Neuroprotektivní péče na pediatrické JIP

Fremuth Jiří
DK LF a FN Plzeň

10 Leading Causes of Death by Age Group, United States – 2018

Rank	<1	1-4	5-9	10-14	15-24	25-34	35-44	45-54	55-64	65+	Total
1	Congenital Anomalies 4,473	Unintentional Injury 1,226	Unintentional Injury 734	Unintentional Injury 692	Unintentional Injury 12,044	Unintentional Injury 24,614	Unintentional Injury 22,667	Malignant Neoplasms 37,301	Malignant Neoplasms 113,947	Heart Disease 526,509	Heart Disease 655,381
2	Short Gestation 3,679	Congenital Anomalies 384	Malignant Neoplasms 393	Suicide 596	Suicide 6,211	Suicide 8,020	Malignant Neoplasms 10,640	Heart Disease 32,220	Heart Disease 81,042	Malignant Neoplasms 431,102	Malignant Neoplasms 599,274
3	Maternal Pregnancy Comp. 1,358	Homicide 353	Congenital Anomalies 201	Malignant Neoplasms 450	Homicide 4,607	Homicide 5,234	Heart Disease 10,532	Unintentional Injury 23,056	Unintentional Injury 23,693	Chronic Low. Respiratory Disease 135,560	Unintentional Injury 167,127
4	SIDS 1,334	Malignant Neoplasms 326	Homicide 121	Congenital Anomalies 172	Malignant Neoplasms 1,371	Malignant Neoplasms 3,684	Suicide 7,521	Suicide 8,345	Chronic Low. Respiratory Disease 18,804	Cerebro-vascular 127,244	Chronic Low. Respiratory Disease 159,486
5	Unintentional Injury 1,168	Influenza & Pneumonia 122	Influenza & Pneumonia 71	Homicide 168	Heart Disease 905	Heart Disease 3,561	Homicide 3,304	Liver Disease 8,157	Diabetes Mellitus 14,941	Alzheimer's Disease 120,658	Cerebro-vascular 147,810
6	Placenta Cord. Membranes 724	Heart Disease 115	Chronic Low. Respiratory Disease 68	Heart Disease 101	Congenital Anomalies 354	Liver Disease 1,008	Liver Disease 3,108	Diabetes Mellitus 6,414	Liver Disease 13,945	Diabetes Mellitus 60,182	Alzheimer's Disease 122,019
7	Bacterial Sepsis 579	Perinatal Period 62	Heart Disease 68	Chronic Low Respiratory Disease 64	Diabetes Mellitus 246	Diabetes Mellitus 837	Diabetes Mellitus 2,282	Cerebro-vascular 5,128	Cerebro-vascular 12,789	Unintentional Injury 57,213	Diabetes Mellitus 84,946
8	Circulatory System Disease 428	Septicemia 54	Cerebro-vascular 34	Cerebro-vascular 54	Influenza & Pneumonia 200	Cerebro-vascular 567	Cerebro-vascular 1,704	Chronic Low. Respiratory Disease 3,807	Suicide 8,540	Influenza & Pneumonia 48,888	Influenza & Pneumonia 59,120
9	Respiratory Distress 390	Chronic Low. Respiratory Disease 50	Septicemia 34	Influenza & Pneumonia 51	Chronic Low. Respiratory Disease 165	HIV 482	Influenza & Pneumonia 956	Septicemia 2,380	Septicemia 5,956	Nephritis 42,232	Nephritis 51,386
10	Neonatal Hemorrhage 375	Cerebro-vascular 43	Benign Neoplasms 19	Benign Neoplasms 30	Complicated Pregnancy 151	Influenza & Pneumonia 457	Septicemia 829	Influenza & Pneumonia 2,339	Influenza & Pneumonia 5,858	Parkinson's Disease 32,988	Suicide 48,344

Data Source: National Vital Statistics System, National Center for Health Statistics, CDC.
Produced by: National Center for Injury Prevention and Control, CDC using WISQARS™.

Centers for Disease Control and Prevention
National Center for Injury Prevention and Control

Guidelines for the Management of Pediatric Severe Traumatic Brain Injury, Third Edition: Update of the Brain Trauma Foundation Guidelines

Pediatric Critical Care Medicine: March 2019 - Volume 20 - Issue 3S - p S1-S82

Guidelines for the Management of Pediatric Severe Traumatic Brain Injury, Third Edition: Update of the Brain Trauma Foundation Guidelines, Executive Summary

Pediatr Crit Care Med. 2019 Mar;20(3):280-289.

- Levels of Recommendations
  - Class I – Therapy "must be done"
  - Class II – Therapy "should be considered"
  - Class III – Therapy "may be considered"

Management of Pediatric Severe Traumatic Brain Injury: 2019 Consensus and Guidelines-Based Algorithm for First and Second Tier Therapies

Pediatr Crit Care Med. 2019 Mar;20(3):269-279.

TBI u dětí

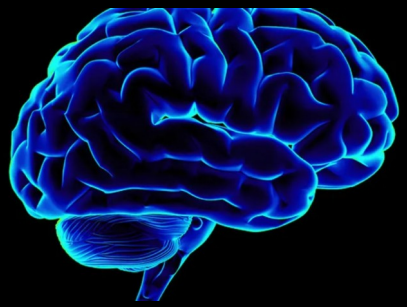
- 35 000 dětí v USA utrpí těžké TBI (GCS ≤ 8b)
- Mortalita na těžké TBI je 20%
- 75% dětí s polytraumatem má současně TBI
- 80% úmrtí u polytraumat je v důsledku TBI
- Cca 50% pacientů po 6M od úrazu má špatný neurologický outcome

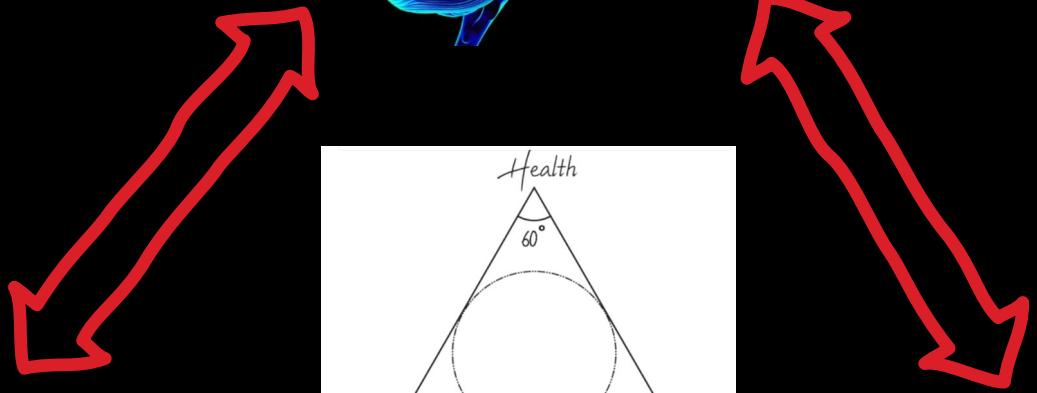
TBI patofyziologie

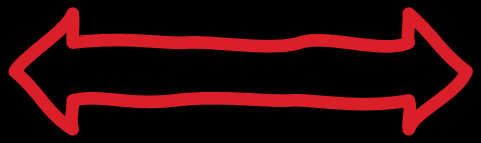
- Primární poranění
- Sekundární poranění
  - Hypoxie, hypotenze - hypoperfuze, hypoglykemie, hypertermie, křeče
  - Edém vzniká do 24-72 hodin od primárního poranění

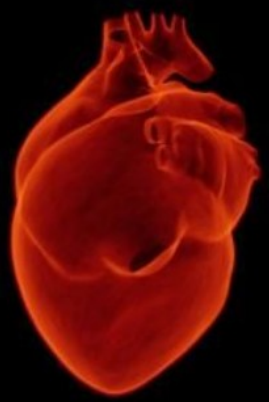
The happiness triangle

The 60 degree rule of sustainable happiness model









Specifika u dětí – anatomie

- Hlava
  - Velká relativně k tělu, kraniotrauma časté při malém insultu (kojenci, batolata)
  - Širší subarachnoideální prostor + otevřené sutury – pojme větší množství krve (delší kompenzace do rozvoje nitrolební hypertenze)
  - Malé (existující) riziko SCIWORA (spinal cord injury without plain radiographic and CT abnormality) – MRI, klinika
  - Při popálenině větší plocha vzhledem k tělu
- Hrudník
  - Elastický, vysoká compliance – fraktura žeber vzácně, často kontuze plic ev. PNO

Specifika u dětí – fyziologie

- Vitální hodnoty se mění s věkem
  - Pokles TF, DF, zvýšení TK
- Metabolismus
  - Vyšší energetický obrat ~ spotřeba kyslíku ~ vyšší riziko hypoxie (nutnost oxygenace)
  - Větší tělesný povrch, riziko hypotermie, rozvoj acidózy
- Oběh
  - Vyšší CI a vyšší SVRI – dítě je nastaveno metabolicky a oběhově „výše“, má menší prostor pro zvýšení fyziologických funkcí (CI, TF, SV, SVR).
  - SVRI a zdravé srdce dokáže kompenzovat krevní ztrátu – hypotenze při ztrátě 30-45% intravaskulárního volumu (dekompenzovaný šok)

Fyziologické hodnoty vitálních funkcí

Table 1 – Normal values for age: respiratory rate.

Respiratory rate for age	1 month	1 year	2 year	5 year	10 year
Upper limit of normal range	60	50	40	30	25
Lower limit of normal range	25	20	18	17	14

Table 2 – Normal values for age: heart rate.

Heart rate for age	1 month	1 year	2 year	5 year	10 year
Upper limit of normal range	180	170	160	140	120
Lower limit of normal range	110	100	90	70	60

Table 3 – Normal values for age: systolic and mean arterial blood pressure (MAP). Fifth (p5) and fiftieth (p50) percentile for age.

Blood pressure for age	1 month	1 year	5 year	10 year
p50 for systolic BP	75	95	100	110
p5 for systolic BP	50	70	75	80
p50 for MAP	55	70	75	75
p5 for MAP	40	50	55	55

pro věk 1-10 let

STK (p5) = 70 mmHg + 2x věk (roky)

MAP (p5) = 40 mmHg + 1,5x věk (roky)

STK (p50) = 90 mmHg + 2x věk (roky)

MAP (p50) = 55 mmHg + 1,5x věk (roky)

Initial trauma management in children with severe multiple trauma

Assessment	Management
0 up to 5 minutes	
Mobilize trauma resources	***Immobilize cervical spine***
	Assess vital signs
Airway – Identify:	
Obstruction	***Open airway; suction secretions***
	Administer 100% O_2
Midface fracture/difficult airway **or** Direct airway injury	Surgical airway
Breathing – Identify:	
Tension pneumothorax	Needle decompression; place chest tube
Massive hemothorax	Place chest tube or pigtail catheter
Open pneumothorax	Apply 3-sided occlusive dressing
Flail chest	Perform bag-valve-mask ventilation
Impaired oxygenation/ventilation	Rapid sequence endotracheal intubation
Circulation – Identify:	
Absent circulation	Cardiac compressions, thoracotomy **if** witnessed arrest
External hemorrhage	Control external hemorrhage
Signs of shock	***Secure IV access; obtain laboratory studies***
	Fluid resuscitation*
Cardiac tamponade	Pericardiocentesis followed by thoracotomy
Pelvic fracture	Wrap or bind pelvis

Initial trauma management in children with severe multiple trauma

Assessment	Management
Disability – Identify:	
Level of consciousness (GCS)	Endotracheal intubation for rapidly declining GCS, GCS ≤8 or herniation¶
Pupillary response	Elevate head of bed to 30° if no signs of shock
Signs of spinal cord injury	
Signs of impending herniation	Moderate hyperventilation (pCO_2 30 to 35)
	Neurosurgical consultation
	Administer osmotic agents if normotensive
Exposure – Identify:	
Hypothermia	***Remove clothing***
	Initiate rewarming

ABCDE Airways- dýchací cesty

Imobilizace krční páteře

1-2% dětí s tupým traumatem lbi mají poranění krční páteře

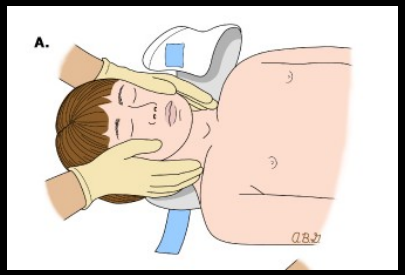
- Indikace
  - Vysoce rizikový mechanismus
    - Autohenoda (úmrtí spolujezdce, částečná nebo úplná katapultace z vozu)
    - Skoky do vody, axiální mechanismus poranění páteře
    - Pád z výšky (cca 3x výška pacienta)
    - Akceleračně/decelerační mechanismus
    - Škrtící poranění (kabel, lano, jiné trakce)
    - Polytrauma (75% dětí má současně kraniotrauma)
  - Nálezy při fyzikálním vyšetření
    - Porucha vědomí (intoxikace,…)
    - Citlivost na pohmat, bolesti krku
    - Neurologický topický nález s patologií
  - Predispoziční faktory
    - Down syndrom, Klippel-Feil syndrom, Ehlers Danlos syndrom

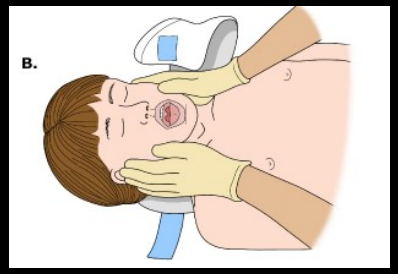
Imobilizace krční páteře II

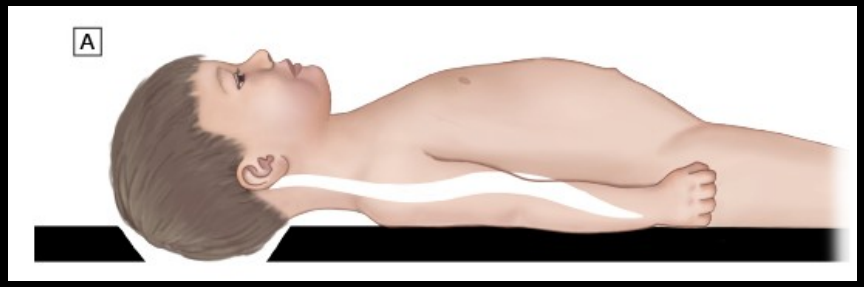
- Kontraindikace rigidního límce
  - Přítomnost fixované krční deformity
  - Masivní otok krku (zhoršení průchodností DC)
  - Potřeba provedení subglotického přístupu do DC
  - Pokus o naložení límce zhorší bolest a neurologický nález

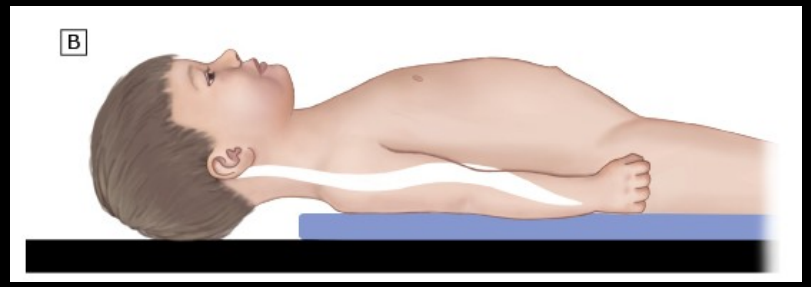
Imobilizace krční páteře III

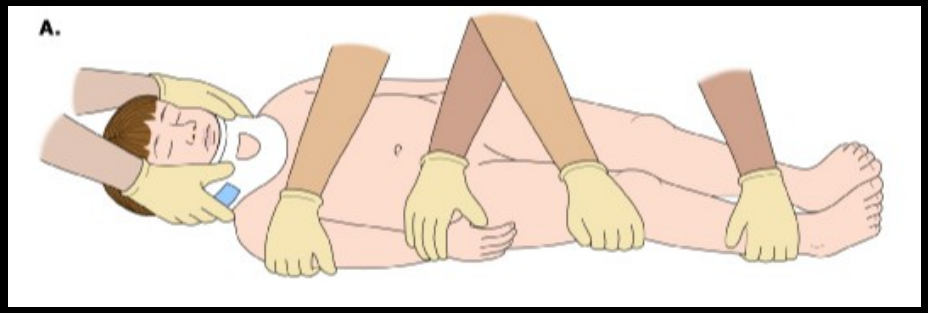
MILS

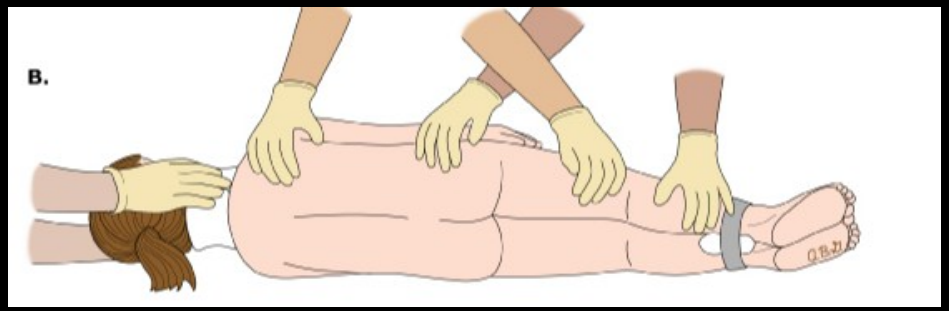


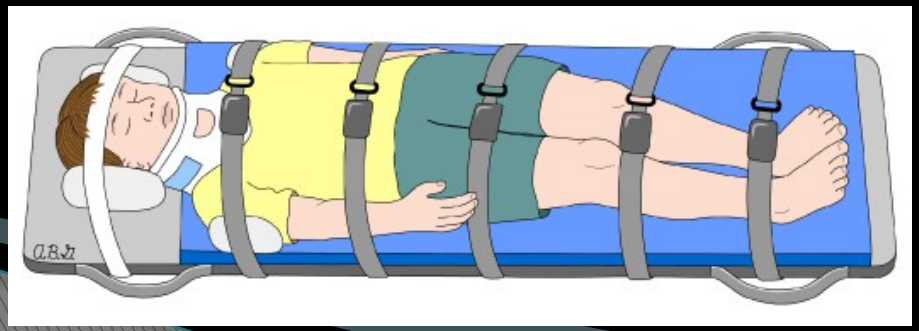






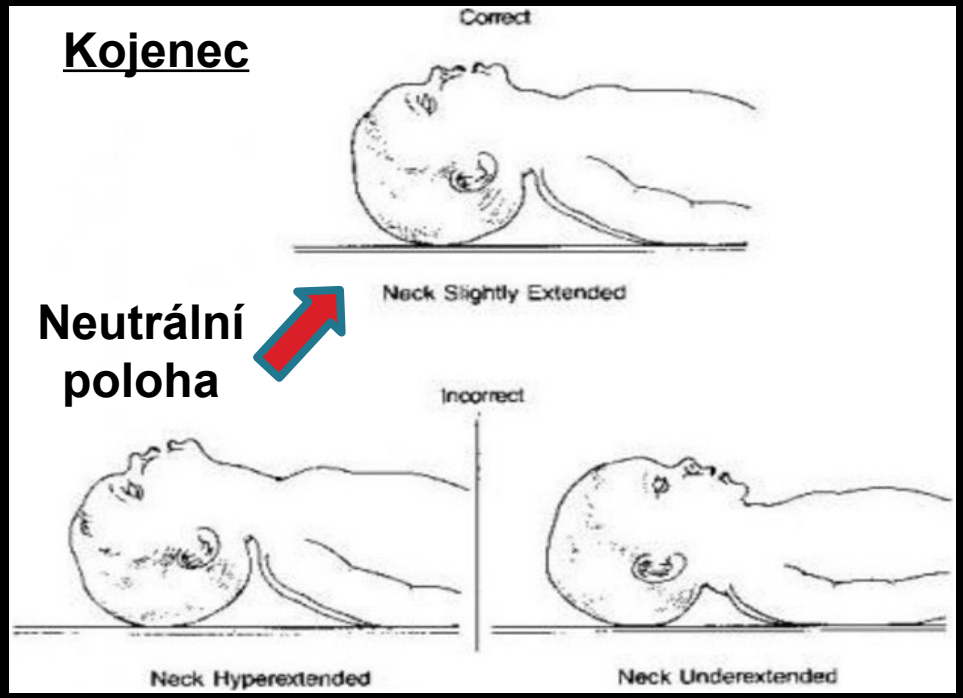




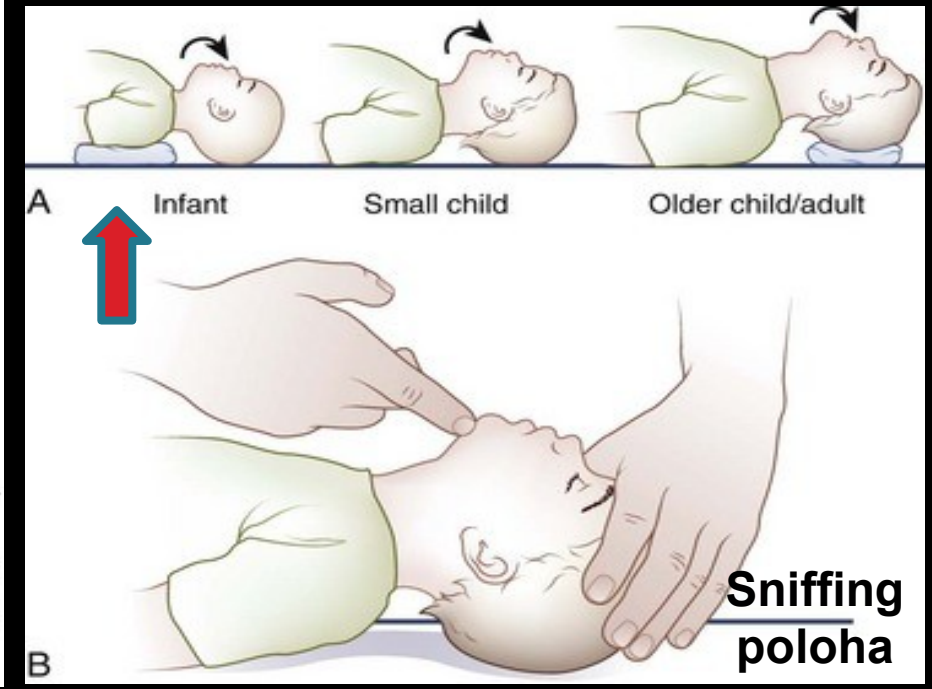


ABCDE Airways- zprůchodnění DC

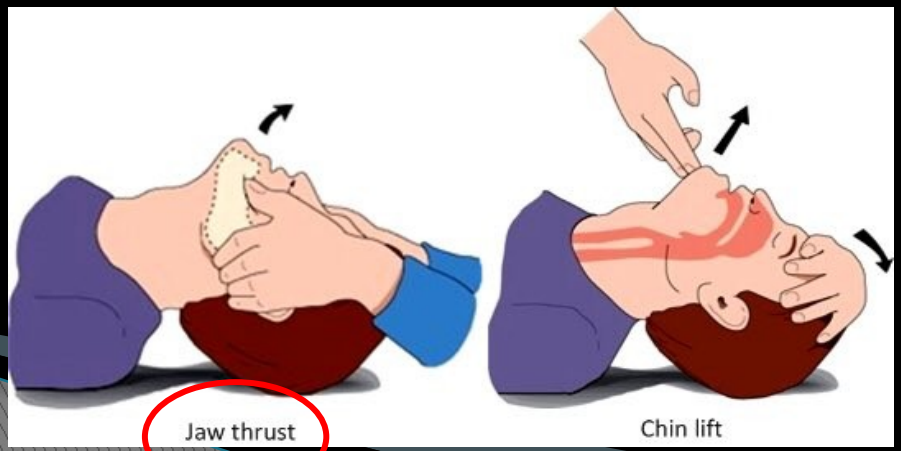
Kojenec



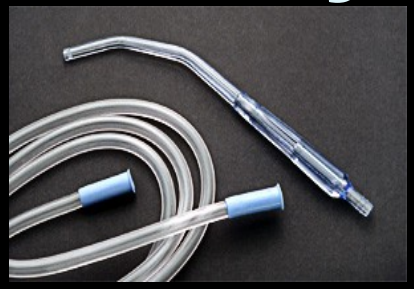
Neutrální poloha

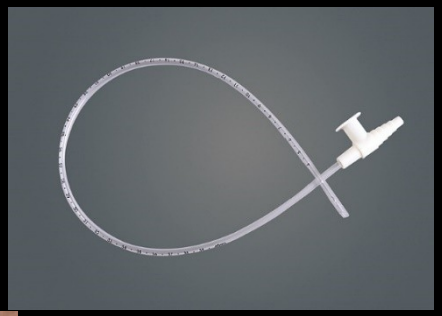


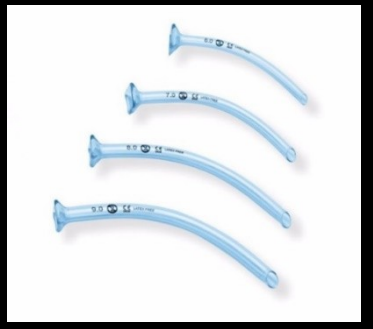
Sniffing poloha

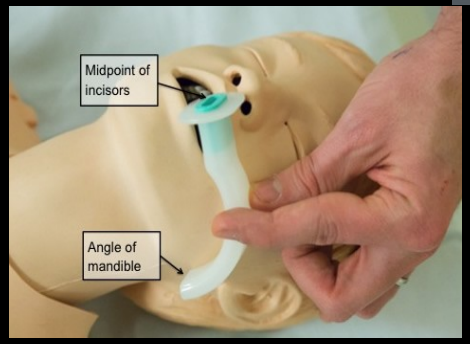


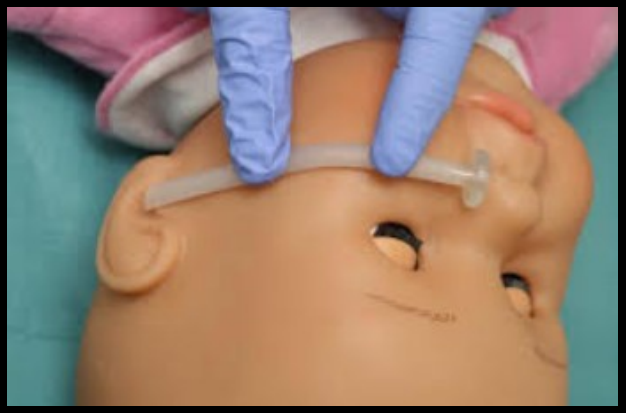
Airways

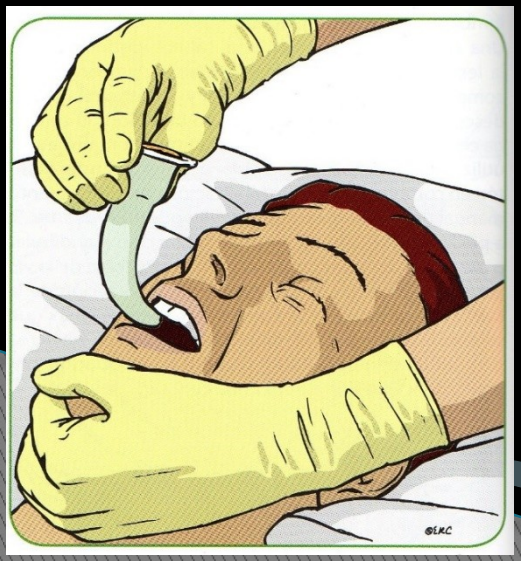


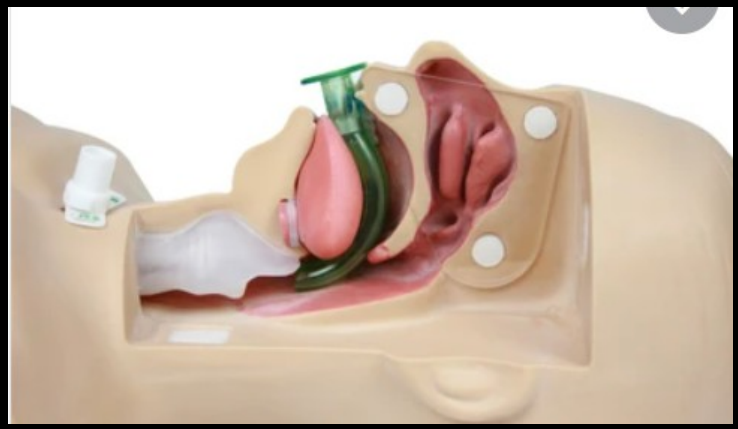












ABCDE Ci

Circulation – Identify:	
Absent circulation	Cardiac compressions, thoracotomy **if** witnessed arrest
External hemorrhage	Control external hemorrhage
Signs of shock	***Secure IV access; obtain laboratory studies***
	Fluid resuscitation*
Cardiac tamponade	Pericardiocentesis followed by thoracotomy
Pelvic fracture	Wrap or bind pelvis

- Klinické příznaky hypovolémie, hemorhagického šoku
  - Tachykarie
  - Změna vědomí (neklid, útlum, koma)
    - Zhoršená/zpomalená odpověď na bolest
  - Prodloužený kapilární návrat (rozdíl periferní, centrální)
  - Bledá barva kůže, mottling kůže, studená periferie
  - Zúžení pulzního tlaku (rozdíl STK a DTK) < 20 mmHg
  - Hypotenze – pozdní známka

- **Terapie hemorhagického šoku/ŽOKu**
  - Identifikace zdroje/ošetření zdroje krvácení
  - Náhrada objemu
  - Podpora koagulace, cílená terapie průvodní poruchy či vyvolávající příčiny
  - Podpora /náhrada orgánových funkcí

Hemorhagický šok u dětí

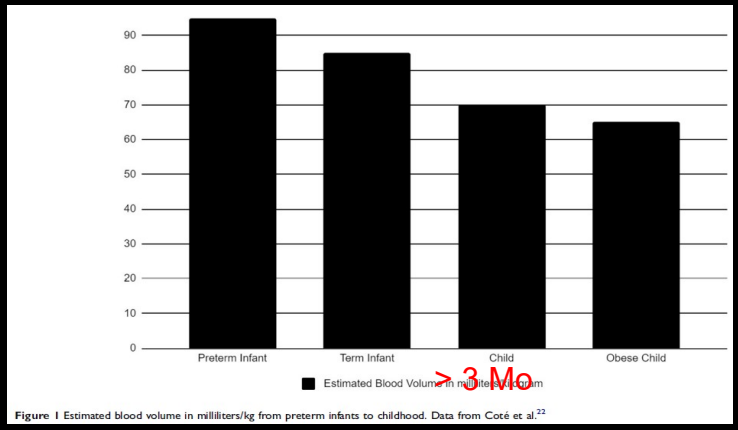


Figure 1 Estimated blood volume in milliliters/kg from preterm infants to childhood. Data from Coté et al.[22]

Classification of hemorrhagic shock in children[1]

	Class I	Class II	Class III	Class IV
Blood volume loss*	Up to 15%	15 to 30%	30 to 40%	≥40%
Pulse rate	Normal	Mild tachycardia	Moderate tachycardia	Severe tachycardia
Blood pressure	Normal/increased	Normal/decreased	Decreased	Decreased
Capillary blanch test	Normal	Positive	Positive	Positive
Respiratory rate	Normal	Mild tachypnea	Moderate tachypnea	Severe tachypnea
Urine output	1 to 2 mL/kg/hour	0.5 to 1.0 mL/kg/hour	0.25 to 0.5 mL/kg/hour	Neglibible
Mental status	Slightly anxious	Mildly anxious	Anxious/confused	Confused/lethargic
Fluid replacement (3:1 rule)	Crystalloid	Crystalloid	Crystalloid% blood	Crystalloid% blood

* Assume blood volume to be 8 to 9% of body weight (80 to 90 mL/kg).

Shock Index Pediatric-Adjusted (SIPA) — Shock index (heart rate/systolic blood pressure) has been adapted to the pediatric population [51]. For children, the cutoffs associated with higher morbidity or mortality by age are [52,53]:

- 1 to 3 years – >1.2
- 4 to 6 years – >1.2
- 7 to 12 years – >1
- Older than 12 years – >0.9 (adult cutoff)

Shock index = TEPOVÁ FREKVENCE / STK

It is superior to age-adjusted hypotension in identifying children that require emergency operation, endotracheal intubation, or early blood tran[illegible] SIPA has a high sensitivity but low specificity for predicting the need for blood transfusion, operation and mortality [55].

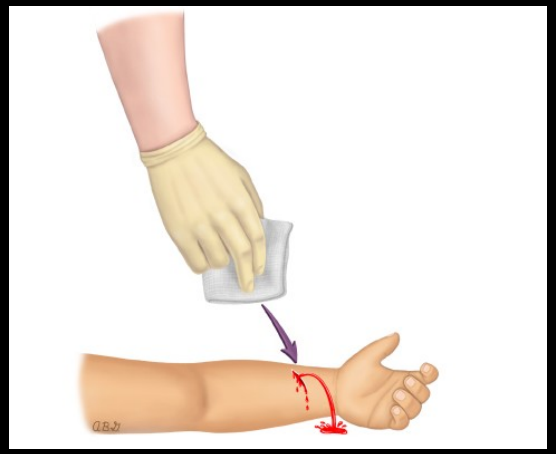
J Surgery. 2017 Mar;161(3):803-807. doi: 10.1016/j.surg.2016.08.050. Epub 2016 Nov 1.

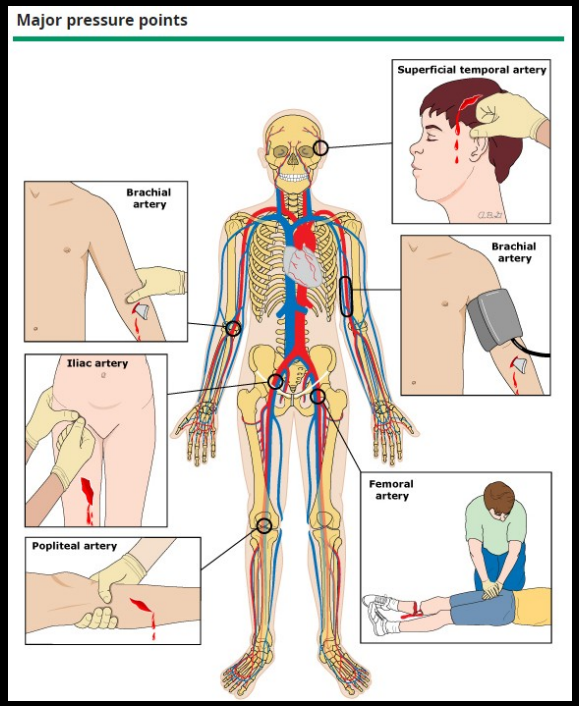
Shock index, pediatric age-adjusted (SIPA) is more accurate than age-adjusted hypotension for trauma team activation

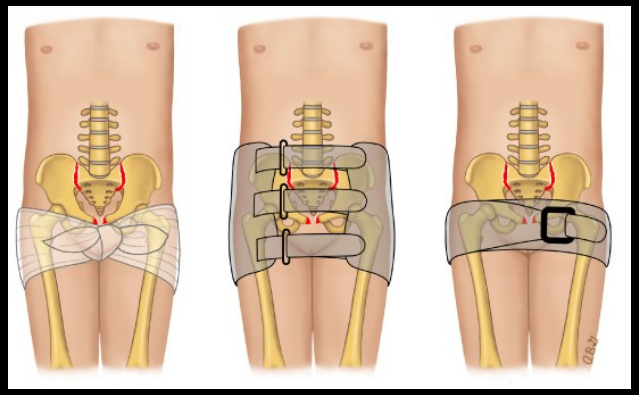
Shannon N Acker [1], Brooke Bredbeck [2], David A Partrick [3], Ann M Kulungowski [3], Carlton C Barnett [4], Denis D Bensard [4]

Hemorhagický šok II - management

- Zástava krvácení
  - Komprese do rány
    - Ev. Zaklampování tepny – pozor na poranění nervu s průběhem podél tepny
  - Kompresní body – šnížení přívodu arteriální krve do oblasti
  - Naložení turniketu
  - Imobilizace končetiny - fraktura (dlaha)







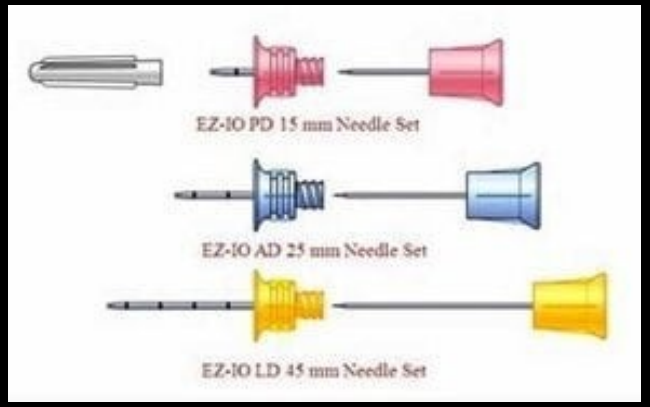
Circulation – žilní vstup

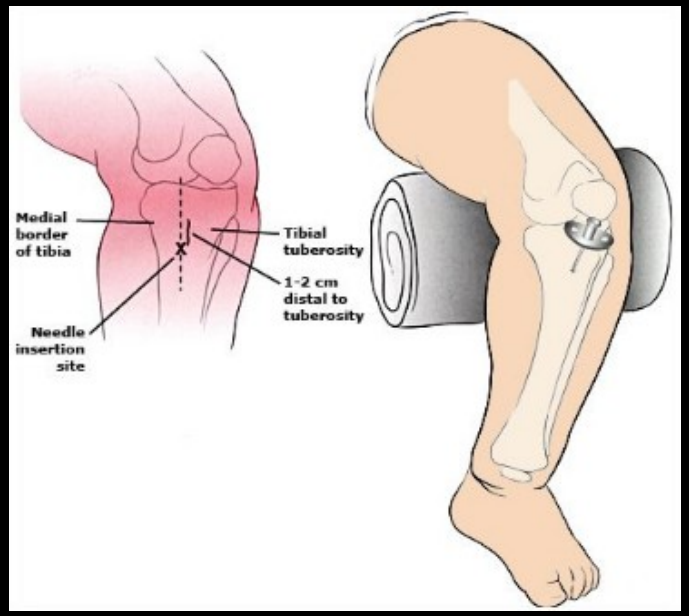
- Žilní vstup - trauma, ŽOK - **2x PŽK**
  - **22 - 24 Ga – novorozenci, kojenci**
  - **18 - 20 Ga – větší dítě**
- IO vstup – manuální x poloautomatická

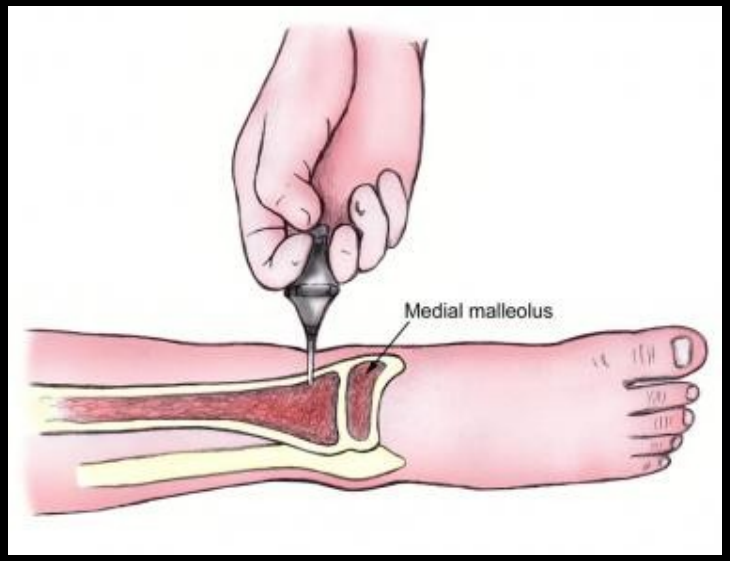
- Růžová (15mm) = kojenci
- Modrá (25mm) = do 40 kg
- Žlutá (45mm)

Table 1 Flow rates of i.v., intraosseous cannulas[6]

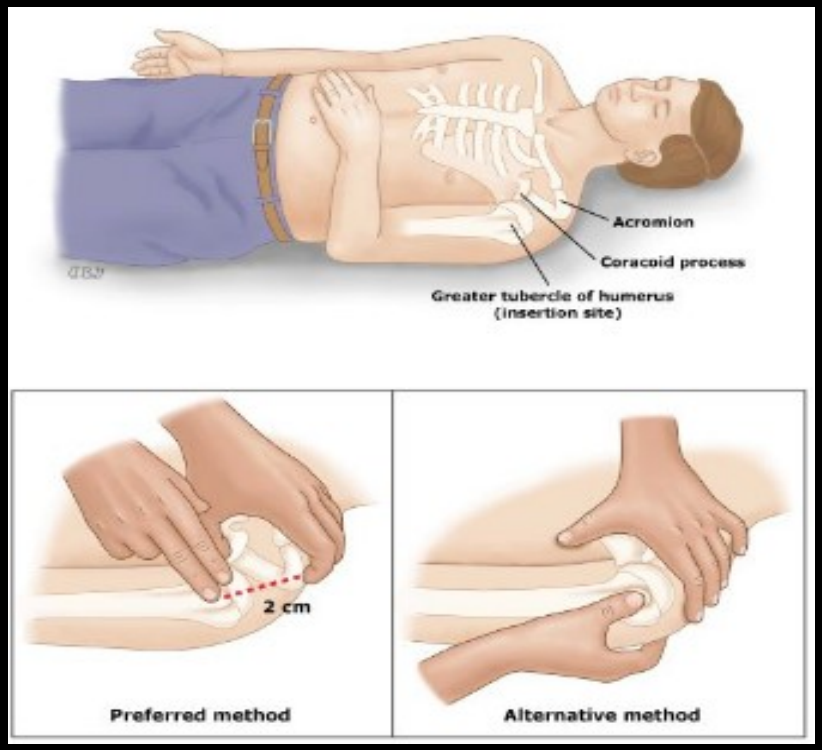
I.V. catheter	Maximum rate of flow with gravity (ml min^{-1})	Maximum rate of flow with pressure (ml min^{-1})
14 G 50 mm cannula	236.1	384.2
16 G 50 mm cannula	154.7	334.4
18 G 45 mm cannula	98.1	153.1
20 G 33 mm cannula	64.4	105.1
22 G 25 mm cannula	35.7	71.4
15 G 25 mm intraosseous needle (tibial)	68.2	204.6




Medial border of tibia
Tibial tuberosity
1-2 cm distal to tuberosity
Needle insertion site


Medial malleolus

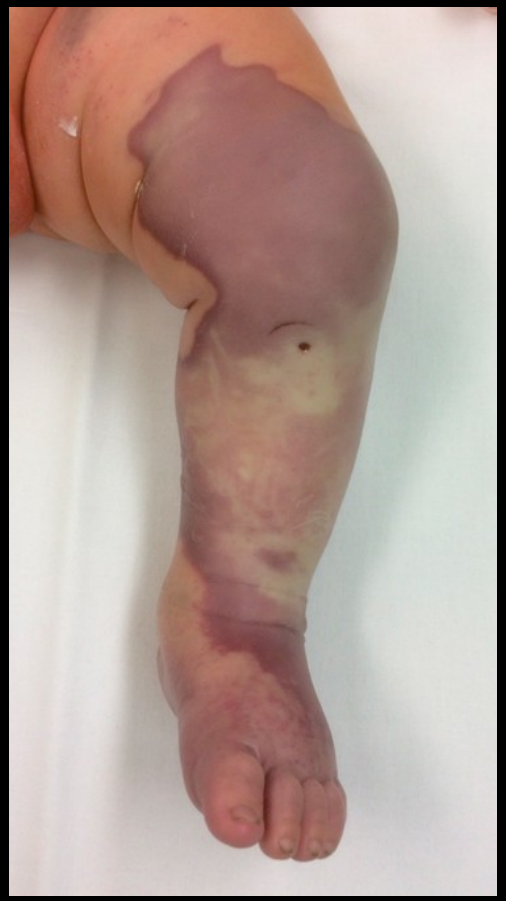

2-3 cm
External femoral condyle

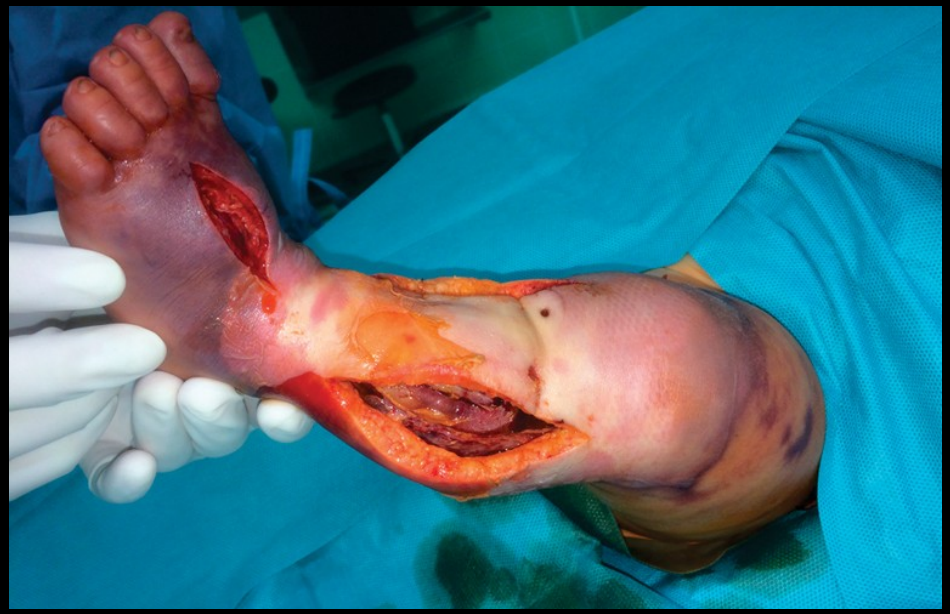

Acromion
Coracoid process
Greater tubercle of humerus (insertion site)
2 cm
Preferred method
Alternative method

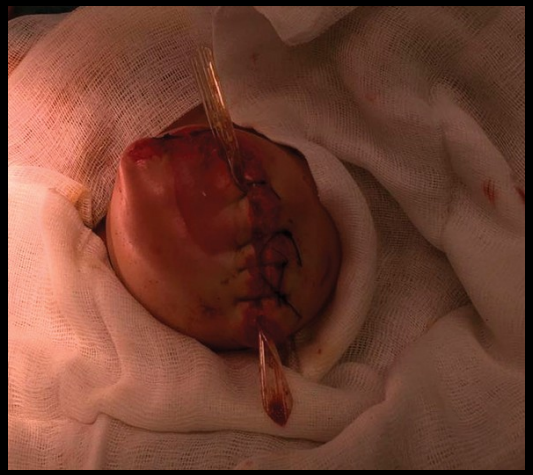
European J Pediatr Surg Rep. 2018 Jan;6(1):e59-e62. doi: 10.1055/s-0038-1661407. Epub 2018 Jul 19.

Serious Complications of Intraosseous Access during Infant Resuscitation.

Molacek J[1], Houdek K[1], Opatrný V[1], Fremuth J[2], Sasek L[2], Treskova I[3], Treska V[1].







Hemorhagický šok - koagulopatie

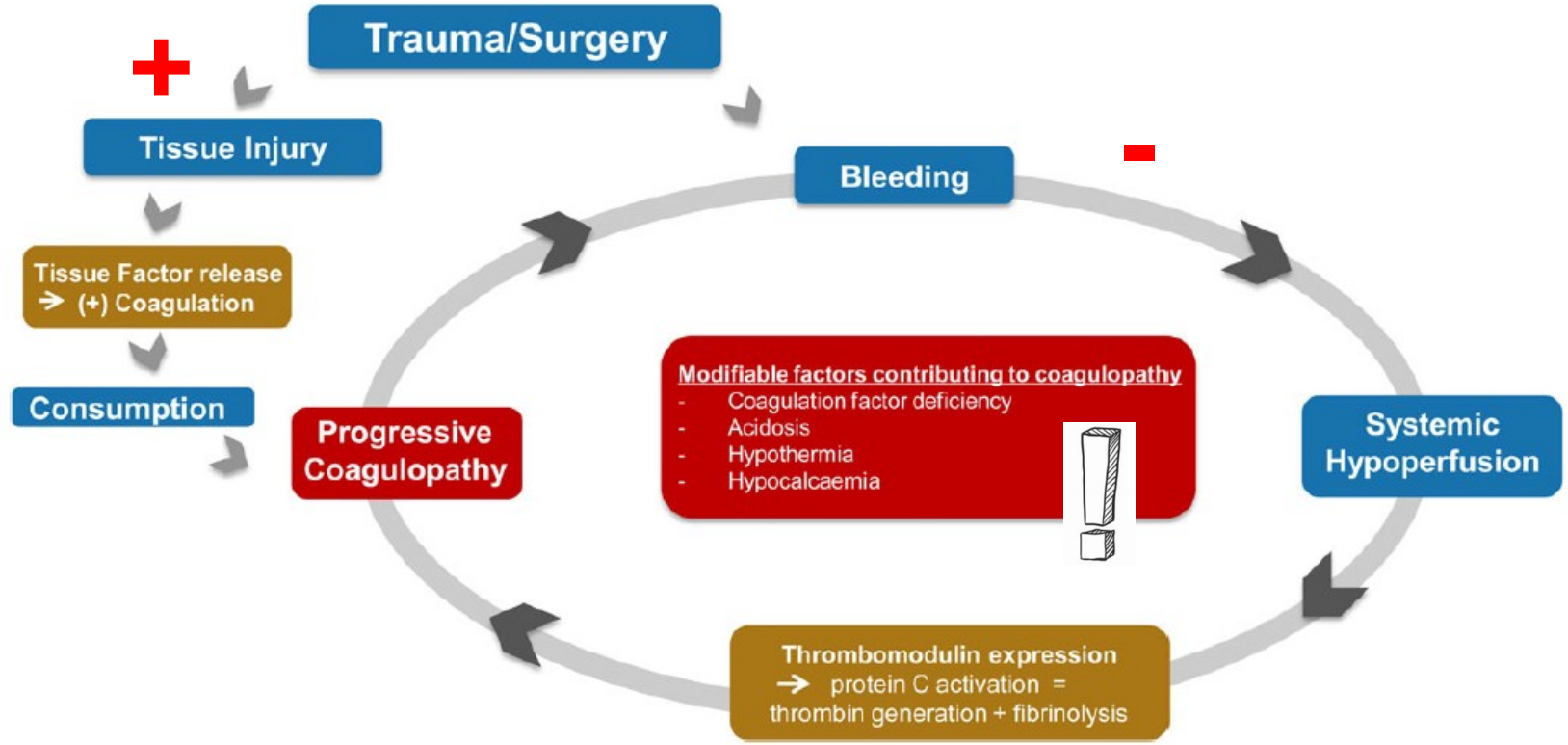


Fig 1 Pathophysiological factors contributing to coagulopathy during massive transfusion. (Modified from Fig. 1 of Diab and colleagues, with permission from *British Journal of Haematology*, John Wiley and Sons.)[1]

Paediatric massive transfusion

S Blain MBBS[1,*] and N Paterson MB ChB DA FFA FANZCA[2]

BJA Education, 16 (8): 269–275 (2016)

Hemorhagický šok III - management

- Perzistující hemorhagie – antifibrinolytika
  - Tranexamová kyselina:
    - do 3 hodin od úrazu (tupé či penetrující poranění torza, izolované kraniotrauma s GCS < 13)
    - TXA: 20mg/kg (do dávky 1g), dále 15-20mg/kg/8hodin (max. 1g)

- Tekutiny
  - Balancované krystaloidy: 10ml/kg bolus – kontrola odpovědi, opakovat 10ml/kg bolus
    - Ideálně ohřáté tekutiny
    - Pokud bylo podáno 20ml/kg krystaloidů, při další potřebě tekutin preferovat podání trans. přípravků
    - Reverze hypotenze při krevní ztrátě vyžaduje cca 3 násobek objemu krystaloidů vs. krevní ztráta

- Krevní deriváty
  - Při traumatu a hypotenzi po 20ml/kg krystaloidů uvažovat o podání transfuze
  - Podat skupinovou ER ev. O Rh-
  - 20ml/kg, ohřátou, přetlakem

  - Masivní krevní ztráta u dětí:
    - > 80 ml/kg/24 hodin (exsanguinace) nebo ztráta > 40ml/kg (50% objemu krve) během 3 hodin
    - > 10% objemu krve / 10 minut
    - > 3 ml/kg/min
    - Život ohožující lokalizace (CNS, novorozenci/kojenci – exsanguinace)
    - Přítomnost laboratorních a klinických známek hypoperfuze orgánů (laktát)

Masivní transfuzní protokol (MTP) – aktivace

The optimal volume trigger for initiating a massive transfusion protocol in children is unknown but some experts use the following weight-based approach:

- <5 kg (neonate) – 55 mL/kg
- 5 to 25 kg (infant) – 50 mL/kg
- 25 to 50 kg (child) – 45 mL/kg
- >50 kg (adolescent) – 40 mL/kg or 6 units PRBC

Cca 40ml/kg krevních derivátů

- Aktivace MTP
  - Intenzivista, hematolog, laboratoř, transfuzní stanice, transport transf. přípravků
- Cílem je koncept hemostatické resuscitace
  - balancovaná transfuzní strategie: 1:1:1 (ERB:FFP:TR)
  - Fibrinogen nad 2g/l (50mg/kg substituce)
  - Ca^{++} nad 1 mmol/l (0,2-0,3 ml/kg 10% Ca gluconicum)
  - pH nad 7,2 BE pod > -6, laktát < 4
  - Hb > 80g/l, destičky > 75 (kraniotrauma > 100)
  - APTT/PT < 1,5 x norma, INR < 1,5
  - Teplota nad 35°C
  - Užití TEG, ROTEM

  - *Permisivní hypotenze u penetrujících poranění*
    - *(x kraniotrauma)*

ABCDE Disability- neurologický status

Assessment	Management
Disability – Identify:	
Level of consciousness (GCS)	Endotracheal intubation for rapidly declining GCS, GCS ≤8 or herniation ¶
Pupillary response	Elevate head of bed to 30° if no signs of shock
Signs of spinal cord injury	pCO2 držet 35-38 mmHg (4,6-5 kPa)
Signs of impending herniation	Moderate hyperventilation (pCO_2 30 to 35) P CO2 4-4,6 kPa
Glykemie, laktát	Neurosurgical consultation
	Administer osmotic agents if normotensive
Exposure – Identify: AMPLE	
Hypothermia Teplota	***Remove clothing***
	Initiate rewarming

Hypoglykémie

Vegetativní příznaky: Tachykardie, pocení, třes, úzkost, hlad

Neuroglykopenie: Bolest hlavy, zmatenost, halucinace, agresivita, křeče, koma

Pozor na příznaky u novorozenců: apnoe, bradykardie, hypotermie

Glukoza i.v.

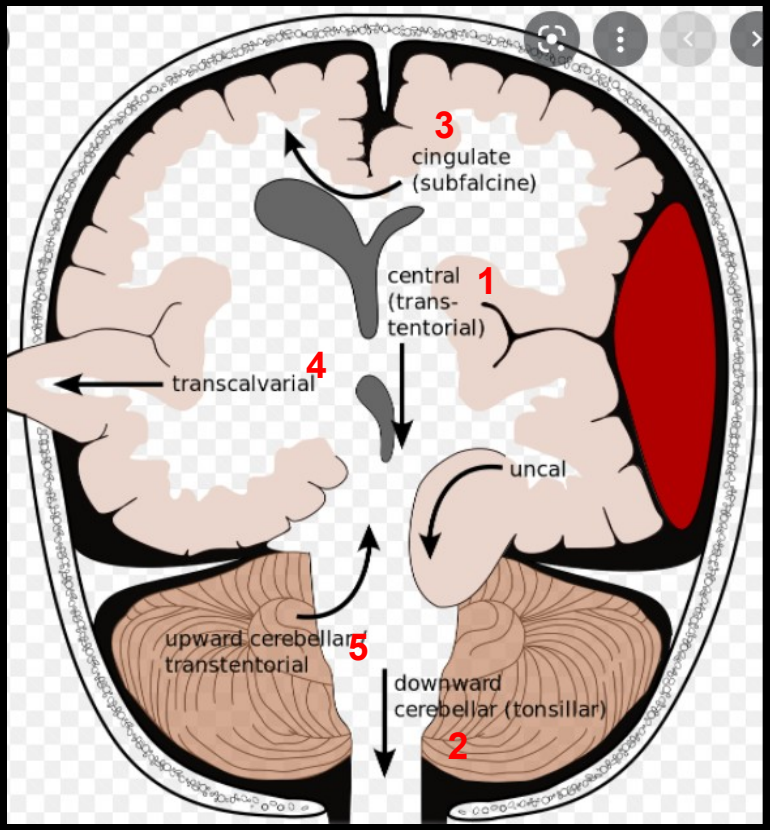
0.2-0.5 g/kg bolus i.v., (max.25g)

10% glu: 2 - 5ml/kg , 20% glu: 1 – 2.5 ml/kg, 50% glu: 1ml/kg

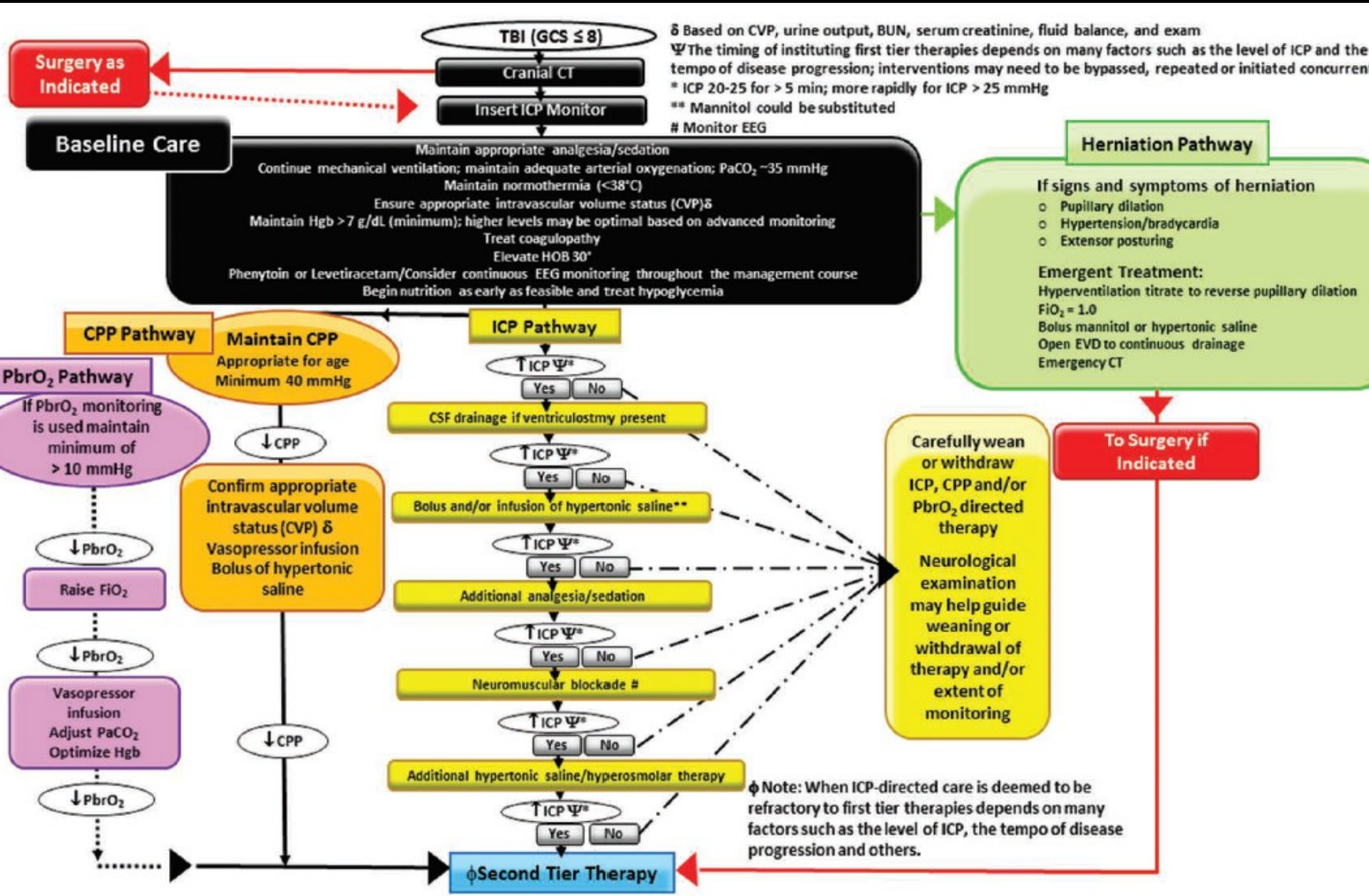
Poté kontinuální přívod: kojenci 5-8 mg/kg/min, větší děti 3-5 mg/kg/min

Glukagon s.c., i.m. - 20ug/kg u dětí, 1mg u dospělých

Herniace



1. Transtentoriální herniace
   - Dilatace zornic, bradykardie
   - Kontralaterální hemiparéza
2. Herniace foramen magnum
   - Nystagmus,
   - Bradykardie, hypertenze, bradypnoe
3. Subfalcinní herniace
   - Unilateráln či bilaterální svalová slabost
4. Dekortikační obraz – postih kortikospinálního tr.
   - Capsula interna, pedunculus cerebrální
5. Decerebrační rigidita
   - Postižení kmene/pontu u transtentoriální herniace


TBI (GCS ≤ 8)
Cranial CT
Insert ICP Monitor
Surgery as Indicated
Baseline Care
Maintain appropriate analgesia/sedation
Continue mechanical ventilation; maintain adequate arterial oxygenation; PaCO2 ~35 mmHg
Maintain normothermia (<38°C)
Ensure appropriate intravascular volume status (CVP)δ
Maintain Hgb >7 g/dL (minimum); higher levels may be optimal based on advanced monitoring
Treat coagulopathy
Elevate HOB 30°
Phenytoin or Levetiracetam/Consider continuous EEG monitoring throughout the management course
Begin nutrition as early as feasible and treat hypoglycemia
δ Based on CVP, urine output, BUN, serum creatinine, fluid balance, and exam
Ψ The timing of instituting first tier therapies depends on many factors such as the level of ICP and the tempo of disease progression; interventions may need to be bypassed, repeated or initiated concurren
* ICP 20-25 for > 5 min; more rapidly for ICP > 25 mmHg
** Mannitol could be substituted
# Monitor EEG
Herniation Pathway
If signs and symptoms of herniation
Pupillary dilation
Hypertension/bradycardia
Extensor posturing
Emergent Treatment:
Hyperventilation titrate to reverse pupillary dilation
FiO2 = 1.0
Bolus mannitol or hypertonic saline
Open EVD to continuous drainage
Emergency CT
To Surgery if Indicated
CPP Pathway
Maintain CPP
Appropriate for age
Minimum 40 mmHg
↓CPP
Confirm appropriate intravascular volume status (CVP) δ
Vasopressor infusion
Bolus of hypertonic saline
↓CPP
PbrO2 Pathway
If PbrO2 monitoring is used maintain minimum of > 10 mmHg
↓PbrO2
Raise FiO2
↓PbrO2
Vasopressor infusion
Adjust PaCO2
Optimize Hgb
↓PbrO2
ICP Pathway
↑ICP Ψ*
Yes
No
CSF drainage if ventriculostmy present
↑ICP Ψ*
Yes
No
Bolus and/or infusion of hypertonic saline**
↑ICP Ψ*
Yes
No
Additional analgesia/sedation
↑ICP Ψ*
Yes
No
Neuromuscular blockade #
↑ICP Ψ*
Yes
No
Additional hypertonic saline/hyperosmolar therapy
↑ICP Ψ*
Yes
No
Carefully wean or withdraw ICP, CPP and/or PbrO2 directed therapy
Neurological examination may help guide weaning or withdrawal of therapy and/or extent of monitoring
ϕ Note: When ICP-directed care is deemed to be refractory to first tier therapies depends on many factors such as the level of ICP, the tempo of disease progression and others.
ϕSecond Tier Therapy

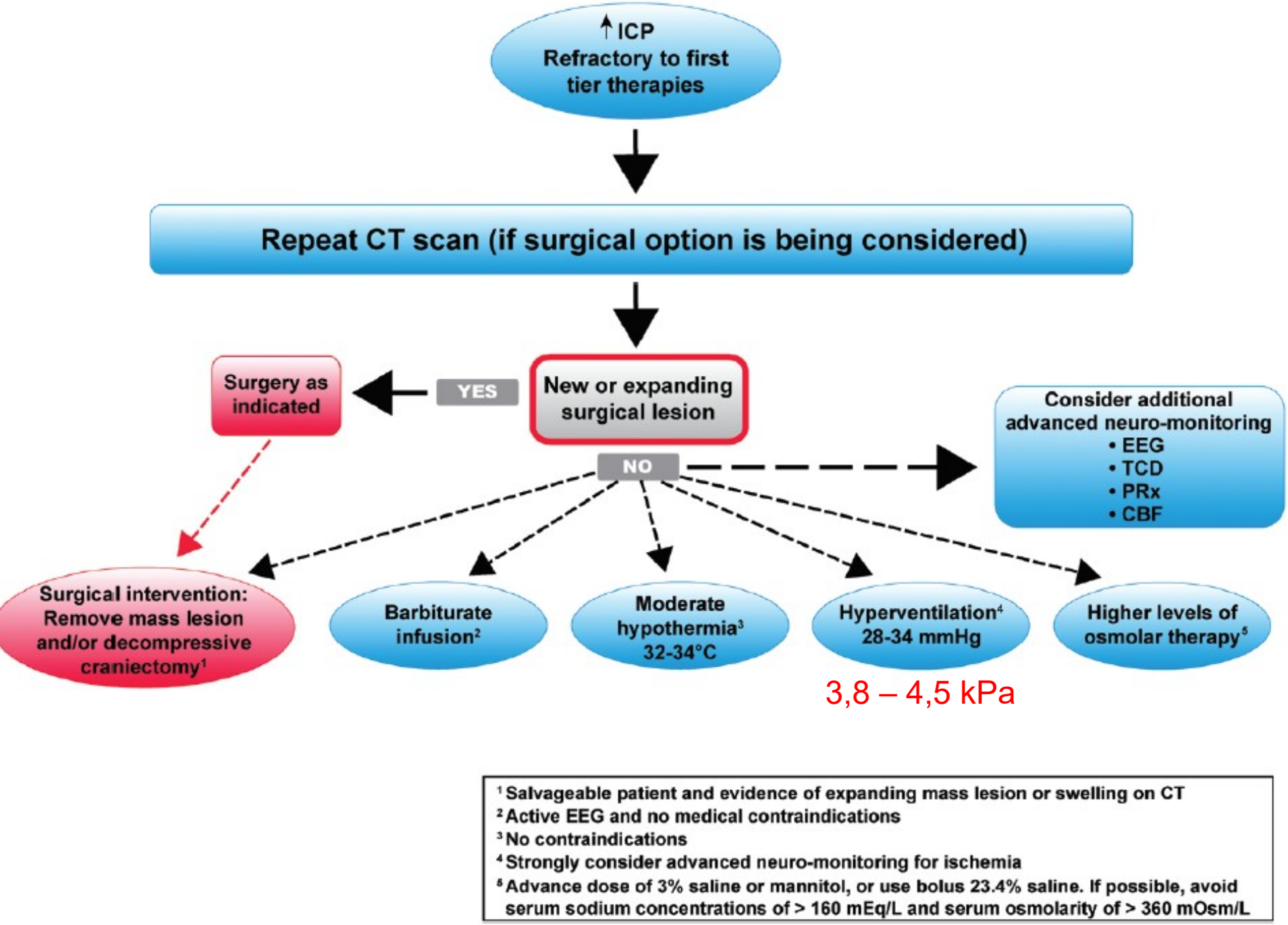

↑ICP
Refractory to first tier therapies
Repeat CT scan (if surgical option is being considered)
New or expanding surgical lesion
YES
Surgery as indicated
NO
Consider additional advanced neuro-monitoring
• EEG
• TCD
• PRx
• CBF
Surgical intervention: Remove mass lesion and/or decompressive craniectomy[1]
Barbiturate infusion[2]
Moderate hypothermia[3] 32-34°C
Hyperventilation[4] 28-34 mmHg
Higher levels of osmolar therapy[5]
3,8 – 4,5 kPa
[1] Salvageable patient and evidence of expanding mass lesion or swelling on CT
[2] Active EEG and no medical contraindications
[3] No contraindications
[4] Strongly consider advanced neuro-monitoring for ischemia
[5] Advance dose of 3% saline or mannitol, or use bolus 23.4% saline. If possible, avoid serum sodium concentrations of > 160 mEq/L and serum osmolarity of > 360 mOsm/L

TABLE 1. Updated Recommendations: Monitoring

Topics	Recommendations
Intracranial pressure monitoring	**Level III** **To improve overall outcomes** III.1. Use of ICP monitoring is suggested.
Advanced neuromonitoring	**Level III** **To improve overall outcomes** III.1. If $PbrO_2$ monitoring is used, maintaining a level >10 mm Hg is suggested. Note 1. There was insufficient evidence to support a recommendation for the use of a monitor of Po_2 in brain interstitium ($PbrO_2$) to improve outcomes. Note 2. Use of advanced neuromonitoring (brain oxygenation) should only be for patients with no contraindications to invasive neuromonitoring, such as coagulopathy, and for patients who do not have a diagnosis of brain death.
Neuroimaging	**Level III** **To improve overall outcomes** **III.1. Excluding the possibility of elevated ICP on the basis of a normal initial (0-6 h after injury) CT examination of the brain is not suggested in comatose pediatric patients.** III.2. Routinely obtaining a repeat CT scan >24 hours after the admission and initial follow-up is not suggested for decisions about neurosurgical intervention, unless there is either evidence of neurologic deterioration or increasing ICP.

ICP = intracranial pressure, $PbrO_2$ = brain tissue oxygen.
Bold indicates new or revised recommendations.

TABLE 2. Updated Recommendations: Thresholds

Topics	Recommendations
Threshold for treatment of intracranial hypertension	**Level III** **To improve overall outcomes** III.1. Treatment of intracranial pressure targeting a threshold of < 20 mm Hg is suggested.
Thresholds for cerebral perfusion pressure	**Level III** **To improve overall outcomes** III.1 Treatment to maintain CPP at a minimum of 40 mm Hg is suggested. III.2. A CPP target between 40 and 50 mm Hg is suggested to ensure that the minimum value of 40 mm Hg is not breached. There may be age-specific thresholds with infants at the lower end and adolescents at or above the upper end of this range.

CPP = cerebral perfusion pressure.

› Pediatr Crit Care Med. 2019 Mar;20(3):280-289.

TABLE 3. Updated Recommendations: Treatments

Topics	Recommendations
Hyperosmolar therapy	**Level II** **For ICP control** **II.1. Bolus hypertonic saline (3%) is recommended in patients with intracranial hypertension. Recommended effective doses for acute use range between 2 and 5 mL/kg over 10-20 min.** **Level III** **For ICP control** III.1. Continuous infusion hypertonic saline is suggested in patients with intracranial hypertension. Suggested effective doses as a continuous infusion of 3% saline range from between 0.1 and 1.0 mL/kg of body weight per hour, administered on a sliding scale. The minimum dose needed to maintain intracranial pressure ICP < 20 mm Hg is suggested. **III.2. Bolus of 23.4% hypertonic saline is suggested for refractory ICP. The suggested dose is 0.5 mL/kg with a maximum of 30 mL.** Safety recommendation (applies to all recommendations for this topic). In the context of multiple ICP related therapies, avoiding sustained (>72 h) serum sodium >170 mEq/L is suggested to avoid complications of thrombocytopenia and anemia, whereas avoiding a sustained serum sodium >160 mEq/L is suggested to avoid the complication of deep vein thrombosis. Note. Although mannitol is commonly used in the management of raised ICP in pediatric traumatic brain injury, no studies meeting inclusion criteria were identified for use as evidence for this topic.
Analgesics, sedatives, and neuromuscular blockade	**Level III** **For ICP control** **III.1. With use of multiple ICP-related therapies, as well as appropriate use of analgesia and sedation in routine ICU care, avoiding bolus administration of midazolam and/or fentanyl during ICP crises is suggested due to risks of cerebral hypoperfusion.** Note 1. In the absence of outcome data, the specific indications, choice, and dosing of analgesics, sedatives, and neuromuscular blocking agents should be left to the treating physician. Note 2. Based on guidance from the US Food and Drug Administration, prolonged continuous infusion of propofol for either sedation or the management of refractory intracranial hypertension is not recommended.
Cerebrospinal fluid drainage	**Level III** **For ICP control** III.1. Cerebrospinal fluid drainage through an external ventricular drain is suggested to manage increased ICP.

› Pediatr Crit Care Med. 2019 Mar;20(3):280-289.

Seizure prophylaxis	**Level III** **For seizure prevention (clinical and subclinical)** **III.1. Prophylactic treatment is suggested to reduce the incidence of early (within 7 d) PTS.** Note. At the present time there is insufficient evidence to recommend levetiracetam over phenytoin based on either efficacy in preventing early PTS or toxicity.
Ventilation therapies	**Level III** **To improve overall outcomes** III.1. Prophylactic severe hyperventilation to a $PaCO_2$ < 30 mm Hg in the initial 48 h after injury is not suggested. III.2. If hyperventilation is used in the management of refractory intracranial hypertension, advanced neuromonitoring for evaluation of cerebral ischemia is suggested.
Temperature control/ hypothermia*	**Level II** **To improve overall outcomes** **II.1. Prophylactic moderate (32°C to 33°C) hypothermia is not recommended over normothermia to improve overall outcomes.** **Level III** **For ICP control** **III.1. Moderate (32°C to 33°C) hypothermia is suggested for ICP control.** Safety recommendation 1. If hypothermia is used and rewarming is initiated, it should be carried out at a rate of 0.5°C to 1.0°C every 12-24 h or slower to avoid complications. Safety recommendation 2. If phenytoin is used during hypothermia, monitoring and dosing adjusted to minimize toxicity, especially during the rewarming period, is suggested.

> Pediatr Crit Care Med. 2019 Mar;20(3):280-289.

TABLE 3. Continued

Topics	Recommendations
Barbiturates	**Level III** **For ICP control** III.1. High-dose barbiturate therapy is suggested in hemodynamically stable patients with refractory intracranial hypertension despite maximal medical and surgical management. Safety recommendation. When high-dose barbiturate therapy is used to treat refractory intracranial hypertension, continuous arterial blood pressure monitoring and cardiovascular support to maintain adequate cerebral perfusion pressure are required because cardiorespiratory instability is common among patients treated with barbiturate coma.
Decompressive craniectomy	**Level III** **For ICP control** III.1. Decompressive craniectomy is suggested to treat neurologic deterioration, herniation, or intracranial hypertension refractory to medical management.
Nutrition	**Level II** **To improve overall outcomes** II.1. Use of an immune-modulating diet is not recommended. **Level III** **To improve overall outcomes** **III.1. Initiation of early enteral nutritional support (within 72 h from injury) is suggested to decrease mortality and improve outcomes.**
Corticosteroids	**Level III** **To improve overall outcomes** **III.1. The use of corticosteroids is not suggested to improve outcome or reduce ICP.** Note. Recommendation III.1 is not intended to circumvent use of replacement corticosteroids for patients needing chronic steroid replacement therapy, those with adrenal suppression, and those with injury to the hypothalamic-pituitary steroid axis.

› Pediatr Crit Care Med. 2019 Mar;20(3):280-289.

The Pittsburgh Protocol for Pediatric TBI

- Once post-resuscitation GCS ≤ 8 is confirmed, do full instrumentation if able (EVD, Licox, Codman). May instrument if GCS is > 8 and there is concern that intracranial hypertension may develop. If not able to place all devices, EVD is most important. Limit movement of patients (to CT scan, IR, radiology, etc) once monitors are placed to avoid ICP spikes and dislodging of devices.
- Keep sedated/paralyzed (first-line ICP therapies) for at least 48 hours. Keep sedated/paralyzed throughout cooling and rewarming of all kids who are made hypothermic. EVD at 10 cm above midbrain and open to drain.
- Continuous EEG for all kids while paralyzed.
- Keep $PaCO_2$ ~ 32 as baseline. May decrease it if ICP is high and PbO_2 is high (theoretically hyperemic phase). May increase it if ICP is low and PbO_2 is low (theoretically oligemic phase). Volume control is preferred for smoothest maintenance of $PaCO_2$.
- Maintain CPP within age-related norms (>50 for infants under 6 months, > 55 for children under 2 years, > 60 for all others) using fluids and vasopressors.
- ICP spikes (sustained for greater than 5 minutes over 20 mmHg) treated with stepwise increases in therapy (2nd line - osmolar (mannitol/3%NaCl), pentobarbital) if other causes of ICP spikes ruled out. Don't give mannitol if serum Osm > 320. Try not to push serum Na greater than 160s.
- If osmolar/pentobarbital fail, consider surgical options or induced hypothermia off-protocol. Any child (including those randomized to normothermia in Cool Kids trial) can be cooled as a rescue therapy for refractory intracranial hypertension.
- Only wean ICP therapies after at least 24 hours of stability (no ICP spikes) and after period of maximal swelling. Take most high-risk therapy away first. Do not change more than one parameter at a time.
- Normal saline is required throughout the course. No dextrose in fluids for the first 48 hours unless hypoglycemic (serum glucose < 70). Start non-dextrose containing TPN on post trauma day 1. Continue intralipids regardless of pentobarbital dosing. Discontinue intralipids if pancreatitis or hyperlipidemia documented.
- Start antiepileptic (fosphenytoin preferred).
- Narcotic sedation only (fentanyl preferred). May start methadone later as trying to wean. May use boluses of pentobarbital if sedation is related to ICP spikes.
- Transfuse to keep Hb > 9, INR < 1.5 and platelets > 100K. These goals can be modified based on surgical bleeding risks.
- Antibiotics for instrumentation at the discretion of Neurosurgery. Antibiotics for suspected infection at the discretion of CCM.

- Keep both Neursurgery Residents/Fellows/Attendings and CCM Fellows/Attendings aware of all changes in patient status. Mike Bell will need to check in to determine if Adverse Events/Serious Adverse Events occur that are reportable to relevant IRBs or DSMBs and to ensure that the protocol is being followed.

ICP Monitoring good or bad in TBI

Virtual World Congress WFPICCS 2020

GOOD	BAD
Improves management	**Does not help**
• Provides a target for treatment – ICP, CPP • ICP monitoring leads to less acute kidney injury with hyperosmolar therapy [Zeng et al (2013) J Neurosurg]	• Increases length of stay [Cochrane Reviews] • Threshold in ICP and CPP unknown • Many therapies lead to better ICP control but no difference in outcome

Pediatrics. 2018 Aug;142(2):e20180594. doi: 10.1542/peds.2018-0594.

Blood Pressure Thresholds and Mortality in Pediatric Traumatic Brain Injury

Pratthana Suttipongkaset [1 2], Nophanan Chaikittisilpa [2 3], Monica S Vavilala [2 4], Abhijit V Lele [4], Arraya Watanitanon [2 4], Theerada Chandee [2 4], Vijay Krishnamoorthy [5 6]

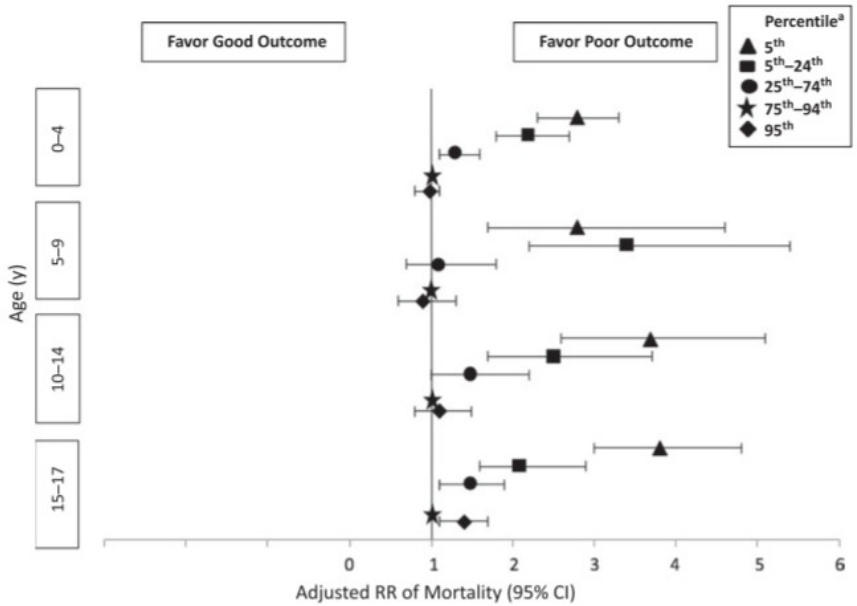


FIGURE 1
Multivariate analysis of the association between early SBP percentiles and mortality by age group by using age-specific SBP in the 75th to 94th percentiles as a reference group. [a] SBP by 50th percentile of height.

Mean Arterial Pressure and Discharge Outcomes in Severe Pediatric Traumatic Brain Injury

Scott L Erickson [1 2 3], Elizabeth Y Killien [4 5], Mark Wainwright [6], Brianna Mills [2 3], Monica S Vavilala [1 2]