Fluids, Electrolytes, and Dehydration

3

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3.1 Normal Fluid Physiology

Although most of us are made up predominantly of water, there is considerable variation based on several factors such as gestation, age, sex, weight, underlying pathology, and most importantly, fluid and electrolyte support in a child who is nil by mouth.

The following diagram depicts the distribution of fluid and various compartments in a healthy human body (Fig. 3.1).

Intravascular fluid is maintained by the oncotic pressure exerted by albumin and the permeability of the capillary bed under the influence of Starling's law.[1]

Multiple organ systems are involved in producing blood and regulating blood volume. These systems communicate with one another to control blood volume, which also depends on age, size, and weight of the individual.

3.2 Age-Related Changes

- ↑ Total body water (80% in neonate vs. 60% in adult)
- ↑ ECF → ICF (almost parity in newborn vs. 3:1 in adult)
- ↑ Surface area/body mass ratio

[1] Ernest Starling (1866–1927) English physiologist

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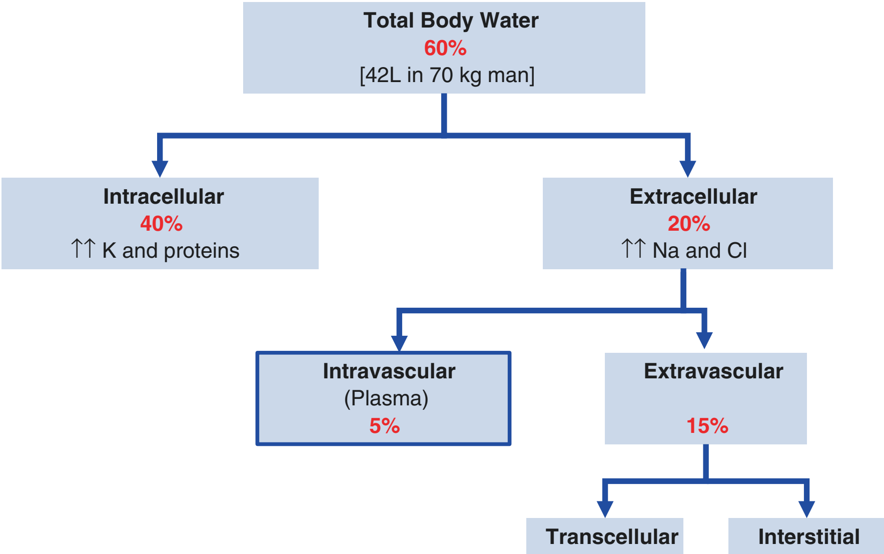

Fig. 3.1 Body composition

3.3 Normal Fluid and Electrolyte Requirements

In general, normal neonatal fluid prescription depends on (a) body weight and (b) day of life (Tables 3.1 and 3.2).

> ***Basic prescription is:***
> ***100 mL/kg/day (up to 10 kg).***
> ***(Beyond neonatal period.)***

Table 3.1 Estimated fluid requirements in childhood

	Day of life	mL/kg/day
Premature infant	1st	60–150
	2nd	70–150
	3rd	90–180
	>3rd	Up to 200

Table 3.1 (continued)

	Day of life	mL/kg/day
Term infant	1st	60–80
	2nd	80–100
	3rd	100–140
	>3rd	Up to 160
Child >4 weeks of age, ≤10 kg		100
Child 10–20 kg		1 L + 50 mL/kg/day for each kg over 10
Child >20 kg		1.5 L + 20 mL/kg/day for each kg over 20

Table 3.2 Sample fluid requirements (by body weight)

Body weight	Calories required (kcal/day)	Maintenance (mL/day)	Maintenance (mL/h)
3	300	300	12
5	500	500	20
10	1000	1000	40
20	1500	1500	60
45	2000	2000	80
70	2500	2500	100

3.4 Insensible Fluid Loss

This is an obligate fluid loss, largely from radiation and evaporation related to body surface area and the work of breathing. Careful consideration is needed to minimize and replace this loss in neonates, especially with those born with anterior abdominal wall defects.

$$\sim 300\,\text{mL}/\text{m}^2/\text{day}$$

$$\text{Body surface area}\left(\text{m}^2\right) = \text{weight}\left(\text{kg}\right) \times \text{height}\left(\text{cm}\right)$$

3.5 Postoperative Fluid Regimens

A meta-analysis (published in 2014) concluded that isotonic fluids are safer than hypotonic fluids in hospitalized children requiring maintenance IV fluid therapy.

The use of the isotonic saline seldom leads to hypernatremia (although it gives far more than the normal daily requirement of Na Cl (Table 3.3).

Further, because of the metabolic response to surgery (see Chap. 4), there is “inappropriate” secretion of ADH, and many units will prescribe **only two-thirds of the calculated maintenance volume in the first 24–48 h postoperatively**. However, it is contentious, and some units will prescribe full maintenance as long as the kidney function is normal.

Table 3.3 Sample electrolyte requirements (by body weight)

	Na (mmol/kg)	K (mmol/kg)
Neonate (preterm)	4–6	2–3
Neonate (term) – 10 kg	3	2
10–20 kg	1–2	1–2
20–Adult	1–2	1

Table 3.4 Electrolyte content of gastrointestinal secretions

Secretion	Na^+ (mmol/L)	K^+ (mmol/L)	Cl^- (mmol/L)	HCO_3^- (mmol/L)
Saliva	44	20	40	–
Gastric	20–120[a]	10	100	–
Bile	140	5	100	40
Pancreas	140	5	70	70–110
Small intestine	110–120	5–10	90–130	20–40

[a]Depends on pH and therefore reciprocal with H^+

Table 3.5 Composition of commonly available intravenous fluids

	Osmolarity (mOsm/L)	Glucose (mmol/L)	Na (mmol/L)	Cl	K	HCO_3	Notes
Intravenous solutions (crystalloid)							
Lactated Ringer’s	273	–	130	110	4	25	Lactate Ca^{2+}
Hartmann’s	278	–	131	111	5	29	Lactate, Ca^{2+}
0.9% NaCl “normal saline”	308	–	154	154	–	–	
Dextrose (5%)	252	300	–	–	–	–	5 g/L = 170 kcal/L
D5 + 0.45% NaCl	454	300	77	77	–	–	
D4 + 0.18% NaCl	284	240	30	30	–	–	Not available in UK
Intravenous solutions (Colloids)							
Haemaccel™	293	–	145	145	5	–	Gelatin (35 g)
Gelofusine™	308	–	154	125	<0.4	–	Gelatin (40 g)
Hetastarch™	310	–	154	154	–	–	Starch (60 g)
Pentastarch™	326	–	154	154	–	–	Starch (100 g)
Albumin (4.5%)	300	–	<160	136	<2	–	

N.B. CHO = 3.4 kcal/g, compared with fat 9 kcal/g

Finally, consider ongoing losses from drains, NG tubes, stomas, and fistulas (Table 3.4). In principle, replace ***Like with Like.*** In most cases, this is an mL for mL replacement with an isotonic (0.9%) saline solution (±20 mmol of K^+/L). The stoma losses are generally replaced above 20 mL/kg/day, accounting for the natural loss.

The composition of intravenous and oral rehydration fluids is illustrated in Tables 3.5 and 3.6.

Table 3.6 Oral rehydration solutions

	Osmolarity (mOsm/L)	Glucose (mmol/L)	Na (mmol/L)	Cl	K	HCO³	Notes
WHO–ORS	330	110	90	80	20	30	
Pedialyte™	270	140	45	35	20	30	
Dioralyte™		90	60	60	20		Common in UK
Electrolade™		111	50	40	20		

3.6 Dehydration

Dehydration
is a contraction in predominantly the ***ECF compartment*** *because of the relative loss of fluids and sodium.*
It is calculated in terms of % body weight loss

One key cause of dehydration is excess intestinal losses due to diarrheal illness, and it is a cause of death in >1.5 million children/year. It is important that a pediatric surgeon has a basic working knowledge of the diarrheal illness, as it is so common both in the community (and, therefore on the ward).

3.6.1 Infective Causes

- Viruses
  - Rotavirus
  - Calcivirus (incl Norovirus)
  - Astrovirus
  - Adenovirus
  - Coronavirus (COVID-19)
- Bacteria
  - *Campylobacter* spp.
  - *Salmonella* spp.
  - *E. coli*
  - *Clostridium difficle*
  - *Shigella* spp.
- Protozoa
  - *Giardia lamblia*
  - *Cryptosporidium*
  - *Entamoeba histolytica*

3.6.2 Surgical Causes

- Intestinal obstruction
- Appendicitis
- Intussusception
- Fistula losses (also stomas)

3.6.3 Management

In general, the treatment aims to restore normal fluid and electrolyte balance safely without precipitating complications (e.g., hypernatremic convulsions). The key is to recognize the degree of dehydration **(expressed in terms of % body weight loss—i.e., 5% of a 20-kg child implies a deficit of 1000 mL of fluid)** (Table 3.7) and then the type as defined by the plasma sodium level (Table 3.8).

Table 3.7 WHO classification of dehydration

	No dehydration	Mild/moderate	Severe
Adult	*<3%*	*3–9%*	*>9%*
Child	*5%*	*10%*	*15%*
Clinical features			
Mental status	Alert	Restless, listless	Lethargic, comatose
Thirst	Normal	Thirsty	Unable to drink
CVS	Normal pulse/BP	Tachycardia, CRT > 2 s	Tachy/brady, CRT >> 2 s
Respiratory	Normal	Rate	Inc rate and volume
Extremities	Normal	Cool	Cold, mottled
Mucous membranes	Moist	Dry	Dry
Skin fold	Immediate recoil	Delayed (>2 s)	>2 s
Urine output	Normal	Diminished	Absent
Management			
	Encourage normal diet and fluids	*ORS*	*IV initially*
		30–80 mL/h [Consider via NG tube if failing.]	e.g. 20 mL/kg NaCl (0.9%)

Note: CRT, capillary return time (in seconds); ORS, oral rehydration solution

Table 3.8 Types of dehydration

Isotonic	130–150 mmol/L
Hypotonic	<130 mmol/L
Hypertonic	>150 mmol/L

Aim for rehydration within 12–24 h, *unless* hypernatremia is documented (Na >150 mmol/L), where the period should be lengthened to ~36–48 h. In general, oral rehydration solutions (Table 3.6) should be used whenever possible (may be defined as the presence of a functioning GI tract). Intravenous resuscitation may well be required for more severe episodes of dehydration, particularly where there is a shock-like state and fall in CBV.

3.7 Specific Electrolyte Problems

3.7.1 Potassium

$$\text{Normal}\,3.5-5.5\,\text{mmol/L} \;-\uparrow \text{variability in neonates}$$

3.7.1.1 Hyperkalemia (<5.5 mmol/L)

NB-beware factitious result due to hemolysis, especially if it is taken from the heel prick.

- **Surgical causes**

  Dehydration, renal failure, post-transfusion, tumor lysis syndrome, rhabdomyolysis.
- **Signs**

  ECG: tall “tented” T waves, ↑ PR interval ↑QRS complex duration (Potassium naturally suppresses cardiac function and Calcium is a myocardial stimulant).
- **Treatment**
  – *Stopping Potassium in all fluids.*
  – Salbutamol (IV or inhaled).
  – Intravenous Dextrose with or without Insulin.
  – Calcium gluconate (100 mg/kg, IV if >7 mmol/L)—myocardial membrane stabilization.
  – Calcium resonium (oral or rectal)—cation exchange resin.

3.7.1.2 Hypokalemia

- Surgical causes

  Fistula, dehydration. Aldosterone-secreting tumors.
- Signs

  ECG: (less obvious changes) flat T waves, U waves, AV conduction defects.
- **Treatment**

  Slow ↑K + replacement (do not exceed KCl 0.51 mmol/kg/h IV, unless on ECG monitor)

3.7.2 Calcium

$$\text{Normal total } 2.0-2.5\,\text{mmol/L} \equiv 8.5-10.2\,\text{mg/dL}$$

$$\text{Normal ionized } 1.0-1.25\,\text{mmol/L} \equiv 4-5\,\text{mg/dL}$$

Most are stored and relatively fixed in the bone. Serum calcium is made up of different components (bound to albumin (~40%) and complexed with bicarbonate (<10%) and free ions (~50%)). Ionized calcium is the active part and is <1% of the total. Calcium balance is regulated by parathormone and acid/base balance.

3.7.2.1 Hypocalcemia (Always Check Magnesium Levels Additionally)

Usually neonates

- Surgical causes
  Chronic renal failure (e.g., PUV), post thyroidectomy, pancreatitis, malabsorption, Di George syndrome, and CHARGE syndrome.
- Signs—tetany, i.e., muscle irritability.
  - **Chvostek**[2]—twitching of facial muscles by tapping facial (VII) nerve.
  - **Trousseau**[3]—inflation of BP cuff causes carpal spasm (*main d'accoucheur*—hand of the obstetrician/deliverer).
- Treatment
  - Calcium (10%) gluconate (IV)
  - Calcium supplements (oral)
  - Vitamin D metabolites

3.7.2.2 Hypercalcemia

Usually children

- Surgical causes
  MEN (types I, II), Chronic renal failure, parathyroid tumors, hyperthyroidism, rhabdomyosarcoma, neuroblastoma, metastatic disease.
- Signs
  "*Stones, Bones, Psychic groans, Abdominal moans*," i.e., renal calculi, osteoporosis, bone cysts, psychiatric manifestations, weakness, confusions, pancreatitis, peptic ulcers.
- *Treatment*
  - Saline rehydration (with furosemide diuresis)
  - Calcitonin
  - Bisphosphonates, etc.

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[2] Frantisek Chvostek (1835–1884), Austrian physician.
[3] Armand Trousseau (1801–1867)—French physician.

3.8 Acid-Base Imbalance

3.8.1 Concepts

Definition
- **Acid** H+ donor
- **Base** – H+ acceptor
- **Cation** is a +ve ion
- **Anion** is a –ve ion

pH = −log 10 [H +]

- Neutral pH at 37 °C = 6.8
- Normal blood pH = 7.4 (≡ H^+ = 40 nmol/L) (range 7.2–7.6)
- Normal intracellular pH = 7.0 (H^+ = 100 nmol/L)

Anion gap—"difference" between summated anions and cations—there is always more of the latter owing to unmeasured anions (e.g., [protein⁻]). An elevated anion gap is usually due to an increase in [lactate⁻], [butyrate⁻], and others.

Normal is up to 30 mmol/L (but depends on what is being measured).

Key Equations
- Henderson[4] equation
  $[H^+]+[HCO^{-3}]\leftrightarrow[H_2CO_3]\leftrightarrow[CO_2]+[H_2O][H^+]+[HCO^{3-}]\leftrightarrow[H_2CO_3]\leftrightarrow[CO_2]+[H_2O]$
- Henderson–Hasslebalch[5] equation
  – $pH = pKa + \log 10 \frac{\text{conjugate base}}{\text{conjugate acid}}$
  – i.e., $pH = pKa + \log 10 \frac{HCO_3}{CO_2}$

3.8.2 Base Excess (or Deficit)

Definition—"the quantity of base (acid) required to return the plasma in vitro to a normal pH under standard conditions."

Normal body equilibration is maintained by a series of buffer systems:

- Chemical
  – Bicarbonate, phosphate, protein

[4] Lawrence J. Hendersen (1878–1942) American biochemist.
[5] Karl A. Hasslebalch (1874–1962) Danish chemist.

- Respiratory
  - Elimination of CO_2
- Renal
  - Elimination or retention of bicarbonate

3.8.3 Abnormal Acid-Base States

3.8.3.1 Metabolic Acidosis

$$\uparrow\left[H^{+}\right]\downarrow\left[HCO_{3}^{-}\right]\downarrow\left[BE\right]$$

Multiple causes, but can be subdivided on the basis of change in anion gap. Thus, the subdivisions are:

- Normal anion gap
  - Loss of base
  - Renal loss of bicarbonate in renal tubular acidosis
  - Fistula loss of bicarbonate (pancreatic)
- Increased anion gap
  - Tissue hypoxia—anaerobic metabolism ↑ [lactate$^-$] + ↑ [H^+]
  - Ketoacidosis—diabetic
- **Treatment**
  - Correct the underlying problem
  - Sodium bicarbonate (4.2% IV) infused over 30 min
  - Ensure ventilation adequate to excrete excess CO_2

N.B. give half calculated dose—repeat blood gas

3.8.3.2 Metabolic Alkalosis

$$\downarrow\left[H^{+}\right]\uparrow\left[HCO_{3}^{-}\right]\uparrow\left[BE\right]$$

This is much less common in pediatric practice. Causes include

- Loss of acid
  - Vomiting of HCl—e.g., pyloric stenosis
  - Loss of acid stools—chronic diarrhea
- Loss of chloride
  - Chronic use of diuretics
  - Renal perfusion impairment with changes in renin/aldosterone axis.
  - Dehydration, cirrhosis
- Hypokalemia
  - Causes ↑hydrogen ion exchange in kidney.

  – Contraction alkalosis—as the body fluids are "alkali," dehydration causes a fall in total body water and ↑concentration of electrolytes, hence ↑pH.
- **Treatment**
  – Treat the underlying cause.
  – Often simple correction of fluid and saline deficit will allow restoration of homeostasis.

  Base deficit (mmol/L) × body weight (kg) × 0.3 = mmol/L of HCO_3

Required for full correction

Further Readings

1. Holliday MA, Ray PE, Friedman AL. Fluid therapy for children: facts, fashions and questions. Arch Dis Child. 2007;92:546–50.
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3. Wang J, Xu E, Xiao Y. Isotonic versus hypotonic maintenance IV fluids in hospitalized children: a meta-analysis. Pediatrics. 2014;133(1):105–13. https://doi.org/10.1542/peds.2013-2041.