MMed and DCH Lectures

Fluid and electrolyte management in paediatrics

April 5th, 2021

Prof Trevor Duke

Content

- Fluid and electrolyte physiology
  - Water compartments in the body
  - Anti-diuretic hormone (ADH)
  - Renin-Angiotensin system
- Rehydration – maintenance, deficit, ongoing losses
  - Calculating fluid replacement in dehydration
- Hyponatraemia
- Hypernatraemia
- Fluid boluses and shock
- Hypernatremia

Fluid physiology

- 2 main compartments of water in the body:
  1. Intracellular (ICF)
  2. Extracellular (ECF)
     - Intravascular (blood volume)
     - Interstitial (between cells)
- In an adult:
  - Total body water (TBW) is 2/3 of weight
    - ICF is 2/3 of TBW
    - ECF is 1/3 of TBW
      - Intravascular volume is 1/3 of ECF

Physiology

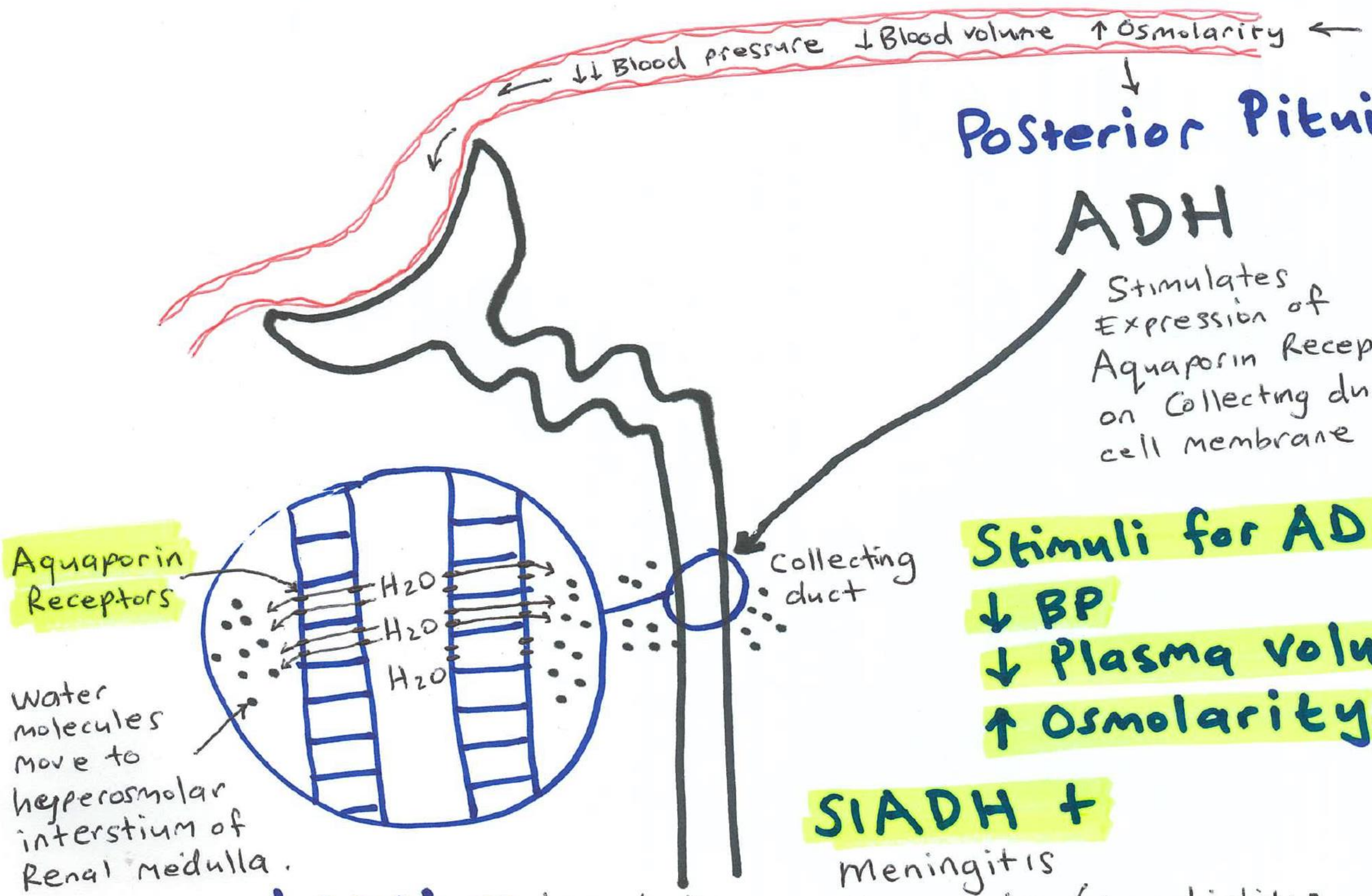
Fluid	TBW (ml/kg)	ICF (ml/kg)	ECF (ml/kg)	Blood volume (ml/kg)
Adult	600	400	200	70
Neonate	800	400	400	85

- Adult blood volume is 70ml/kg. In a 70 kg adult is 5L (this is the cardiac output/min and circulating volume)
- **Neonates have higher ECF: interstitial fluid, and blood volume**
- Infants and children somewhere in the middle

Posterior Pituitary

ADH

Stimulates Expression of Aquaporin Receptors on Collecting duct cell membrane



Stimuli for ADH +

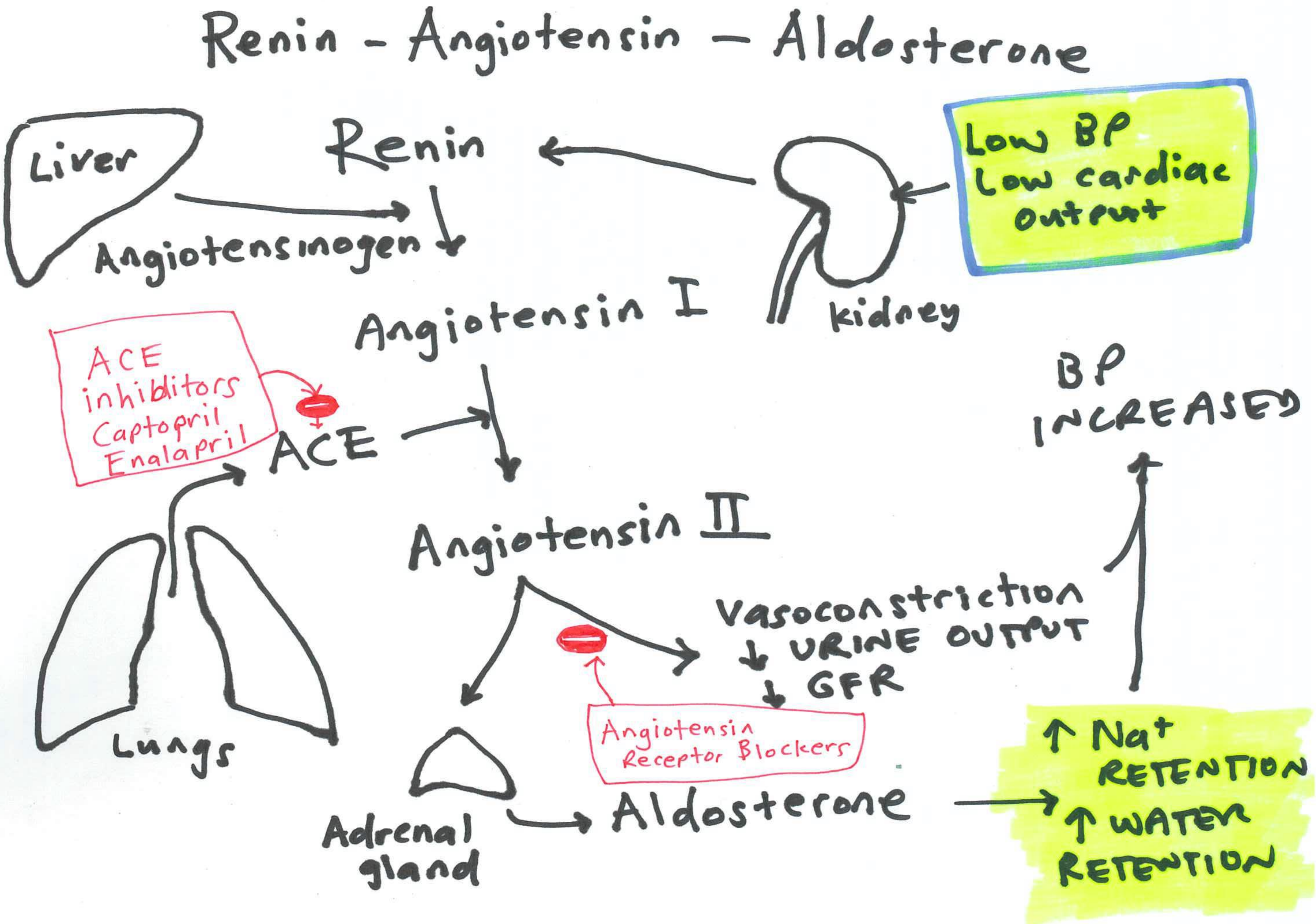
- **↓ BP**
- **↓ Plasma volume**
- **↑ Osmolarity**

SIADH +

- Meningitis
- Pneumonia / bronchiolitis
- Sepsis
- Anaesthetic drugs / Surgery

↓ADH – ↓osmolarity

- Hypertension / Fluid overload
- Diabetes insipidis
  - Central
  - Nephrogenic



Renin - Angiotensin - Aldosterone
Liver
Renin
Angiotensinogen
Low BP
Low cardiac output
kidney
Angiotensin I
ACE inhibitors
Captopril
Enalapril
ACE
BP INCREASED
Angiotensin II
Lungs
Vasoconstriction
↓ URINE OUTPUT
↓ GFR
Angiotensin Receptor Blockers
Adrenal gland
Aldosterone
↑ Na+ RETENTION
↑ WATER RETENTION

Water, electrolyte and energy requirements

Body weight	Water (ml/kg/d)	Water (ml/kg/h)	Sodium (mmol/kg/d)	Potassium (mmol/kg/d)	Glucose	Energy * (kcal/kg/d)
0-10 kg	100	4	2-4	1.5-2.5	30	100
10-20 kg	1000+50	40+2	1-2	0.5-1.5	15	1000+50
+20 kg	1500+20	60+1	0.5-1	0.2-0.7	6	1500+20

* Kcal = 4.18 kj

Maintenance fluid volume: 4, 2, 1

- A 17 kg girl will need
  - 100 ml x 10 = 1000
  - 50 x 7 = 350 ml
  - Total of 1350 in 24 hours
  - =56ml/hour
- A 35 kg boy will need
  - 100 ml x 10 = 1000 ml
  - 50 ml x 10 = 500 ml
  - 20 ml x 15 =300 ml
  - Total of 1800 ml in 24 hours
  - = 75ml/hour

* The fluid volume required under ***normal*** conditions so that:

The kidneys excrete excess solute load (urea, creatinine, electrolytes…)

Replace insensible losses

The urine is isotonic

Rehydration

- Maintenance
  - 4 / 2 / 1
- Deficit
  - % body water loss
  - Based on clinical signs of dehydration
- Ongoing losses
  - 50ml per diarrhoeal stool <2 years
  - 100ml per diarrhoeal stool >2 years
- Correct shock
- Replace deficit over 12 hours

14 month old ♂

3 days vomiting + diarrhoea

lethargic, sunken eyes, poor skin turgor, cold limbs.

Weight 9.2 kg

10% dehydrated ⇒ 900ml **deficit**

Replace over 12 hours ⇒ 900/12 = 75 ml/h

Maintenance 9.2 × 100 = 920ml

Replace over 24h ⇒ 920/24 = 38ml/h

Ongoing losses: 4 diarrhoeal stools in 12 hours ⇒ 4 × 50ml = 200ml / 12 = 17ml/h

Total over first 12h

75 + 38 + 17 = 130 ml/h for 12h.

Enteral fluid

- Safer than IV
- ORS effective rehydration in gastroenteritis
- Avoids nosocomial sepsis from IV drips and electrolyte disturbance
- Provides nutrition
- Benefits to the gut
  - Maintains peristalsis and mucosal integrity
  - Reduces sepsis (bacterial translocation)
  - Gastric protection
  - Reduces constipation

Hyponatraemia

Condition	Study	No	Na+ <135	Na+ <130
Septicaemia	Jensen AG, Denmark	85	45%	-
Bronchiolitis	Steensel-Moll H, Holland	48	21%	-
Pneumonia	Shann F, PNG	73	45%	20%
Meningitis	Duke T, PNG	321	46%	19%

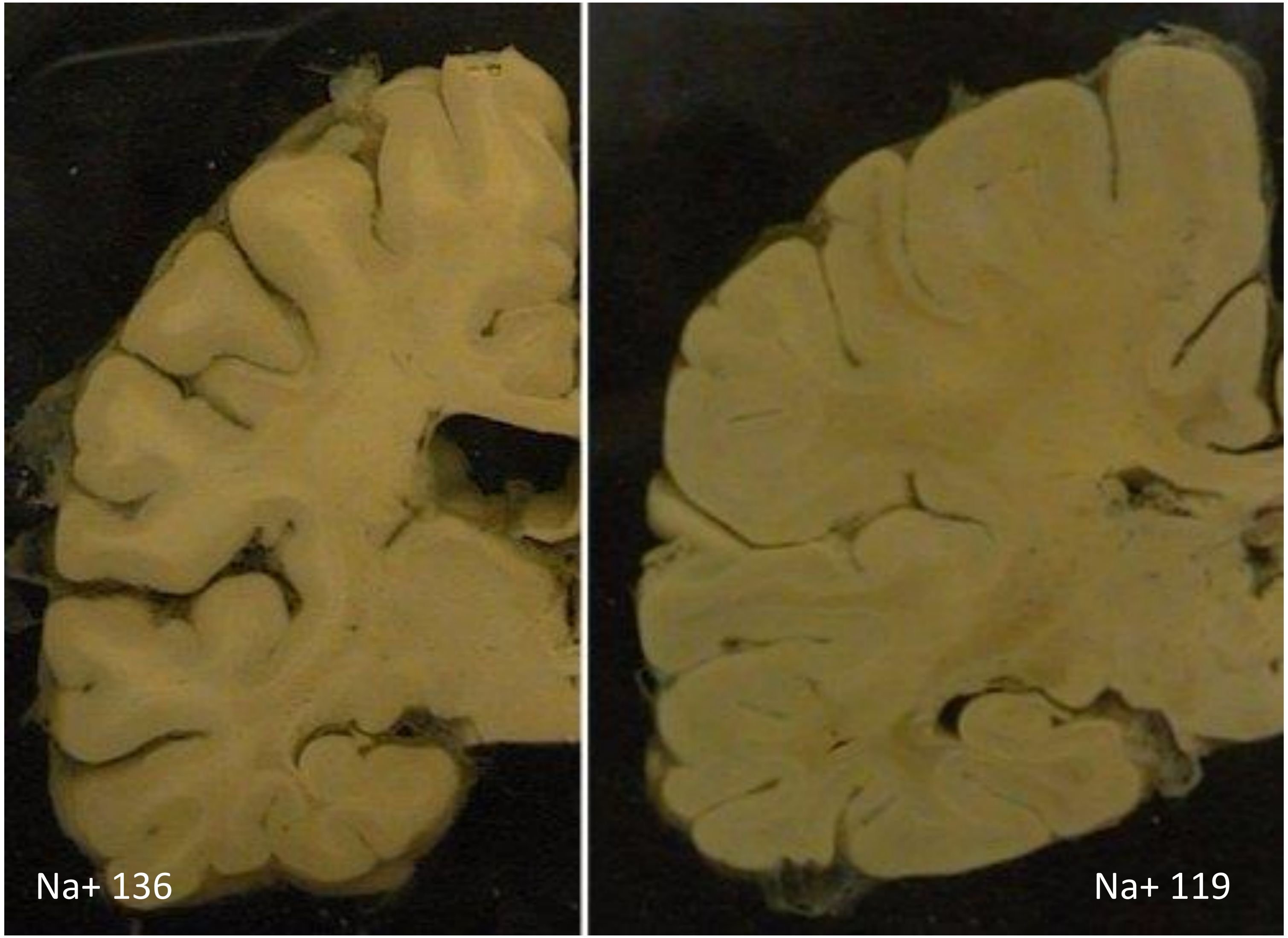
Hyponatraemia and neurological outcomes

Study	Disease state and no	Reduction in serum $[Na^+]$ or level at time of complication	IV fluid type and volume	Adverse event
Cooke RE	2-year-old girl with tuberculosis	130 → 120	Not stated	Coma, seizures
McJunkin JE	127 children with encephalitis.	All children with neurological deterioration had a fall in serum Na+ (mean 138 to 134)	'Hypotonic' fluid	Neurological deterioration included cerebral herniation, status epilepticus
Mor J	Infant with pneumonia	107 after fluid	0.18% saline at 150ml/kg/day for 2 days	Seizures and cerebral oedema
Potts FL	17-month-old with minor burns	133 → 113	0.2% saline at 250ml/kg/day	Seizures
Jackson J	2 children: one with viral respiratory tract infection, one with meningitis.	121 and 128 after fluid administration	5% dextrose at 35-40ml per kg	Seizures, cerebral oedema and death
Playfor S	Child with diarrhoea and vomiting	137 → 120	0.18% NaCl	Seizures, cerebral oedema and death

Effect of hyponatraemia

- Hypo-osmolarity, cerebral oedema, seizures, brain herniation

Na+ 127 mmol/L


Na+ 136
Na+ 119

- The Northern Ireland Inquiry into Hyponatraemia-related Deaths (Nov 2008-2016)
- UK National Patient Safety Alert – removal of 0.18% NaCl
- Australia / Canada banned use of 0.18% NaCl on wards
- WHO recommended against hypotonic solutions

Seriously ill children have impaired free-water excretion: “SIADH”

- SIADH
  - Hyponatraemia (<130 mmol/L)
  - Normal hydration / overhydrated
  - Concentrated urine
    - Would normally expect a dilute urine if the child has an adequate TBW but has hyponatraemia, but because ADH being produced “inappropriately” (to the serum Na+), the urine remains concentrated (because H_2O is absorbed from the collecting ducts).
- Aetiology
  - Meningitis, pneumonia, post-operative
- **Main implication – do not give too much IV fluid, and do not give hypotonic fluid**

Fluid requirements of severely ill children

Increased fluid requirement

- High metabolic rate: fever, sepsis
- External losses: vomiting, tachypnoea
- Internal losses: capillary leak and vasodilatation

Decreased fluid requirement

- **High ADH**
  - Meningitis
  - Pneumonia
  - Sepsis
- Low metabolic rate: inactivity, hypothermia
- Reduced urine output: impaired renal perfusion

Intravenous fluid composition

Fluid	Na	K	Cl	Glucose	Ca++	Lactate *
0.18% NaCl + 4.3% dex	31	0	31	40	0	0
½ Strength Darrow's	61	16	52	50	0	27
Hartmann's solution	130	5.4	112	50	1.8	27
0.9% (Normal) saline	154	0	154	0	0	0
Plasma	135-145	3.5– 5.0	95-110	70-130	1.15-1.30	<2

* Lactate is metabolised by the liver to bicarbonate

Alexis Frank Hartmann (1898 -1964)
Clinical pediatrician and biochemist
St Louis, Missouri, USA

1932: Added sodium lactate to Ringer's solution

STUDIES IN THE METABOLISM OF SODIUM *r*-LACTATE. I. RESPONSE OF NORMAL HUMAN SUBJECTS TO THE INTRAVENOUS INJECTION OF SODIUM *r*-LACTATE

By ALEXIS F. HARTMANN and MILTON J. E. SENN

(From the Department of Pediatrics, Washington University School of Medicine, and the St. Louis Children's Hospital, St. Louis)

(Received for publication September 10, 1931)

In recently published studies, Hartmann and Darrow (1, 2, 3) emphasized the fact that if sodium bicarbonate were properly administered along with other indicated therapeutic measures, severe acidosis could be much more effectively treated. There were recognized, however, a number of objections to the administration of sodium bicarbonate. The most serious was that, if given intravenously in amounts large enough to insure effectiveness, it tended to produce too rapid a change in the reaction of the body fluids, and often resulted in an almost immediate shift from uncompensated acidosis to uncompensated alkalosis, even though the sodium bicarbonate content of the body fluids was not made abnormally high; i.e., the ratio $\frac{BHCO_3}{H_2CO_3}$ increased because the numerator was added to more rapidly than the denominator could be increased by the production of carbon dioxide in the tissues and its accumulation in the body fluids through reduced pulmonary ventilation. This danger was usually avoided by giving the alkali in fractional dosages and checking the effect by chemical examination of the blood. The latter constituted another objection, particularly in the case of the young infant. Other disadvantages lay in the fact that if sodium bicarbonate were to be injected subcutaneously or intraperitoneally, it had first to be sterilized by Berkefeld filtration, and then rendered less irritatingly alkaline by bubbling carbon dioxide through it.[1] Unless sealed, such a mixture would of course become too alkaline again as a result of loss of carbon dioxide. Another disadvantage lay also in the fact that the injection of sodium bicarbonate alone tended, at least theoretically, to disturb the ionic balance between sodium, potassium, calcium and magnesium.

In order to overcome those objections the mixture of sodium lactate and hypotonic Ringer's solution was devised (5). The conversion of

[1] Cunningham and Darrow (4) have recently overcome this objection by partly neutralizing sodium bicarbonate previously sterilized in the dry state with hydrochloric acid.

Brain injury from IV fluids: not just hypotonic fluids

- Too much IV fluid
- Not taking account of *other* fluids
- Factors we don't understand
- In a susceptible host, e.g. blood-brain barrier permeability

What volume of maintenance fluid?

- Often the 4/2/1 rule will result in over-hydration
- 25% of children with meningitis will develop facial oedema if given 100% maintenance and will do badly. (Annals of Tropical Paediatrics 2002;22:145–157)
- Avoid over-hydration: teach 4-2-1 rule, but start with 2/3 or ½
- **Know the TFI**
  - IV, nasogastric, oral
  - Drug flushes and diluents: may add 50% to TFI

How to make dextrose solution

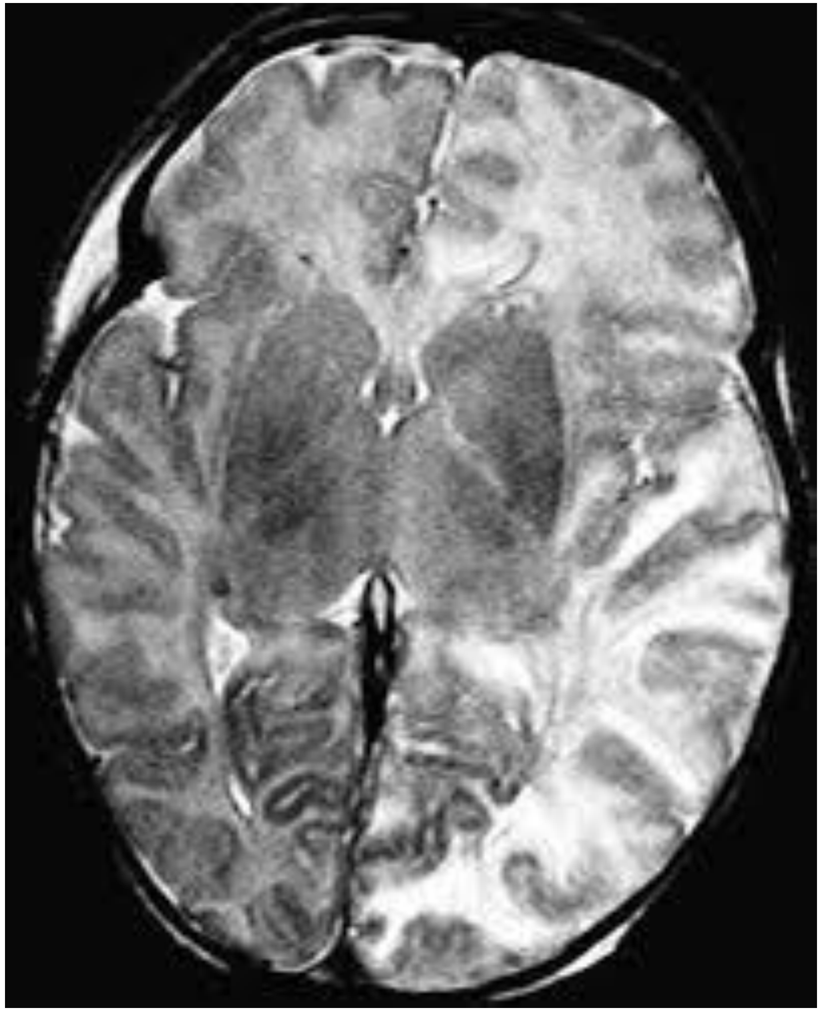
- To make IV fluid with added 5% dextrose
  - Dilute at a ratio of 1:9
  - Example:
    - Add 100ml 50% dextrose to 900 ml Hartmann’s solution
    - To make a 5% solution: add 50-gram dextrose to 1000 ml fluid, therefore you need to add 100ml of 50% dextrose

Hypernatraemia

- Losing more water than salt
  - Dehydration from gastroenteritis, “osmotic diarrhoea”
  - Diabetes insipidus
  - Osmotic diuresis
  - Polyuric phase of acute kidney injury
  - Skin loss - severe burns
- Ingesting more salt than water
  - Salt poisoning

Hypernatraemic dehydration signs

- Lethargy
- Irritability
- Skin feels "doughy"
- Ataxia, tremor
- Hyperreflexia, seizures, reduced GCS



Hypernatraemic dehydration (Na^+ >150)

- Rehydrate slowly – over 48-72 hours
- Na^+ should fall no faster than 0.5mmol/L per hour, i.e. 12mmol/24 hours

Monitoring of children on IV fluids

- **Check for oedema every day**: check for puffy eyes and lower limb swelling. If present, stop or slow the IV fluids.
- **Check for signs of dehydration every day**: poor capillary refill, cold limbs, sunken eyes, poor skin turgor, tachycardia, hypotension, low pulse pressure. If present, correct the deficit and look for the cause.
- **Weigh the child on IV fluids every day.** ↑↑ weight of 5% over 24 hours = fluid overload. Stop the IV, check serum sodium.
- **Check serum electrolytes daily.** Sodium <130 mmol/L (or ↓5mmol), or >150 mmol/L (or ↑5mmol/L), reassess.

Fluid boluses

The NEW ENGLAND JOURNAL of MEDICINE

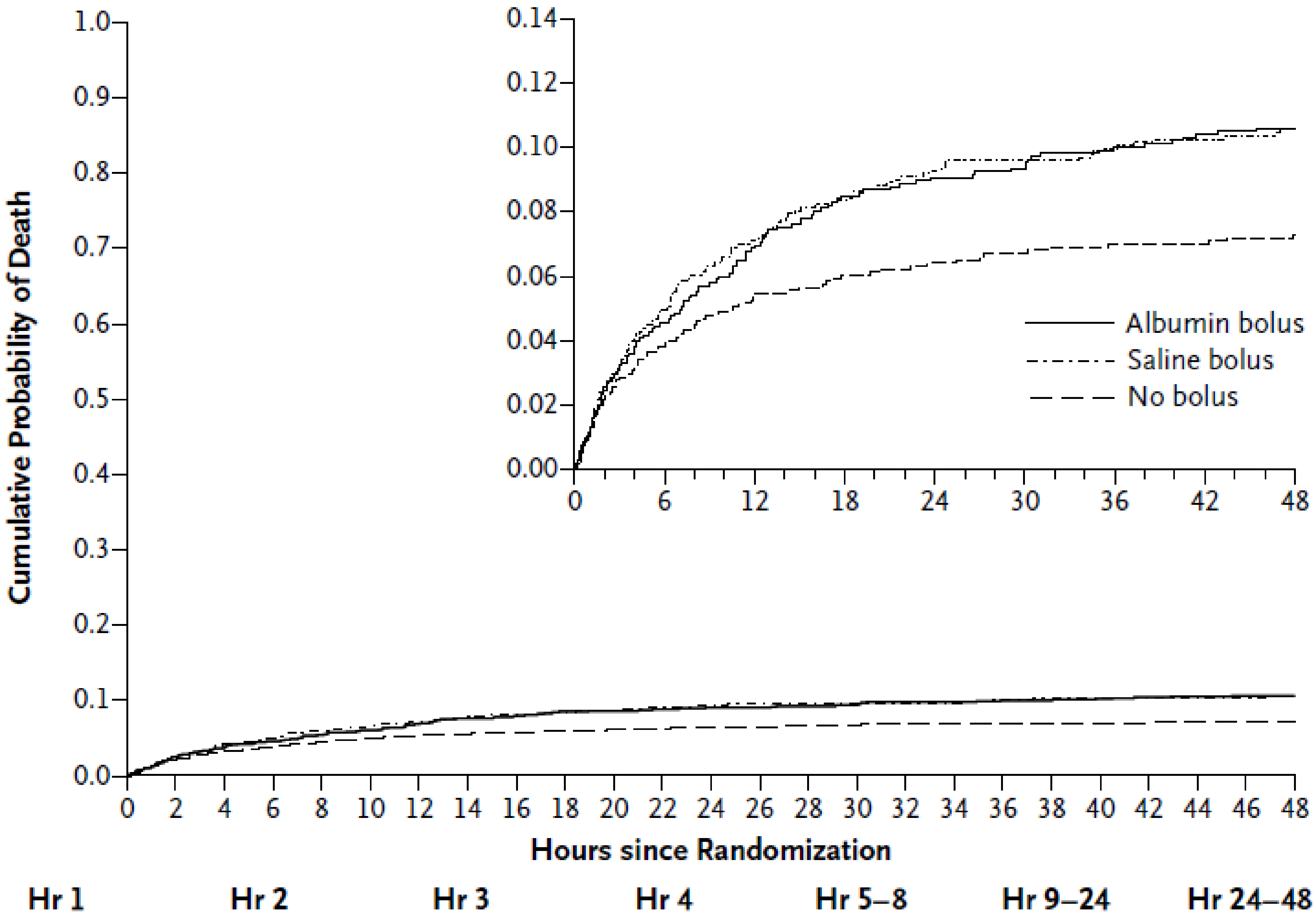
ORIGINAL ARTICLE

Mortality after Fluid Bolus in African Children with Severe Infection

- Fluid Expansion as Supportive Therapy (FEAST)
- Randomised trial in 3141 children in Uganda, Kenya, and Tanzania
- Fever or history of fever with impaired consciousness or respiratory distress and *any one or more* of
  - Capillary refill equal to or longer than 3s
  - Tachycardia
  - Weak radial pulse volume
  - Lower limb-temperature gradient (cold extremities)

FEAST Trial Results

- 48-hour mortality:
  - Albumin bolus: 10.6% (111 of 1050 children)
  - Saline bolus: 10.5% (110 of 1047 children)
  - No bolus: 7.3% (76 of 1044 children)
- Relative risk for any bolus vs. control, 1.45; 95% CI, 1.13 to 1.86; P = 0.003)
- 4-week mortality: 12.2%, 12.0%, and 8.7% in the three groups (P = 0.004 for bolus vs control)


Cumulative Probability of Death
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48
Hours since Randomization
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0 6 12 18 24 30 36 42 48
Albumin bolus
Saline bolus
No bolus
Hr 1
Hr 2
Hr 3
Hr 4
Hr 5–8
Hr 9–24
Hr 24–48

Summary – fluid management in shock

- Excessive IV fluid boluses are dangerous in children with common febrile illnesses (when shock or hypovolaemia not present)
- Cautious about fluid boluses
- Smaller boluses more appropriate: 10ml/kg…then reassess
- Any child requiring more than 40ml/kg must have an ICU review, as they need a *differentiated* response based on pathophysiology
  - Inotrope, vasoconstrictor, echo, more fluid, less fluid, diuretic, positive pressure respiratory support, calcium, adrenaline, packed cells…

After bacterial sepsis…what other causes of shock?

- Infections
  - Toxic shock syndrome (Staph. Strep)
  - Viral sepsis – influenza, enterovirus, COIVID-19, dengue
  - Malaria
- Cardiac – arrhythmias, myocarditis
- Anaphylaxis
- Poisoning
  - Cardio-toxic drugs: chloroquine, beta-blockers, colchicine, anti-arrhythmic drugs
- Kawasaki disease
- Metabolic – DKA, hyperammonaemia, inborn errors of metabolism
- Snake-bite

Summary

- Calculating fluids in dehydration:
  - Maintenance / deficit / ongoing losses
- Use isotonic fluid to minimise the risk of hyponatraemia
- Avoid over-hydration: teach 4-2-1 rule, but start with 2/3
- Know the TFI of patients on IV fluids
- Do not give IV fluid boluses to children with common febrile illnesses if shock or hypovolaemia not present
- Smaller boluses: 10ml/kg…then reassess
- Any child who still has signs of shock after 40ml/kg should have an ICU review
- Ask every day:
  - Does this patient still need this IV today?
  - Are we giving enough nutrition?