LANDESKRANKENHAUS FELDKIRCH

Akademisches Lehrkrankenhaus

Ki Jugendheilkunde

Gemeinsam von einander lernen.

PICU MASTERCLASS

SBG 28./29. NOV 2024

Flüssigkeiten

Burkhard Simma

November 2024

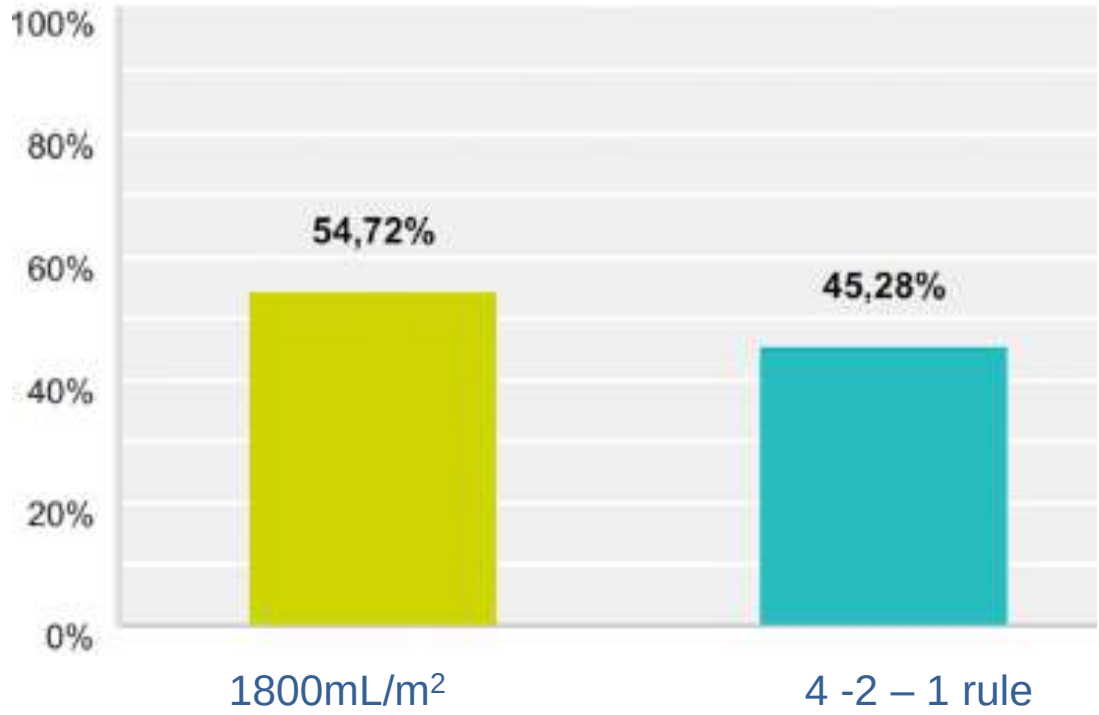
Tagesflüssigkeit

- 1800ml/m²KÖF/d
- 4-2-1 rule

Survey in Austria, n=53

Maintenance Fluid

Survey in Austria, n=53



THE MAINTENANCE NEED FOR WATER IN PARENTERAL FLUID THERAPY

By Malcolm A. Holliday, M.D., and William E. Segar, M.D.
Department of Pediatrics, Indiana University Medical Center

Based on 2 theoretical assumptions

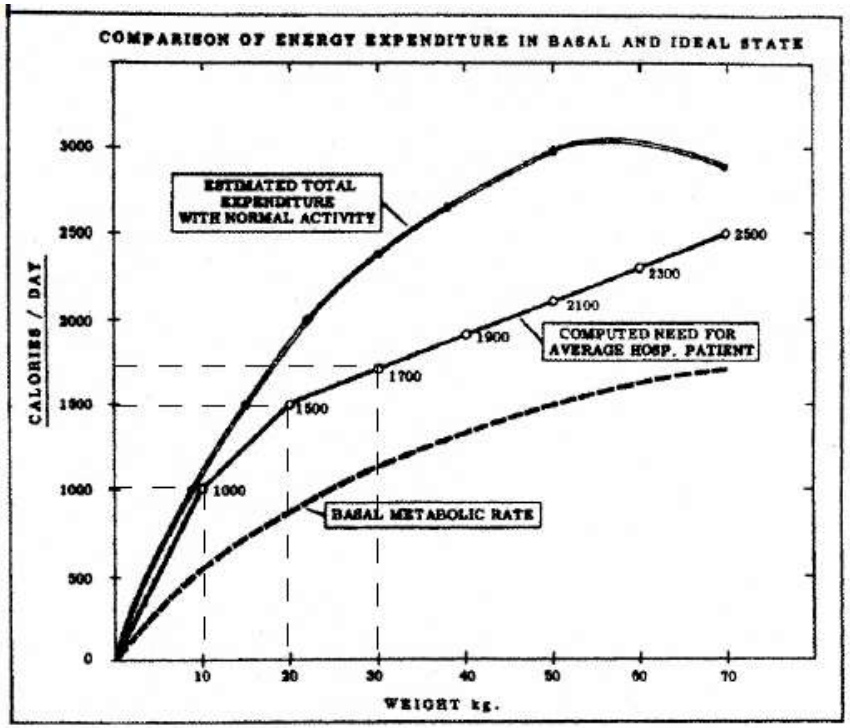
→ Water requirements determined by caloric expenditure
→ Maintenance = [insensible loss + renal loss – $H_2O_{oxidation}$

100kacl =100mL

Holliday MA, Segar WE, Pediatr 1957

Maintenance Fluid

Caloric expenditure and body weight



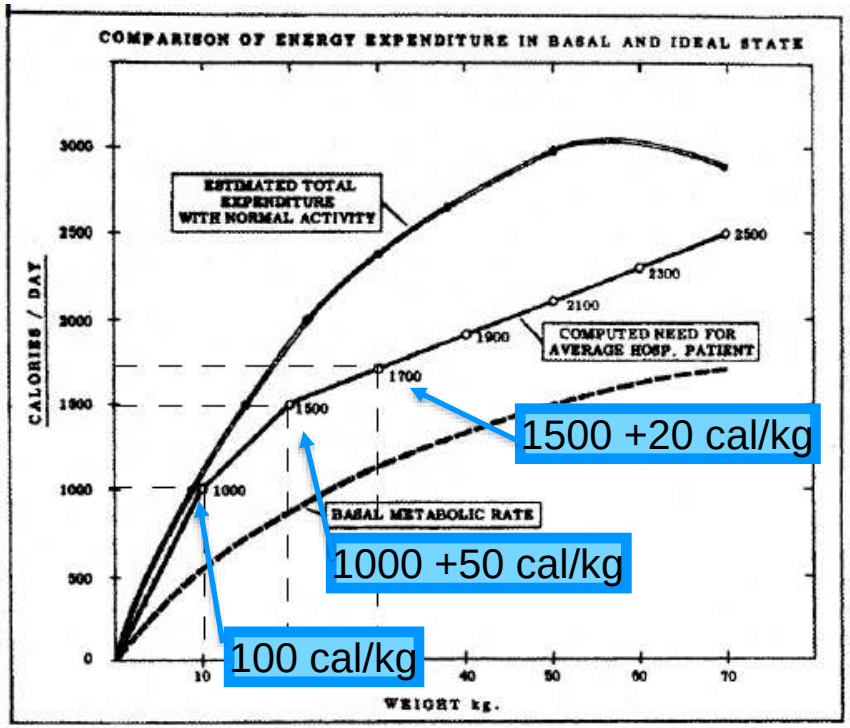
INTAKE OF ELECTROLYTES PROVIDED PER ESTIMATED 100 CALORIES ON VARIOUS REGIMENS

Regimen	mEq/100 cal/day		
	Na	Cl	K
Human milk*	1.0	1.2	2.0
Cow's milk	3.5	4.5	6.0
Recommended†	3.0	2.0	2.0
Recommended (Darrow)	3.0	2.0	3.0
Recommended adult**	3.0	3.0	1.0

Holliday MA, Segar WE, Pediatr 1957

Maintenance Fluid

Caloric expenditure and body weight



INTAKE OF ELECTROLYTES PROVIDED PER ESTIMATED 100 CALORIES ON VARIOUS REGIMENS

Regimen	mEq/100 cal/day		
	Na	Cl	K
Human milk*	1.0	1.2	2.0
Cow's milk	3.5	4.5	6.0
Recommended†	3.0	2.0	2.0
Recommended (Darrow)	3.0	2.0	3.0
Recommended adult**	3.0	3.0	1.0

Holliday MA, Segar WE, Pediatr 1957

THE MAINTENANCE NEED FOR WATER IN PARENTERAL FLUID THERAPY

By Malcolm A. Holliday, M.D., and William E. Segar, M.D.
Department of Pediatrics, Indiana University Medical Center

Based on 2 theoretical assumptions

→ Water requirements determined by caloric expenditure
→ Maintenance = [insensible loss + renal loss – $H_2O_{oxidation}$

Daily caloric expenditure per kg body weight

<10 kg:	100 cal/kg
10-20 kg:	1000 cal + 50 cal/kg
>20 kg:	1500 cal + 20 cal/kg

Holliday MA, Segar WE, Pediatr 1957

Maintenance Fluid

1-10 kg:	100 mL/kg/d	4 mL/kg/h	
11-20 kg:	1000 mL + 50 mL/kg/d	40 mL/h	+ 2 mL/kg/h
>20 kg:	1500 mL + 20 mL/kg/d	60 mL/h	+ 1 mL/kg/h

„4-2-1 rule“

or 1500 (-1800) mL/m^2 body surface area

Holliday MA. Pediatr 1957; Robroch AH. ADC 2011; AAP. Textbook of Pediatric Care 2009

Elektrolyte - Natrium

A: 20 – 40mmol/L

B: >40mmol/L

C: <20mmol/l

D: weder A - C

Elektrolyte - Natrium

Survey in Austria, n=53

A: 20 – 40mmol/L	51%
B: >40mmol/L	38%
C: <20mmol/l	0%
D: weder A – C	11%

Electrolytes

NaCl 30 mval/L

KCl 20 mval/L

INTAKE OF ELECTROLYTES PROVIDED PER ESTIMATED 100 CALORIES ON VARIOUS REGIMENS

Regimen	mEq/100 cal/day		
	Na	Cl	K
Human milk*	1.0	1.2	2.0
Cow's milk	3.5	4.5	6.0
Recommended†	3.0	2.0	2.0
Recommended (Darrow)	3.0	2.0	3.0
Recommended adult**	3.0	3.0	1.0

Holliday MA. Pediatr 1957; Robroch AH. ADC 2011; AAP. Textbook of Pediatric Care 2009

Tagesflüssgkeit erhöht bei beatmeten Patienten

A: unverändert

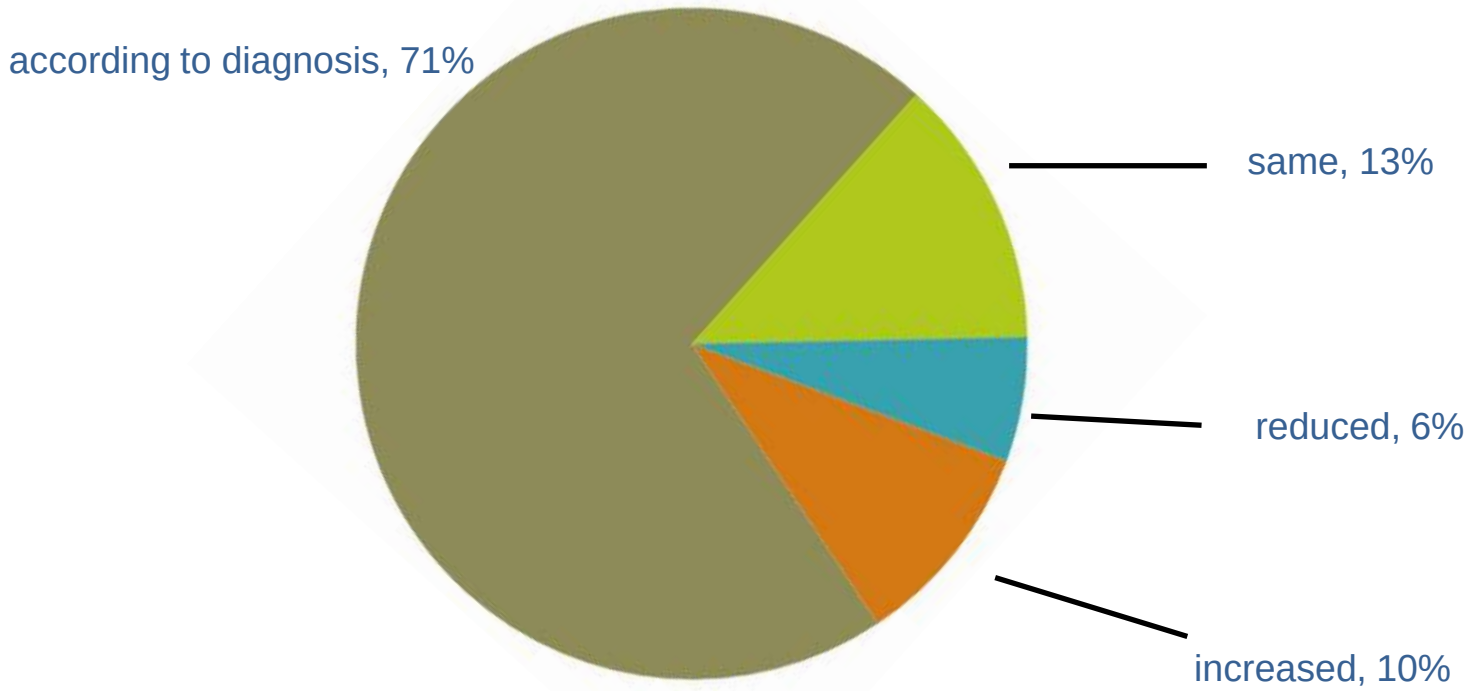
B: erhöht um >10%

C: vermindert z.b. um 20-30%

D: je nach Diagnose

Do you change volume in a ventilated child?

Survey in Austria, n=53



Maintenance Fluid

based on 3(!) children and assumptions from adults (1800mL/m^2)

+ NaCl 30mval/L (!!) ~Tonicity: 0.18%

+ KCl 20mval/L

Incidence of hyponatremia (<135mmol/L): 17-45%
Free water

Increased vasopressin (SIADH): meningitis, encephalitis, brain tumors, pneumonia, bronchiolitis, chronic lung disease (CLD), severe head injury

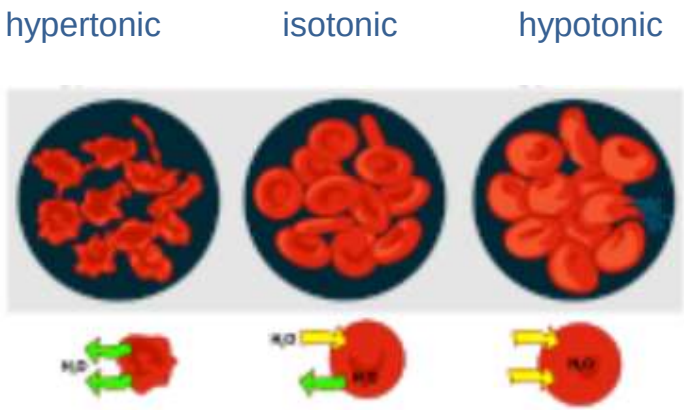
Tonicity

Compares sodium content of solution vs. plasma

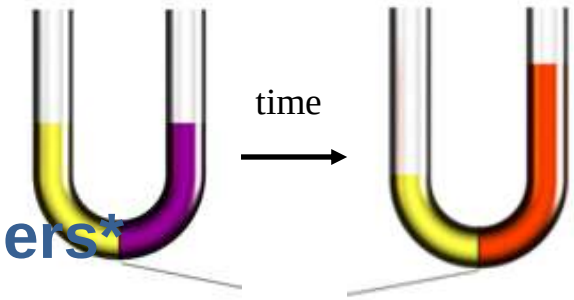
isotonic: 154 mmol Na^+/L

hypotonic: < 154 mmol/L

hypertonic: > 154 mmol/L



Osmolality (Osmo)



= 2xNa + (Glucose, mg/dL:18) + (BUN mg/dL:2.8) + others*

Measured > calculated Osmo
- Hyperlipidemia
  - True Na = measured Na (0.021xTG(g/dL) + 0.994
- Hypoproteinemia
- Hyperglycemia

*Osmotically active substances like
mannitol, contrast agents, alcohol intoxication

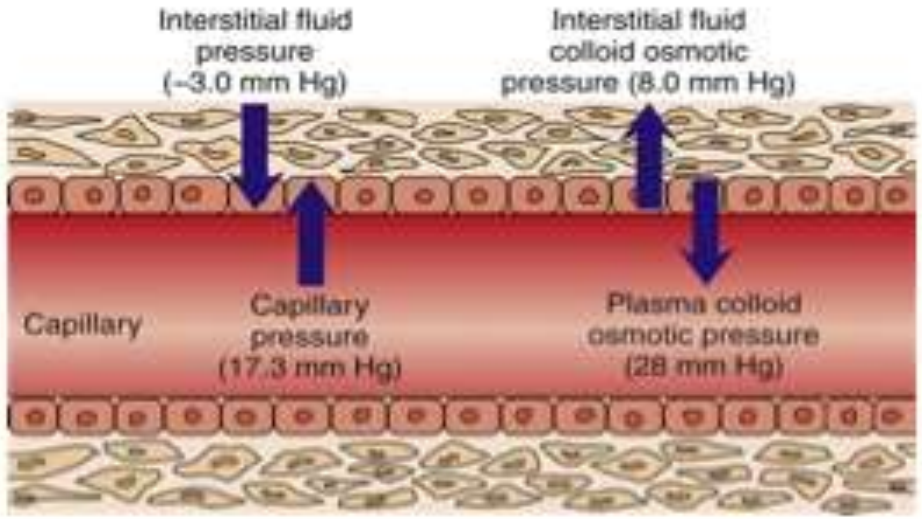
Small changes in the plasma lead to great changes in osmolality

Colloid Oncotic (Osmotic) Pressure

= 19mmHg of dissovekd protein + 9mmHg Donnan effect

Oncotic pressure: 80% albumin, 20% globulin, fibrinogen

Donnan effect: osmotic pressure caused by molecular Na, K and other cations held in the plasm by proteins



Great changes in the plasma lead to small changes in oncotic pressure

Colloids

EUROPEAN MEDICINES AGENCY
SCIENCE MEDICINES HEALTH

- Because of the risk of kidney injury and mortality, HES solutions **must** no longer be used in patients with sepsis (bacterial infection in the blood) or burn injuries or critically ill patients.
- HES solutions may continue to be used to treat hypovolaemia (low blood volume) caused by acute (sudden) blood loss. However, the doctor should monitor the patient's kidney function after HES administration.

19th Dec 2013

Bundesamt für Sicherheit im Gesundheitswesen
BASG

- Suspension of the approval because of continued use in patients with increased risk

15th Nov 2022

Which Crystalloid?

	Plasma	0.9% NaCl	Ringer Solution	Ringer´s Lactate	3% NaCl	Elo Paed Bal
Na (mmol/L)	142	154	147	130 - 135	513	142
K^+ (mmol/L)	4.0	-	4.0	5.0 - 5.4	-	4
Cl (mmol/L)	104	154	155	112	513	126
Anion (mmol/L)	Bicarb, Ph, Protein 33	-	-	lactate/ acetate 29	-	acetate
Osmol (mosm/L)	280-295	304	309	280	1000	Glucose 10g
pH	7.4	5.0 - 7.0	5.0 - 7.5	7	4.5 - 7.0	7

Which Crystalloid?

				Balanced		Balanced
	Plasma	0.9% NaCl	Ringer Solution	Ringer´s Lactate	3% NaCl	Elo Paed Bal
Na (mmol/L)	142	154	147	130 - 135	513	142
K^+ (mmol/L)	4.0	-	4.0	5.0 - 5.4	-	4
Cl (mmol/L)	104	154	155	112	513	126
Anion (mmol/L)	Bicarb, Ph, Protein 33	-	-	lactate/ acetate 29	-	acetate
Osmol (mosm/L)	280-295	304	309	280	1000	Glucose 10g
pH	7.4	5.0 - 7.0	5.0 - 7.5	7	4.5 - 7.0	7

Which Crystalloid?

	Plasma	0.9% NaCl	Ringer Solution	Ringer´s Lactate	3% NaCl	Elo Paed Bal	G% K5 Vollektrolyt
Na (mmol/L)	142	154	147	130 - 135	513	142	140
K^+ (mmol/L)	4.0	-	4.0	5.0 - 5.4	-	4	5
Cl (mmol/L)	104	154	155	112	513	126	117
Anion (mmol/L)	Bicarb, Ph, Protein 33	-	-	lactate/ acetate 29	-	acetate	35
Osmol (mosm/L)	280-295	304	309	280	1000	Glucose 10g	Glucose 5g
pH	7.4	5.0 - 7.0	5.0 - 7.5	7	4.5 - 7.0	7	560

LANDESKRANKENHAUS FELDKIRCH

Akademisches Lehrkrankenhaus

Available online at www.sciencedirect.com

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

EUROPEAN RESUSCITATION COUNCIL

European Resuscitation Council Guidelines 2021: Paediatric Life Support

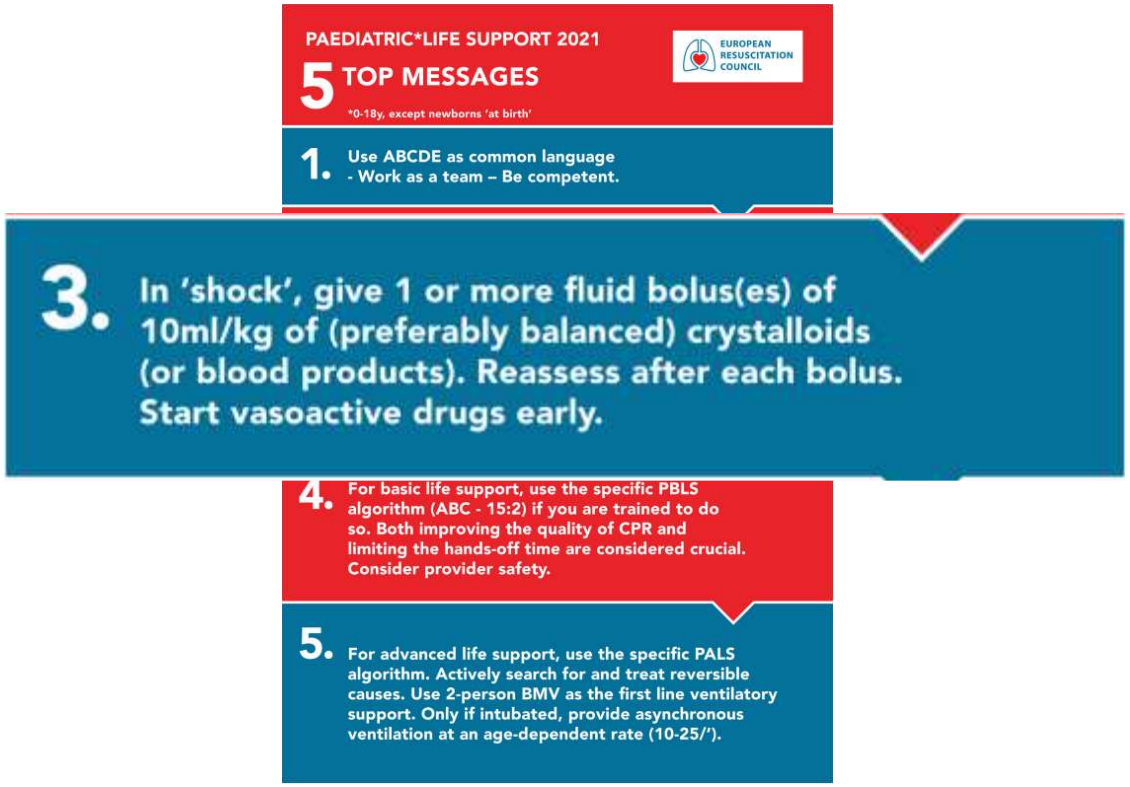


Fig. 1 – Main messages of the 2021 paediatric guidelines.

Impact of the Magnitude and Timing of Fluid Overload on Outcomes in Critically Ill Children: A Report From the Multicenter International Assessment of Worldwide Acute Kidney Injury, Renal Angina, and Epidemiology (AWARE) Study

Critical Care Medicine 51(5):p 606-618, May 2023.

Fluid Overload in Children

Outcomes by Fluid Overload at the End of ICU Day 1, *n* = 4,596, and Fluid Overload at the End of ICU Day 2, *n* = 2,885

End of ICU Day 1[a]						
Category, *n* (%)	FO < 5%, *n* = 2,843 (61.9%)	FO ≥ 5%, *n* = 1,753 (38.1%)	*p* (ES)	FO < 10%, *n* = 4,059 (88.3%)	FO ≥ 10%, *n* = 537 (11.7%)	*p* (ES)
28-d ICU-free days	26 (22–26)	24 (20–25)	< 0.001 (0.34)	25.0 (22.0–26.0)	23.0 (16.0–25.0)	< 0.001 (0.53)
28-d mortality	70 (2.5)	82 (4.7)	< 0.001 (0.12)	109 (2.7)	43 (8)	< 0.001 (0.24)
End of ICU Day 2[b]						
28-d ICU-free days	23.0 (20.0–25.0)	23.0 (18.0–24.0)	< 0.001 (0.22)	23 (20–25)	22 (17–24)	< 0.001 (0.38)
28-d mortality[c]	39 (2.9)	74 (4.8)	0.008 (0.10)	66 (3.1)	47 (6.5)	< 0.001 (0.16)

Mortality doubles each time when FO is >5% and >10%

J.S. 18.07.2020

03.09.24

Case #3

since six days fever, abdominal pain, headache and diarrhoea

VS: T 39.6°C, HR 155/min, BP 77/30-42 mmHg, RR 40/min, SpO_2 94%,

recap..., GCS 14

WBC 2.8 G/L, Hb 10g/dL, Thrombo 30G/L

CRP 4mg/dL, IL-6 800.000pg/mL, PCT 21ng/dl; lactate 2.5mmol/L

INR 1.5; Fibrinogen 320mg/dL

J.S. 18.07.2020

03.09.24

Case #3

A: Gastroenteritis

B: Infection with Phoenix Sepsis Score of 3

C: „wait and see“

D: something is wrong/strange

E: Infection Phoenix Sepsis Score 3 and volume (balanced)

Original Investigation | Caring for the Critically Ill Patient
ONLINE FIRST FREE
January 21, 2024

International Consensus Criteria for Pediatric Sepsis and Septic Shock

Luregn J. Schlapbach, MD, PhD[1,2]; R. Scott Watson, MD, MPH[3,4]; Lauren R. Sorce, PhD, RN[5,6]; et al

JAMA Network

From: International Consensus Criteria for Pediatric Sepsis and Septic Shock

JAMA. Published online January 21, 2024. doi:10.1001/jama.2024.0179

Suspected infection with Phoenix Sepsis Score of 3

Table. The Phoenix Sepsis Score[a]

Variables	0 Points	1 Point	2 Points	3 Points
Age based[f]				
	Mean arterial pressure, mm Hg[g]			
<1 mo	>30	17-30	<17	
1 to 11 mo	>38	25-38	<25	
1 to <2 y	>43	31-43	<31	
Coagulation (0-2 points)[h]				
		1 Point each (maximum 2 points)		
	Platelets ≥100 × 10^3/μL	Platelets <100 × 10^3/μL		
	International normalized ratio ≤1.3	International normalized ratio >1.3		
	D-dimer ≤2 mg/L FEU	D-dimer >2 mg/L FEU		
	Fibrinogen ≥100 mg/dL	Fibrinogen <100 mg/dL		

Balanced crystalloid: 2 x 20mL/kg

Jabarkhel, Saira
ÜW9 0601103178/7240049029

Vitalparam-Bericht Standard 3 Sep 24 15:22:38

	3 Sep 13:18	13:47	13:53	13:55	14:00	14:15	14:30	14:45	15:00	15:15	15:22	15:30
NBPs	88	82	81	87	85	81	88	85	82	80		78
NBPd	33	30	30	34	34	35	45	35	35	56		37
NBPm	52	46	45	53	52	49	56	53	49	65		51
HF	131	120	120	122	123	120	122	121	128	132	124	130
SpO_2	95	96	95	95	94	93	94	96	96	96	95	94
AF	48	47	41	48	40	35	38	39	39	37	41	32

Temp.: 38,1°C 38,5°C 37,4°C

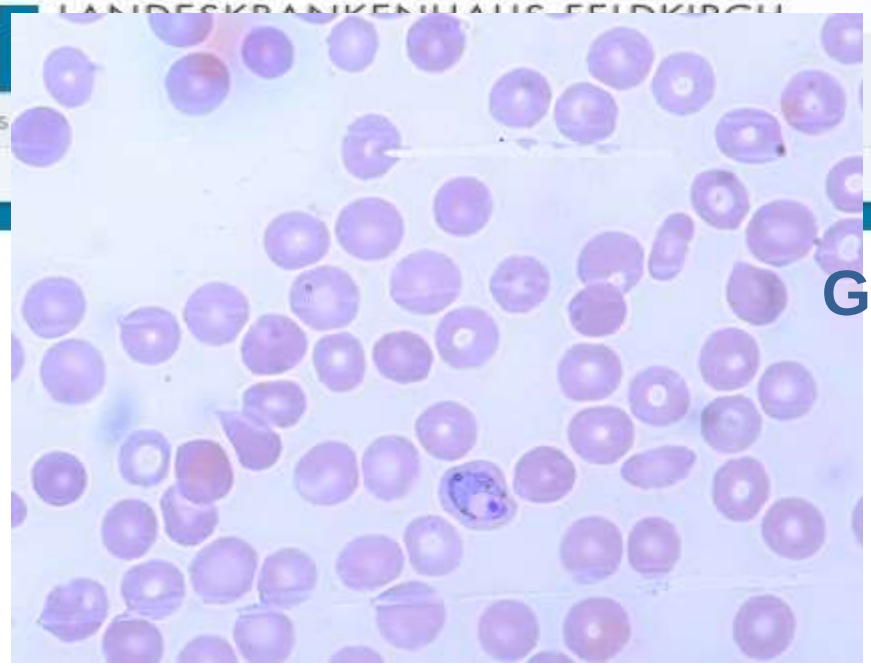
J.S. 18.07.2020

03.09.24

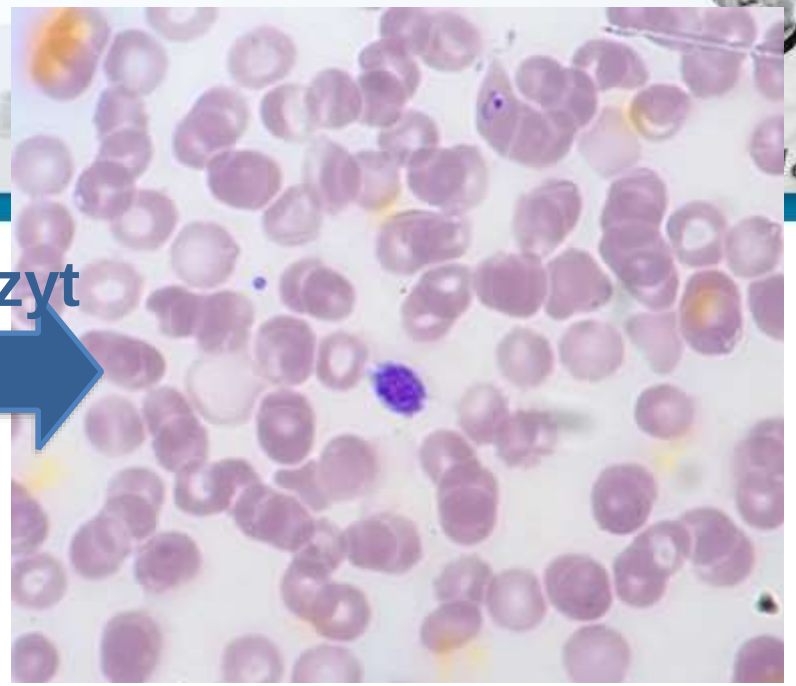
Case #3

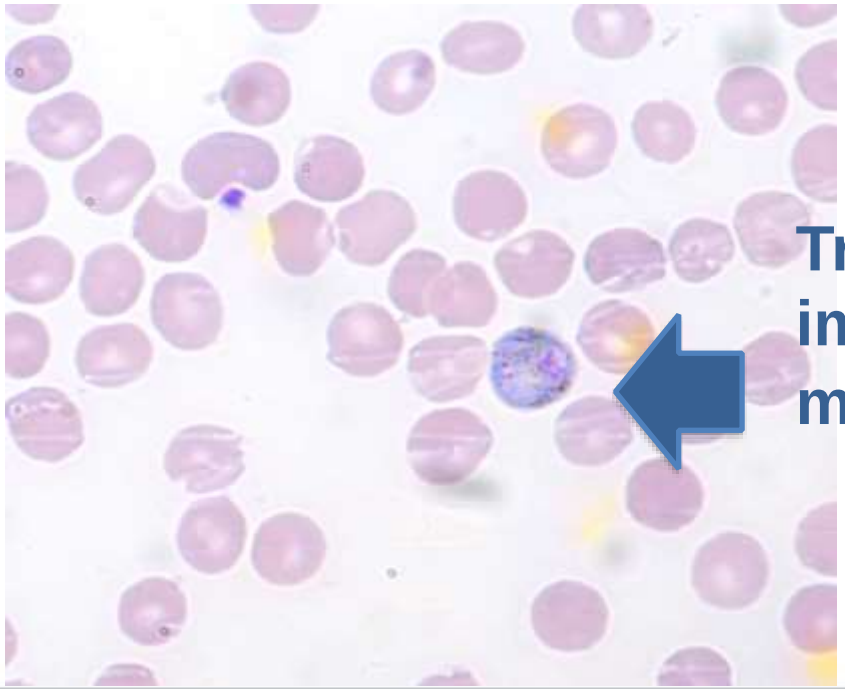
something is wrong

- Visit in Afghanistan 07.06. – 24.08.2024
- Leucopenia 2.8; Anemia Hb <10; Thrombocytopenia 30

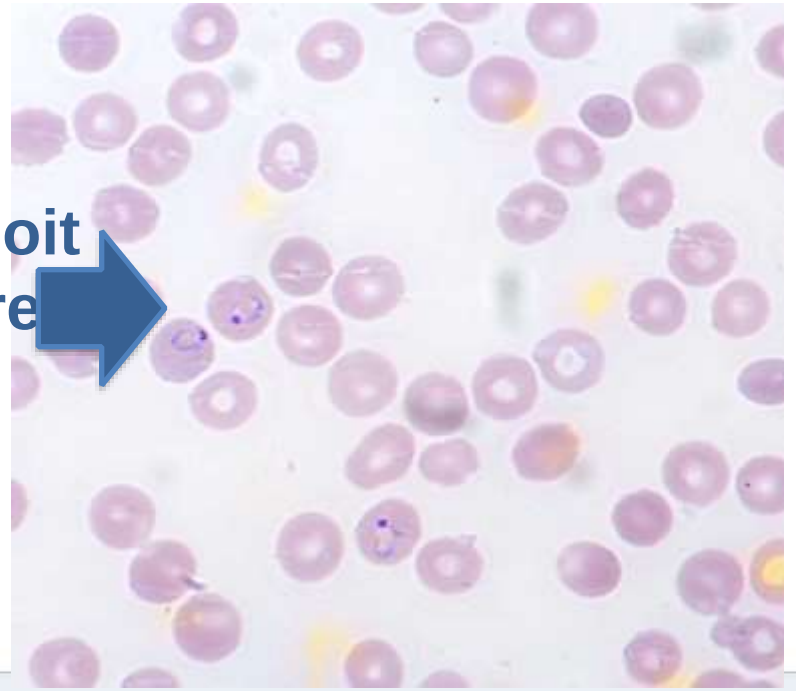


Gametozyt





Trophozoit
immature
mature



J.S. 18.07.2020

03.09.24

Case #3

it´s **Malaria**

J.S. 18.07.2020

03.09.24

https://wwwnc.cdc.gov/travel/yellowbook/2024/infections-diseases/malaria

Sepsis – Fluids

Crystalloid vs. Colloids?

Severe infectious diseases: malaria or dengue hemorrhagic shock

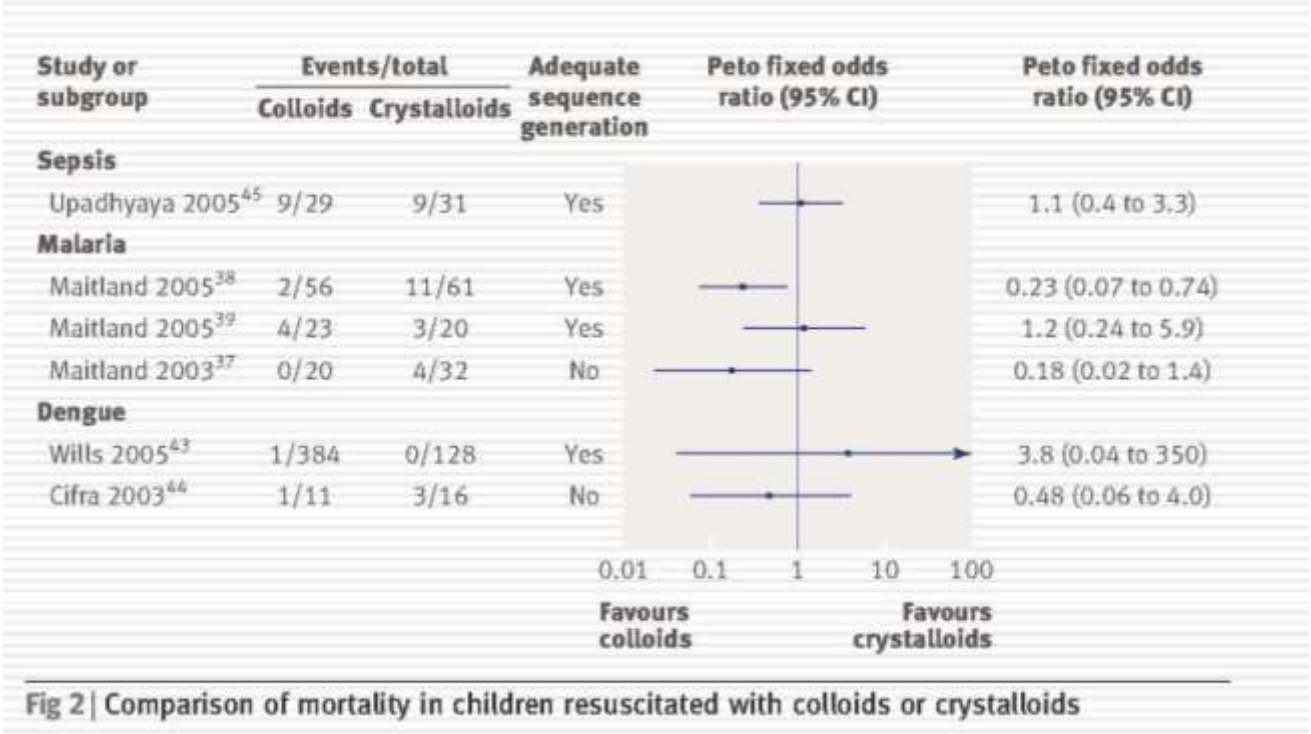


Fig 2 | Comparison of mortality in children resuscitated with colloids or crystalloids

The NEW ENGLAND JOURNAL of MEDICINE
ESTABLISHED IN 1812 JUNE 30, 2011 VOL. 364 NO. 26

Mortality after Fluid Bolus in African Children with Severe Infection

Kathryn Maitland, M.B., B.S., Ph.D., Sarah Kiguli, M.B., Ch.B., M.Med., Robert O. Opoka, M.B., Ch.B., M.Med., Charles Engoru, M.B., Ch.B., M.Med., Peter Olupot-Olupot, M.B., Ch.B., Samuel O. Akech, M.B., Ch.B., Richard Nyeko, M.B., Ch.B., M.Med., George Mtove, M.D., Hugh Reyburn, M.B., B.S., Trudie Lang, Ph.D., Bernadette Brent, M.B., B.S., Jennifer A. Evans, M.B., B.S., James K. Tibenderana, M.B., Ch.B., Ph.D., Jane Crawley, M.B., B.S., M.D., Elizabeth C. Russell, M.Sc., Michael Levin, F.Med.Sci., Ph.D., Abdel G. Babiker, Ph.D., and Diana M. Gibb, M.B., Ch.B., M.D., for the FEAST Trial Group*

Severe Infection

Crystalloid or Colloids vs. no bolus?

Fluid Expansion as Supportive Therapy (FEAST) Trial

n>3141, <12 yrs

Severe febrile illness with

- Impaired consciousness
- Respiratory distress
- Impaired perfusion

  recap. >3sec; temperature gradient; weak radial puls

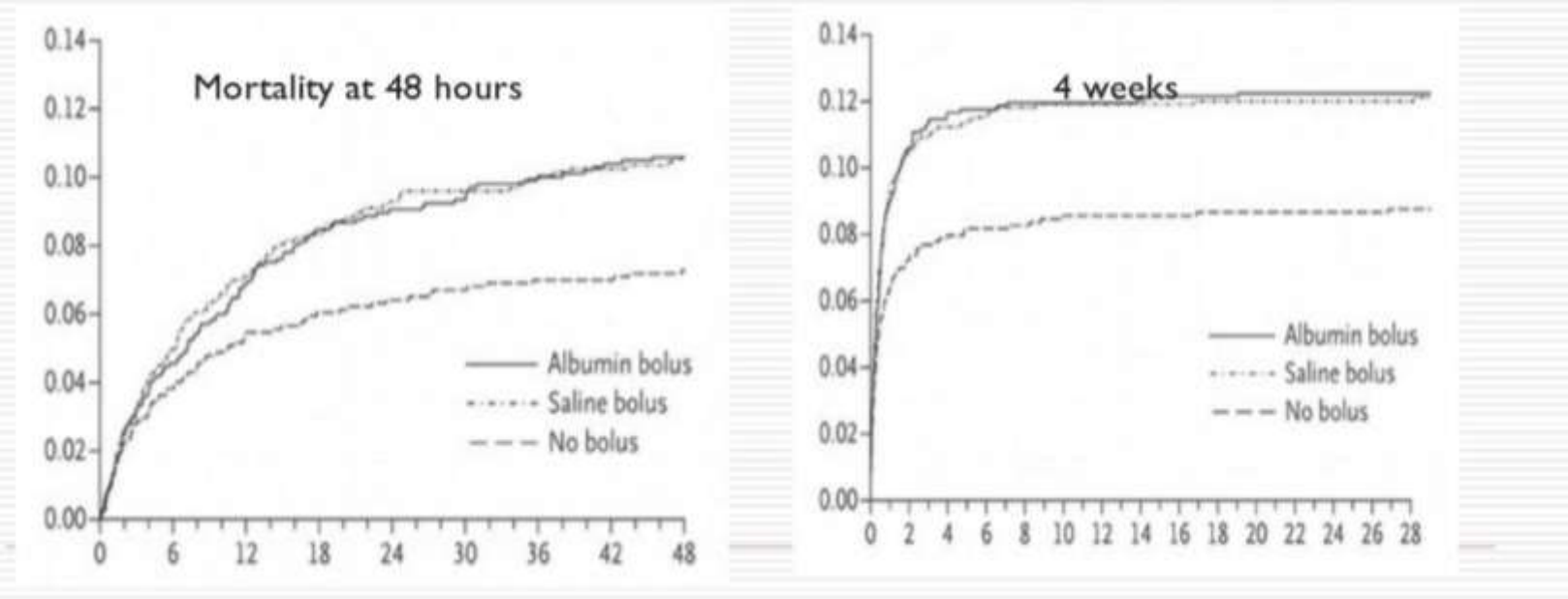
  severe tachycardia

The NEW ENGLAND JOURNAL of MEDICINE
ESTABLISHED IN 1812 JUNE 30, 2011 VOL. 364 NO. 26

Mortality after Fluid Bolus in African Children with Severe Infection

Severe Infection

Crystalloid vs. Colloids vs. no bolus?



ADC

Treating the wrong children with fluids will cause harm: response to 'mortality after fluid bolus in African children with severe infection'

D P Southall and M P Samuels

Arch Dis Child 2011 96: 905-906 originally published online June 28,

Severe Infection

Crystalloid vs. Colloids vs. No bolus?

FEAST Trial

n>3000, <12 yrs: severe febrile illness, depressed mental status a/o respiratory distress and impaired perfusion

57% malaria, 32% Hb <5 g/l, 37% convulsions

ADC

Treating the wrong children with fluids will cause harm: response to 'mortality after fluid bolus in African children with severe infection'

D P Southall and M P Samuels

Arch Dis Child 2011 96: 905-906 originally published online June 28, 2011

Severe Infection

Crystalloid vs. Colloids vs. No bolus?

FEAST Trial

n>3000, <12 yrs: severe febrile illnes[illegible]d mental status a/o respiratory distres[illegible]red perfusion

57% malari[illegible]<5 g/l, 37% convulsions

treating the wrong children with fluids will cause harm

Sodium - Differential

	SIADH	CSWS	DI
Serum Sodium (mmol/L)	<130	<130	>150
Serum Osmo (mOsm/kg)	<275	<275	>305
Urin Sodium (mmol/L)	>60	>120	<40
Urin Osmo (mOsm/kg)	>300	>500	<250
Urine Output (mL/kg/h)	<1	>1	>3
Volume status	Euvolemic	Hypovolemic	Hypovolemic

SIADH...Syndrome of Inappropiate Antidiuretic Hormone
CSWS...Cerebral Salt Wasting Syndrome
DI...Diabetes Insipidus

Available online at ScienceDirect
Resuscitation
EUROPEAN RESUSCITATION COUNCIL

Clinical paper

Calcium use during paediatric in-hospital cardiac arrest is associated with worse outcomes

Katherine Cashen [a], Robert M. Sutton [b], Ron W. Reeder [c], Tageldin Ahmed [d],

RESUSCITATION 185 (2023) 109673

Calcium

Should it be given empirically?

Estimated Effect of Calcium Use on Outcomes

Outcome	Adjusted odds ratio (95% CI)	Adjusted effect (95% CI)	P-value
Return of spontaneous circulation[1]	0.87 (0.61, 1.24)		0.445
Survival to hospital discharge	0.68 (0.52, 0.89)		0.005
Survival to hospital discharge with favourable neurologic outcome[2,3]	0.75 (0.57, 0.98)		0.038
Survival to hospital discharge with PCPC of 1, 2, or no worse than baseline[2]	0.77 (0.59, 1.01)		0.060
Change from baseline to hospital discharge in functional status (FSS) of survivors[2]		0.02 (−0.57, 0.61)	0.942
New morbidity (survivors only)[4]	0.95 (0.63, 1.42)		0.792

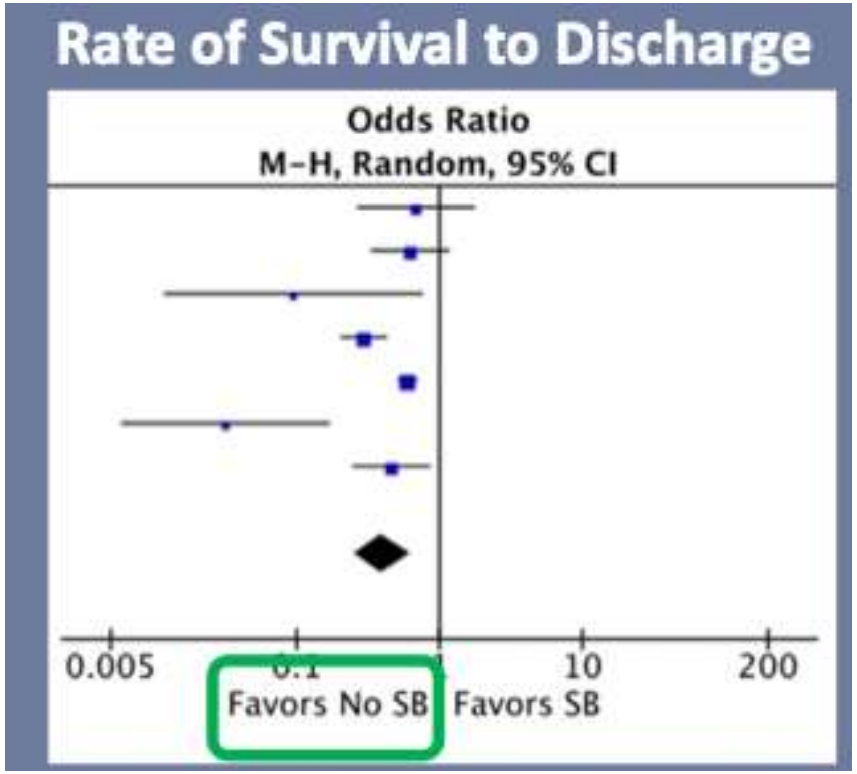
Review > Resuscitation. 2021 May:162:188-197. doi: 10.1016/j.resuscitation.2021.02.035. Epub 2021 Mar 1.

Sodium bicarbonate administration during in-hospital pediatric cardiac arrest: A systematic review and meta-analysis

Chih-Yao Chang [1], Po-Han Wu [1], Cheng-Ting Hsiao [2], Chia-Peng Chang [1], Yi-Chuan Chen [3], Kai-Hsiang Wu [4]

Sodium Bicarbonate

Should it be given empirically?



This meta-analysis ... supported current PLS guideline...

routine administration of SB is not recommended in pediatric cardiac arrest

Chang C. *Resuscitation.* 2021

Sodium Bicarbonate—The Swings and Roundabouts Will Not Stop Without Randomized Evidence*
Burkhard Simma, MD Haresh Kirpalani, MD, MSc
September 2013 • Volume 41 • Number 9
Critical Care Medicine

Paradoxe intrazelluläre Azidose

Natrium Bikarbonat

$HCO_3^- + H^+ = H_2O + CO_2$ → $CO_2 + H_2O = HCO_3^- + H^+$

Blut Hirn

Phosphate – Oxygen Bindung Curve

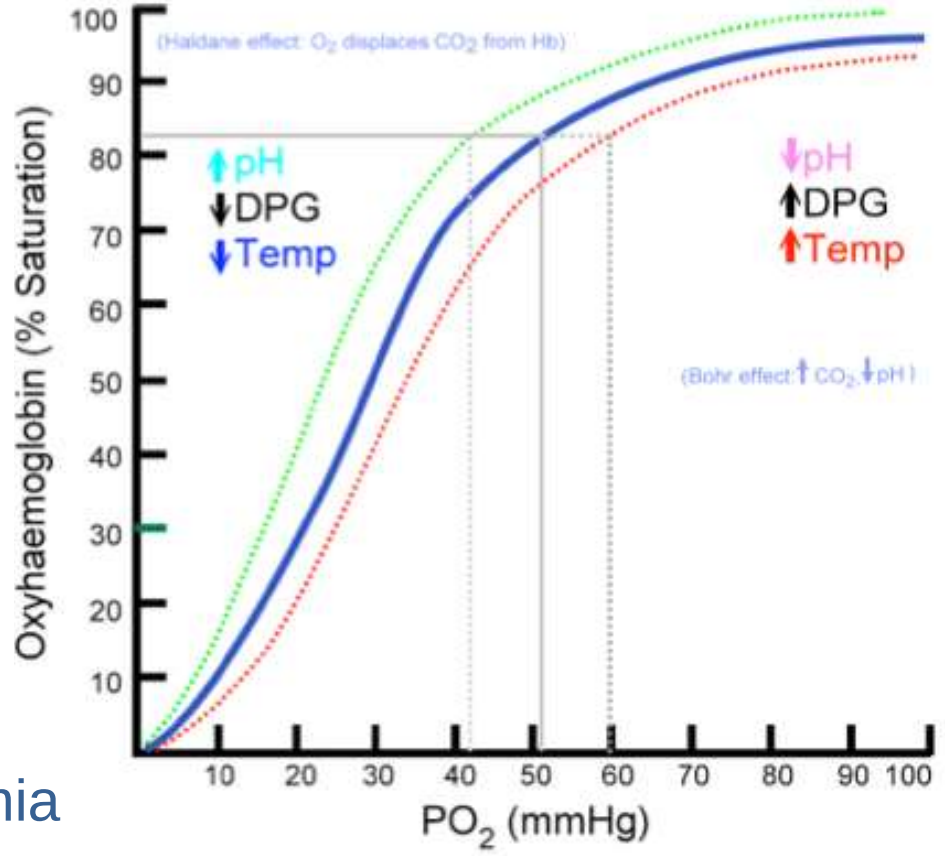
2,3 biphospho-gylcerat (DPG)

DPG increase:

O_2 binding curve shifts to the right

O_2 is bound **less** tightly to hemoglobin

facilitates the delivery of oxygen in target tissues



consider KCL plus KPhos to reduce hyperchloremia

Fluid: a „new drug“ in the PICU?

Association ≠ causal relation

Can cause harm by
- wrong composition
- wrong volume

No clear amount and content for maintenance fluid
- Holliday Segar formula overestimates fluid requirement in infants
- consider at 1⁄2-2/3 of the standard maintenance rate

More fluid – higher morbidity/mortality or patients with more severe diseases?

No ideal way of monitoring

So, every i.v. fluid we use is abnormal?

Arikan AA. PPCM 2015