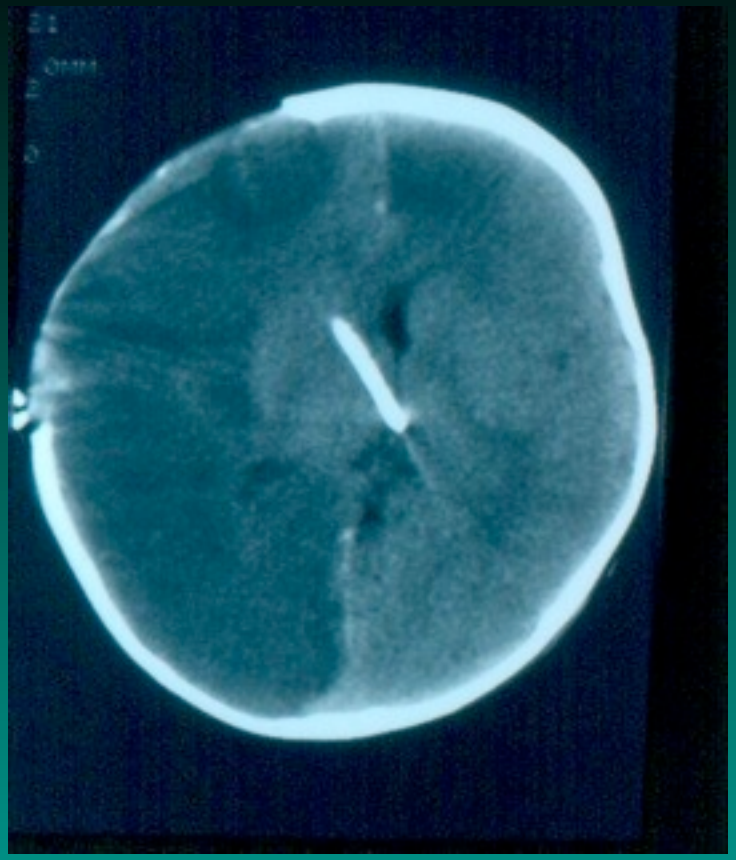
- **Persistent headaches**
- **Dizziness / lightheadedness**
- **Difficulty with concentration**
- **Irritability, stress intolerance**
- **Often in intelligent patients**
- **Normal neurologic exam**

Cerebral Contusion

Seizures

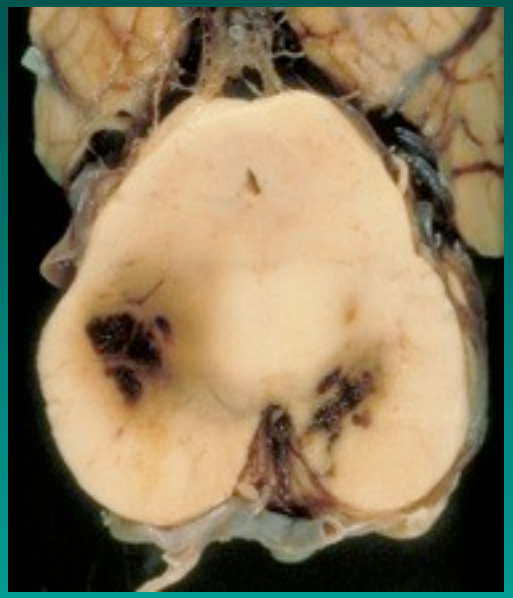
- Increase CBF and ICP
- Higher incidence with GCS
- ~20% if cerebral contusion
- Immediate seizures not recurrent
- ? Prophylactic anticonvulsant use
- Treat for 2-4 weeks??

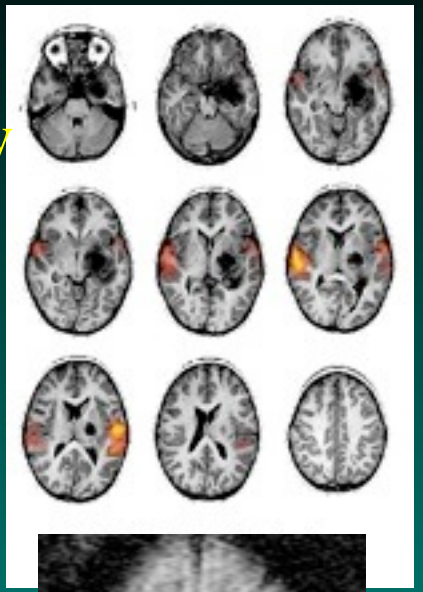
Diffuse Axonal Injury

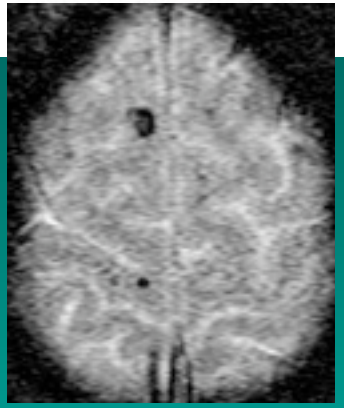


Diffuse Axonal Injury

Some evidence that axons are not initially disrupted only swollen







Diffuse Axonal Injury

- **Diffuse cerebral swelling in 2-5 X more common in children than in adults, possibly due to ischemia**
  - Zwienenburg Muizelaar *J Neurotrauma* 16(10):937-43
- **In severe head injury,** autoregulation is intact 59% of the time, and dysfunctional 41%
  - Muizelaar, *et al J Neurosurg* 71:72-76
- **If autoregulation is intact, ICP varies inversely with MAP, directly if autoregulation is not intact**
  - Bouma *et al J Neurosurg* 77:15-19

Pediatric Head Injury:

Part II - Current management

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Hyperventilation

- Immediate ↓ in CSF pH
- 1 torr PCO_2 ↓ CBF by ~ 3%
- May try mild hypervent. in kids
- Prophylactic use ineffective
- Recent data do not support use
- Appropriate in severe cases of impending herniation

Head Position

- **Great controversy!**
- **Modest ICP improvement**
- **Improves jugular return**
- **30 - 45 degrees optimal**
- **Avoid during hypotension**
- **? A-line tranducer position**

Osmotic Agents

- **Immediate ↓ in blood viscosity**
- **Improves blood flow**
- **1-3 ml/Kg 3% NaCl**
- **0.25 - 2 gm/kg dose mannitol**
- **Hypertonic saline effective**
- **Primary effect by dehydration**
- **BBB must be intact**
- **Monitor serum osmolality (~ 300)**

Hypothermia

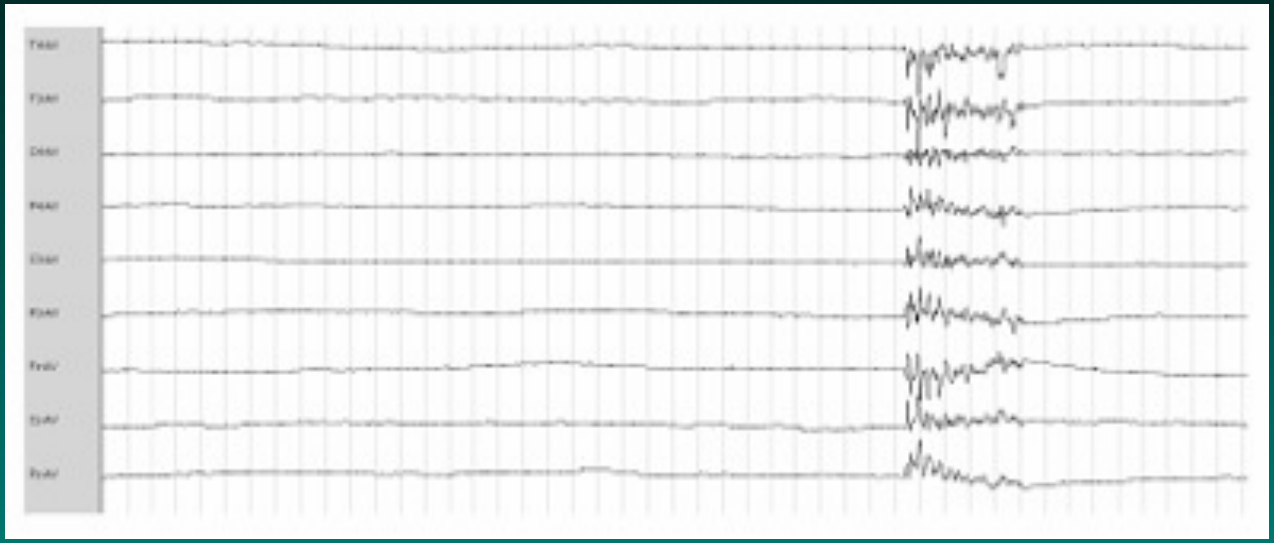
- Initially suggested by Phelps in 1897
- Mild hypothermia to 32 - 34^0
- 5 - 10% $CMRO_2$ change per ^0C
- Hyperthermia injures BBB
- 2 randomized trials in adults
- No consistent data in children

Hypothermia

- **Reduces cerebral metabolism (7% / °C heat)**
- **Currently under trial for refractory ICP control**
- **Moderate cooling 32-34 degrees can decrease the severity of increased ICP, but not the average ICP in head injured children without coagulopathy**
- **There was no difference in outcome**
  - Biswas *et al Crit Care Med* 2002 30(12):2742-51
- **CoolKids trial underway**
- **? Inc. mortality w/ rapid rewarming**

  (Hutchinson, et al, NEJM 2008)

Barbiturate Coma



Cardiovascular depressant (watch your BP!)
Lowers cerebral metabolic rate and ?vasoconstricts
Burst surpression goal on EEG

Barbiturates

- No controlled trials in children
- Decrease $CMRO_2$
- ↓ CNS lactate & glutamate
- EEG burst suppression or levels
- ? ↑ Survival, but poor outcome
- Arterial hypotension common
- Recent success in small series

Barbiturates

- **Suppress brain metabolism, up to 50%**
  - Piatt, Schiff Neurosurgery 1984 15:427-44
- **Alters cerebral vascular tone**
- **Associated reduction of coupled CBF, reduces cerebral blood volume and therefore ICP**
  - **Bolus iv delivery 10mg/kg, over 30 min**
  - **Then 5mg/kg/hr for 3 hours**
  - **Hourly delivery 1-5mg/kg**
  - **Usually dosed to burst suppression on EEG**
  - **May also dose by levels, but not recommended**
    - Kassell et al Neurosurgery 1980 7:598-603

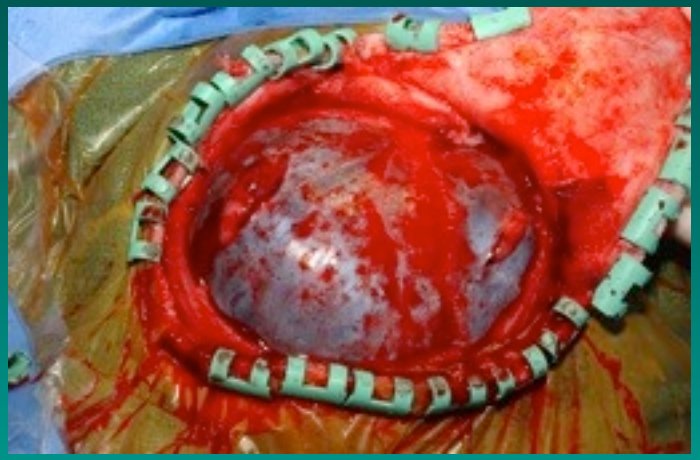
Barbiturate Coma

- **Prophylactic use is unsupported**
- **May develop decreased jugular venous saturation of <45%, associated with poor outcome**
  - Cruz *J Neurosurg* 1996 85:758-61
- **Myocardial suppression and hypotension requiring inotropic infusion**
  - Adelson *et al Pediatr Crit Care Med* 2003 4(3):S49-52
- **Role in refractory ICP elevation unclear**
  - Pittman *et al Pediatr Clin N Am* 1980 27:715-727

Decompressive Craniectomy

- **Initially described by Cushing -1905**
- **Some studies suggested ↑ edema**
- **Increased use recently (selective)**
- **Better outcomes in young patients**
- **Second tier therapy with barb. coma**

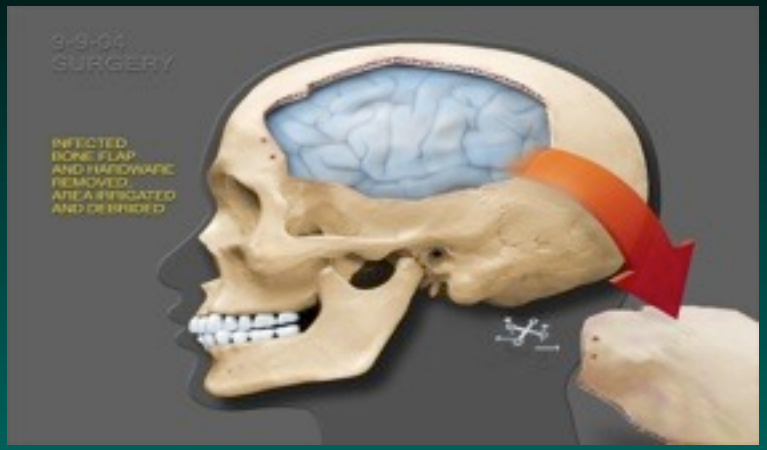
Decompressive Craniectomy



Some recent studies: improved functional outcomes, less mortality

(JNS Jaganathan 2007; Cochrane Database, 2006)

Decompressive Craniectomy



- **Bifrontal craniectomy was effective in resolving refractory intracranial hypertension in 44% of patient**
- **(Polin *et al Neurosurgery* 1997 41(1):84-94)**
- **Pilot study showed efficacy in all 6 patients with refractory elevated ICP**
  - **(Ruf *et al Crit Care* 2003 7(6):R133-8)**
- **Craniectomy, primary or delayed showed positive influence on outcome and survival on pediatric subpopulation (16)**
  - **(Messing-Junger *et al Zentralbl Neurochir* 2003 64:171-7)**

Decompressive Craniectomy

- **COMPLICATIONS ---**

- **Brain shift form overdrainage**
- **Bone flap storage in children is challenging**
  - Frozen flap
  - Subcutaneous space is small
  - Demineralization?
- **Bone resorption in children could be as high as 50% (Grant, Ellenbogen, *et al* JNS:Spine 2004)**

Lumbar Drainage

- **Controversial technique to treat refractory high ICP when ventriculostomy and medical management is ineffective**
  - Levy *et al J Neurosurg* 1995 83(3):453-60
  - Munch *et al Crit Care Med* 2001 29(5)976-81
- **Can lead to tonsillar herniation**
  - 2 patients, Munch *et al Crit Care Med* 2001 29(5)976-81
  - Baldwin, Rekate *Pediatr Neurosurg* 1991-2 17(3): 115-20

Controversies in Management

- **Steroids**
- **Hemodilution**
- **Hypoglycemia**
- **Prophylactic anticonvulsants**
- **Controlled arterial hypertension**
- **Liquid ventilation / ECMO**

Cell Damage

Voltage-dependent calcium channels
glutamate release
metabotropic
PLC
IP_3 + DAG
endonucleases
calcium-activated kinases (PKC)
Glutamate
NMDA
$[Ca^{2+}]_i$
calpains
cell damage
xanthine oxidase
$[Na^+]_i$
cell swelling
phospholipases
free radicals
Glutamate leakage
AMPA/ kainate
depolarization reversal
arachidonic acid
ONOO⁻
NO synthase
$NO^{\bullet} + {}^{\bullet}O_2^-$
Ca^{2+}_i
$Na^+ - Ca^{2+}$ exchanger
$3Na^+_o$
cell boundary

Prevention

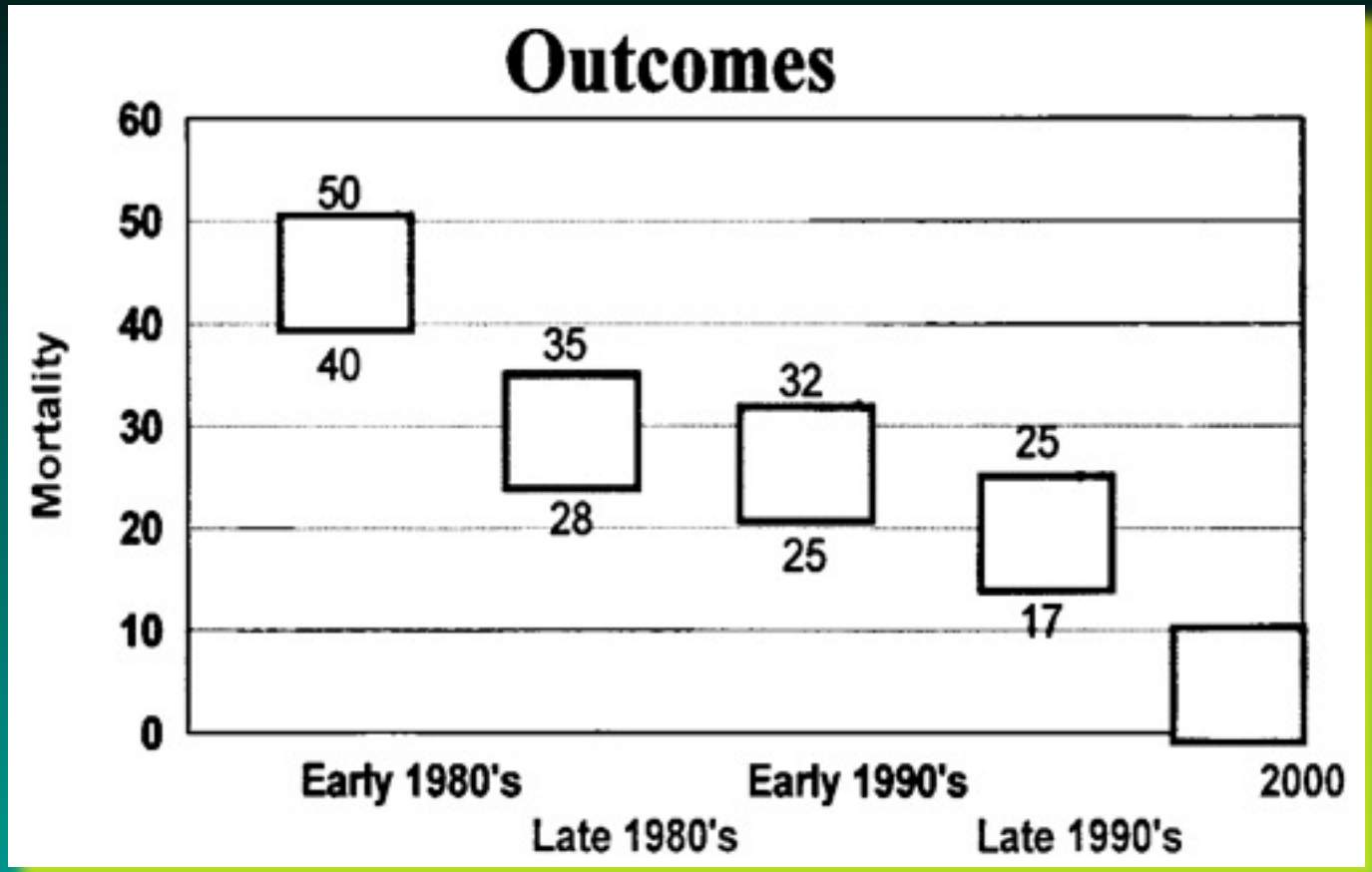
- **Almost always forgotten!!!**
- **Simple common sense**
- **Use available resources**
- **Child seat enforcement**
- **Occupant Protection Program**
- **ThinkFirst program**
- **Safe Kids programs**

Outcomes

- **Good = 75%**
- **Moderate = 10%**
- **Severe = 5-10%**
- **Death = 1-5%**

- **Where do we send our HI patients?**
- **Be an eternal, pragmatic optimist!**

Mortality Rates



Discussion

- **Marked increase in diagnosis**
- **Some improvement in outcome**
- **Better understanding of pathophysiology and brain injury**
- **Future looks somewhat better**
- **Cautious optimism appropriate**

Deterioration

"…patients at greatest risk for inadequate diagnosis and treatment [are] those who are predicted to be at relatively low risk of dying…"

Klauber MR, Marshall LF, Luerssen TG, et al.: Determinants of head injury mortality: Importance of the low risk patient. Neurosurgery 24:31-36, 1989

Discussion

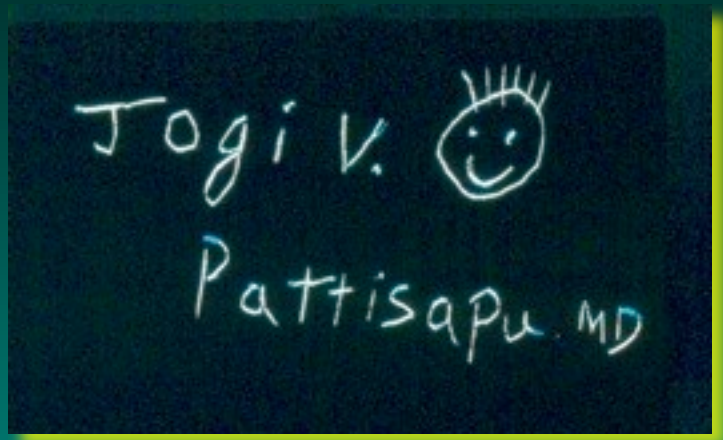
Incidents that lead to injuries may not be intentional - BUT, they are <u>PREVENTABLE</u>

Conclusion

Conclusion

Optimal care of the child with traumatic brain injury requires timely intervention by a highly specialized group of dedicated individuals.

Thank You!



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