Lab Values, Fluids, Electrolytes and ABGs Made Easy

Normal Values, Interpretation, Formulas and ICU Clinical Scenarios for Students, House Officers and Postgraduate Trainees

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Preface

Laboratory reports, fluid charts and arterial blood gases are read every hour in surgical wards and ICUs. A house officer who can interpret them quickly and safely is worth a great deal to the patient. This book gathers the normal values, the meaning of abnormal results, the essential formulas and a simple method for reading ABGs, then applies them to real ICU scenarios.

How to use this book

1. Chapters 1–4: normal values and interpretation of common investigations.
2. Chapters 5–8: fluids and electrolytes, with every formula worked through.
3. Chapters 9–10: reading ABGs step by step.
4. Chapter 11: clinical scenarios that combine everything.
5. The quick reference card at the end can be printed and kept in your pocket.

Units. Values are given in conventional units (mg/dL, g/dL), as used by most laboratories in Pakistan, with SI units (mmol/L, µmol/L) where helpful.

Important safety note

- Reference ranges differ between laboratories, analysers, age groups, sex and pregnancy. **Always use the range printed on your own laboratory's report.** The values here are typical adult ranges for learning.
- Doses and rates given are typical adult guidance from widely used protocols. Always confirm with your hospital's protocols, senior colleagues and current guidelines, and adjust for children, the elderly, and cardiac or renal failure.
- Treat the patient, not the number: a result that does not fit the clinical picture should be repeated.

Chapter 1: Haematology and Coagulation

The complete blood count (CBC) and clotting profile are the commonest tests before and after surgery.

Complete blood count — adult reference values

Test	Typical normal range
Haemoglobin (Hb)	Men 13.5–17.5 g/dL; women 12.0–15.5 g/dL
Haematocrit (Hct / PCV)	Men 41–53%; women 36–46%
RBC count	Men 4.5–5.9 × 10^{12}/L; women 4.0–5.2 × 10^{12}/L
MCV	80–100 fL
MCH	27–33 pg
MCHC	32–36 g/dL
RDW	11.5–14.5%
Total leucocyte count (TLC/WBC)	4.0–11.0 × 10^{9}/L
Neutrophils	2.0–7.5 × 10^{9}/L (40–75%)
Lymphocytes	1.0–4.0 × 10^{9}/L (20–45%)
Monocytes	0.2–0.8 × 10^{9}/L (2–10%)
Eosinophils	0.04–0.4 × 10^{9}/L (1–6%)
Basophils	< 0.1 × 10^{9}/L (< 1%)
Platelets	150–400 × 10^{9}/L
Reticulocytes	0.5–2.5%
ESR	Men up to about age ÷ 2 mm/h; women up to about (age + 10) ÷ 2 mm/h

Interpreting abnormal results

Finding	Common causes	Surgical relevance
Low Hb, low MCV (microcytic)	Iron deficiency (chronic blood loss), thalassaemia trait, anaemia of chronic disease	Unexplained iron deficiency in adults → investigate GI tract (colonic or gastric cancer)

Finding	Common causes	Surgical relevance
Low Hb, high MCV (macrocytic)	B12 or folate deficiency, alcohol, liver disease, hypothyroidism	Previous gastrectomy or ileal resection → B12 deficiency
Low Hb, normal MCV	Acute blood loss, chronic disease, renal failure	After acute bleeding, Hb may be normal for several hours until haemodilution
High Hb / Hct	Dehydration, polycythaemia, smoking, COPD	Rising Hct in acute pancreatitis or burns suggests fluid deficit
High WBC with neutrophilia	Bacterial infection, inflammation, surgery, steroids, tissue necrosis	Appendicitis, abscess, anastomotic leak, ischaemic bowel
Low WBC	Overwhelming sepsis, viral infection, drugs, marrow failure	WBC < 4 can be a sign of severe sepsis
Eosinophilia	Allergy, parasites, drug reaction	Hydatid cyst, ascariasis
Low platelets	Sepsis, DIC, heparin (HIT), hypersplenism, dengue, drugs	Risk of bleeding; check before surgery and epidural
High platelets	Reactive (infection, bleeding, after splenectomy), iron deficiency, myeloproliferative	Post-splenectomy thrombocytosis increases thrombosis risk

Rule of thumb for anaemia: always look at the MCV first; it divides anaemia into three groups and points to the cause.

Coagulation profile

Test	Typical normal	Measures	Prolonged in
PT	11–13.5 s (lab-specific)	Extrinsic pathway (VII) and common pathway	Warfarin, vitamin K deficiency, liver disease, DIC
INR	0.8–1.2	Standardised PT	Same as PT; target 2–3 on warfarin for most indications
APTT	About 25–35 s (lab-specific)	Intrinsic pathway (VIII, IX, XI, XII)	Unfractionated heparin, haemophilia, DIC, lupus anticoagulant
Fibrinogen	200–400 mg/dL (2–4 g/L)	Clot substrate	Low in DIC, massive transfusion, liver failure

Test	Typical normal	Measures	Prolonged in
D-dimer	< 0.5 mg/L FEU	Fibrin breakdown	DVT/PE, DIC, sepsis, after surgery; useful mainly to *exclude* DVT/PE in low-risk patients
Bleeding time	2–7 min	Platelet function	Antiplatelet drugs, uraemia, von Willebrand disease

DIC pattern: prolonged PT and APTT, low platelets, low fibrinogen and high D-dimer, in a patient with sepsis, trauma, obstetric catastrophe or malignancy.

Before surgery (common practice): INR ⩽ 1.5 is generally acceptable for most operations; follow local protocols for neuraxial anaesthesia and high-risk procedures.

> **Remember:** Microcytic anaemia in an adult man or post-menopausal woman is GI cancer until proven otherwise.

Chapter 2: Renal Function, Electrolytes and Urine

Adult reference values

Test	Conventional units	SI units
Sodium (Na^+)	135–145 mEq/L	135–145 mmol/L
Potassium (K^+)	3.5–5.0 mEq/L	3.5–5.0 mmol/L
Chloride (Cl^-)	98–107 mEq/L	98–107 mmol/L
Bicarbonate (HCO_3^-)	22–28 mEq/L	22–28 mmol/L
Urea	15–45 mg/dL	2.5–7.5 mmol/L
Blood urea nitrogen (BUN)	7–20 mg/dL	—
Creatinine	Men 0.7–1.3 mg/dL; women 0.6–1.1 mg/dL	Men 62–115 µmol/L; women 53–97 µmol/L
Uric acid	Men 3.4–7.0 mg/dL; women 2.4–6.0 mg/dL	0.20–0.42 mmol/L (men)
Calcium (total)	8.5–10.5 mg/dL	2.15–2.60 mmol/L
Ionised calcium	4.5–5.3 mg/dL	1.12–1.32 mmol/L

Test	Conventional units	SI units
Phosphate	2.5–4.5 mg/dL	0.8–1.45 mmol/L
Magnesium	1.7–2.4 mg/dL	0.7–1.0 mmol/L
Serum osmolality	275–295 mOsm/kg	275–295 mOsm/kg
eGFR	> 90 mL/min/1.73 m²	—

Urea (mg/dL) ≈ BUN (mg/dL) × 2.14.

Interpreting raised urea and creatinine

Pattern	Suggests
Urea raised much more than creatinine (BUN : creatinine > 20 : 1)	Pre-renal (dehydration, bleeding, shock), upper GI bleed (blood protein digestion), high protein intake, steroids
Urea and creatinine both raised proportionately	Intrinsic renal injury (ATN) or chronic kidney disease
Rapid rise with anuria	Obstruction (check catheter, ultrasound for hydronephrosis) or severe ATN
Low urea	Liver failure, malnutrition, pregnancy, overhydration

Acute kidney injury (KDIGO criteria) — any one of: creatinine rise ⩾ 0.3 mg/dL within 48 hours; creatinine ⩾ 1.5 × baseline within 7 days; urine output < 0.5 mL/kg/h for 6 hours.

Stage	Creatinine	Urine output
1	1.5–1.9 × baseline or ⩾ 0.3 mg/dL rise	< 0.5 mL/kg/h for 6–12 h
2	2.0–2.9 × baseline	< 0.5 mL/kg/h for ⩾ 12 h
3	⩾ 3 × baseline, or ⩾ 4.0 mg/dL, or dialysis started	< 0.3 mL/kg/h for ⩾ 24 h, or anuria ⩾ 12 h

Useful renal formulas

Fractional excretion of sodium (FENa):

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FE_{Na}(\%) = \frac{U_{Na} \times P_{Cr}}{P_{Na} \times U_{Cr}} \times 100
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- FENa < 1% → pre-renal (kidney is conserving sodium)

- FENa > 2% → intrinsic renal (ATN)
- After diuretics FENa is unreliable; use fractional excretion of urea (FEUrea < 35% suggests pre-renal).

Worked example. Urine Na 10, plasma Na 140, urine creatinine 100 mg/dL, plasma creatinine 2.0 mg/dL. FENa = (10 × 2.0) ÷ (140 × 100) × 100 = 20 ÷ 14,000 × 100 = **0.14%** → pre-renal; give fluids.

Cockcroft-Gault creatinine clearance (for drug dosing):

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CrCl\ (mL/min) = \frac{(140 - \text{age}) \times \text{weight (kg)}}{72 \times \text{creatinine (mg/dL)}} \quad (\times 0.85 \text{ for women})
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Worked example. 60-year-old man, 70 kg, creatinine 1.4 mg/dL: (80 × 70) ÷ (72 × 1.4) = 5,600 ÷ 100.8 = **56 mL/min**. Adjust doses of renally excreted drugs (e.g. aminoglycosides, enoxaparin).

Urine examination — normal

Test	Normal
Volume	Adult ≥ 0.5 mL/kg/h (about 800–2,000 mL/day)
Specific gravity	1.005–1.030
pH	4.5–8.0
Protein, glucose, ketones, nitrite	Negative
RBC	0–2 /HPF
Pus cells (WBC)	0–5 /HPF
Casts	Occasional hyaline casts only

Abnormal urine clues: nitrite + leucocytes → UTI; RBC casts → glomerulonephritis; muddy-brown granular casts → ATN; haematuria without infection in an adult → investigate for urological cancer; dark urine with positive blood dipstick but no RBCs → myoglobin (rhabdomyolysis) or haemoglobin.

> **Remember:** In a surgical patient with rising creatinine, first exclude the three treatable causes: hypovolaemia, a blocked catheter or obstructed ureters, and nephrotoxic drugs (NSAIDs, aminoglycosides, contrast).

Chapter 3: Liver Function Tests, Pancreas and Proteins

Adult reference values (vary between laboratories)

Test	Typical normal range
Total bilirubin	0.3–1.2 mg/dL (5–21 µmol/L)
Direct (conjugated) bilirubin	< 0.3 mg/dL (< 5 µmol/L)
ALT (SGPT)	About 7–56 U/L (many labs: up to 40)
AST (SGOT)	About 10–40 U/L
Alkaline phosphatase (ALP)	40–130 U/L (higher in children, adolescents and pregnancy)
Gamma-GT (GGT)	Men < 60 U/L; women < 40 U/L
Total protein	6.0–8.3 g/dL
Albumin	3.5–5.0 g/dL (35–50 g/L)
Globulin	2.0–3.5 g/dL
A : G ratio	1.1–2.2
Amylase	About 30–110 U/L
Lipase	Lab-specific (often < 60 U/L)
Ammonia	15–45 µmol/L
LDH	About 140–280 U/L

Jaundice is usually visible when bilirubin exceeds about **2.5–3 mg/dL**.

The three patterns of abnormal LFTs

Pattern	Main rise	Common causes
Pre-hepatic (haemolytic)	Unconjugated bilirubin; enzymes normal	Haemolysis, Gilbert's syndrome, resorption of a large haematoma
Hepatocellular	ALT and AST much higher than ALP	Viral hepatitis (B, C, E), drugs (paracetamol, anti-TB), ischaemic "shock liver", alcohol

Pattern	Main rise	Common causes
Cholestatic (obstructive)	ALP and GGT much higher than ALT; conjugated bilirubin	CBD stones, carcinoma head of pancreas, cholangiocarcinoma, periampullary tumours, PBC/PSC, drugs

Helpful clues

- ALT and AST in the **thousands** → acute viral hepatitis, drug toxicity (paracetamol) or ischaemic hepatitis.
- **AST : ALT > 2** → suggests alcoholic liver disease.
- Raised ALP with **normal GGT** → bone source (bone metastases, Paget's disease, healing fracture, growing child).
- Raised ALP **and** GGT → liver/biliary source.
- Painless progressive obstructive jaundice with a palpable gallbladder (Courvoisier's law) → think of carcinoma head of pancreas.
- A short spike of ALT/AST (often a few hundred) with pain → a CBD stone passing.

Synthetic function — the best indicators of how well the liver is working:

- **Albumin** (low in chronic liver disease, but also in malnutrition, sepsis, nephrotic syndrome, burns)
- **PT/INR** (prolonged; corrects with vitamin K in obstructive jaundice but not in severe liver failure)
- Glucose (low in severe liver failure)

Low albumin is common in ICU patients due to inflammation and dilution; it affects calcium (Chapter 8) and the anion gap (Chapter 10).

Pancreas

- Acute pancreatitis is diagnosed by 2 of 3 (Revised Atlanta): typical abdominal pain; amylase or lipase **> 3 times** the upper limit of normal; characteristic imaging.
- **Lipase** is more specific and stays raised longer than amylase.
- Amylase can also rise in perforated peptic ulcer, intestinal ischaemia or obstruction, ruptured ectopic pregnancy, salivary disease and renal failure.
- The *level* of amylase does **not** indicate severity. Use clinical scores and organ failure (e.g. modified Glasgow-Imrie, BISAP) and CRP > 150 mg/L at 48 hours.

> **Remember:** Hepatocellular = ALT high; obstructive = ALP high. Synthetic function = albumin and INR.

Chapter 4: Glucose, Lipids, Cardiac, Sepsis, Thyroid, Iron and Tumour Markers

Glucose and diabetes

Test	Normal	Prediabetes	Diabetes
Fasting plasma glucose	70–99 mg/dL (3.9–5.5 mmol/L)	100–125 mg/dL	⩾ 126 mg/dL (7.0 mmol/L)
2-hour OGTT (75 g)	< 140 mg/dL	140–199 mg/dL	⩾ 200 mg/dL (11.1 mmol/L)
HbA1c	< 5.7%	5.7–6.4%	⩾ 6.5%
Random glucose	—	—	⩾ 200 mg/dL with symptoms

To convert glucose: mg/dL ÷ 18 = mmol/L. Hypoglycaemia: < 70 mg/dL (3.9 mmol/L); treat urgently below 54 mg/dL (3.0 mmol/L).

Surgical relevance. HbA1c above about 8.5% (69 mmol/mol) before elective surgery is linked to more wound infection and complications; many guidelines advise optimising before elective surgery. In ICU, a glucose target of about 140–180 mg/dL is generally recommended; tighter control increases hypoglycaemia.

Lipid profile (fasting)

Test	Desirable
Total cholesterol	< 200 mg/dL
LDL cholesterol	< 100 mg/dL (lower in high cardiovascular risk)
HDL cholesterol	Men > 40 mg/dL; women > 50 mg/dL
Triglycerides	< 150 mg/dL (> 1,000 mg/dL can cause acute pancreatitis)

Cardiac markers

Test	Normal	Interpretation
Troponin (I or T, high-sensitivity)	Below the assay's 99th percentile (lab-specific)	A rise and/or fall above this, with ischaemia, indicates myocardial infarction. Also raised in sepsis, PE, renal failure and after major surgery (myocardial injury after non-cardiac surgery)
CK	About 30–200 U/L	Very high (> 5 × normal, often thousands) in rhabdomyolysis, crush injury, compartment syndrome
BNP	< 100 pg/mL	High in heart failure; helps when breathlessness may be cardiac
NT-proBNP	< 125 pg/mL (age < 75)	As BNP; higher cut-offs in elderly and renal failure

Inflammation and sepsis markers

Test	Normal	Interpretation
CRP	< 5 mg/L (some labs < 10)	Rises within 6–12 h, peaks at 48 h. After major abdominal surgery a CRP that keeps rising after day 3, or stays high (e.g. > 150 mg/L), should raise suspicion of anastomotic leak or collection
Procalcitonin	< 0.05 ng/mL	> 0.5 ng/mL suggests bacterial sepsis; > 2 high likelihood; falling values support stopping antibiotics
Lactate	0.5–2.0 mmol/L	> 2 = hypoperfusion; ⩾ 4 = severe. Septic shock: vasopressors needed to keep MAP ⩾ 65 mmHg **and** lactate > 2 despite adequate fluids

Thyroid

Test	Normal	Pattern
TSH	About 0.4–4.0 mIU/L	Low TSH + high free T4/T3 = hyperthyroidism; high TSH + low free T4 = primary hypothyroidism

Test	Normal	Pattern
Free T4	About 0.8–1.8 ng/dL (10–23 pmol/L)	
Free T3	About 2.3–4.2 pg/mL	Isolated high T3 = T3 toxicosis

Patients must be euthyroid before thyroidectomy to avoid thyroid storm.

Iron studies

Test	Normal	Iron deficiency	Anaemia of chronic disease
Serum iron	60–170 µg/dL	Low	Low
TIBC	250–450 µg/dL	High	Low/normal
Transferrin saturation	20–50%	Low (< 16–20%)	Low/normal
Ferritin	Men about 30–400; women 15–150 ng/mL	Low (< 30 confirms)	Normal or high (ferritin is an acute-phase protein)

Vitamin B12: about 200–900 pg/mL. Folate: above about 3–4 ng/mL.

Tumour markers — used for monitoring and follow-up, **not** for screening or diagnosis alone.

Marker	Usual upper limit	Main use
CEA	< 3 ng/mL (non-smokers); < 5 (smokers)	Colorectal cancer follow-up
CA 19-9	< 37 U/mL	Pancreatic and biliary cancer (also raised in cholangitis and obstructive jaundice)
AFP	< 10 ng/mL	Hepatocellular carcinoma, germ cell tumours of testis
β-hCG	< 5 IU/L (non-pregnant)	Germ cell tumours, pregnancy
CA-125	< 35 U/mL	Ovarian cancer monitoring
PSA	Age-related, commonly < 4 ng/mL	Prostate cancer
Calcitonin	Lab-specific	Medullary thyroid carcinoma

> **Remember:** A rising CRP after day 3 following bowel anastomosis needs examination and imaging, not just more antibiotics.

Chapter 5: Body Fluids, IV Fluids and Maintenance Formulas

Every fluid prescription answers three questions: Is the patient dry, wet or normal? Do they need **resuscitation**, **replacement** of ongoing losses, or **routine maintenance**? Which fluid, how much, and how fast?

Body fluid compartments (70 kg adult man)

Compartment	Share of body weight	Volume
Total body water (TBW)	60%	42 L
Intracellular fluid (ICF)	40% (two-thirds of TBW)	28 L
Extracellular fluid (ECF)	20% (one-third of TBW)	14 L
— Interstitial fluid	15% (three-quarters of ECF)	10.5 L
— Plasma	5% (one-quarter of ECF)	3.5 L

TBW factor: 0.6 in adult men and children, 0.5 in adult women and elderly men, 0.45 in elderly women, about 0.7–0.8 in infants. Blood volume ≈ 70 mL/kg in adults, 80 mL/kg in children, 85–90 mL/kg in neonates.

Normal daily water balance (adult)

Intake	mL/day	Output	mL/day
Drinks	about 1,500	Urine	about 1,500
Food	about 800	Insensible (skin and lungs)	about 800–1,000
Metabolic water	about 300	Stool	about 100–200

Fever increases insensible loss by roughly 10% for every 1 °C above 37 °C.

Composition of common IV fluids (per litre)

Fluid	Na^+ (mmol)	K^+	Cl^-	Other	Osmolarity (mOsm/L)	Main use
0.9% NaCl (normal saline)	154	0	154	—	308	Resuscitation; replacing gastric losses; hypochloraemic alkalosis
Ringer's lactate / Hartmann's	130–131	4–5	109–111	Ca 1.4–2, lactate 28–29	273–278	Resuscitation (balanced); burns; GI losses
Plasma-Lyte 148	140	5	98	Mg 1.5, acetate 27, gluconate 23	294	Balanced resuscitation and replacement
5% dextrose (D5W)	0	0	0	Glucose 50 g (≈ 170 kcal)	≈ 278 (becomes free water)	Free water; hypernatraemia; maintenance with other fluids
4% dextrose / 0.18% NaCl	30	0	30	Glucose 40 g	≈ 283	Maintenance (risk of hyponatraemia)
0.45% NaCl	77	0	77	—	154	Hypernatraemia (cautious)
3% NaCl (hypertonic)	513	0	513	—	1,026	Severe symptomatic hyponatraemia; raised ICP
4% succinylated gelatin	154	0	120	—	≈ 274	Colloid volume expander
Human albumin 4–5% / 20%	—	—	—	Albumin	—	Selected cases (e.g. large-volume paracentesis, SBP)

Where does the fluid go? After redistribution, roughly a quarter of an isotonic crystalloid (0.9% saline, Ringer's) stays in the circulation; the rest moves into the interstitium. Only about one-twelfth of 5% dextrose stays intravascular, because the glucose is metabolised and the water spreads through all compartments. So **dextrose is not a resuscitation fluid**.

Useful additives

Ampoule	Content
KCl 15%, 10 mL	20 mmol K^+ (7.45% KCl: 1 mmol/mL) — always check the label
$NaHCO_3$ 8.4%	1 mmol/mL
Calcium gluconate 10%, 10 mL	2.2 mmol Ca^{2+}
Calcium chloride 10%, 10 mL	6.8 mmol Ca^{2+} (more irritant; central line preferred)
Magnesium sulphate 50%, 2 mL	1 g = about 4 mmol Mg^{2+}
Dextrose 50%, 50 mL	25 g glucose

Maintenance requirements — adults

- Water: **25–30 mL/kg/day** (20–25 mL/kg/day in elderly, frail, cardiac or renal failure; use ideal body weight if obese)
- Sodium, potassium and chloride: about **1 mmol/kg/day** each
- Glucose: **50–100 g/day** to limit starvation ketosis (this is not nutrition)

Worked example — 70 kg adult, nil by mouth

1. Water: 70 × 25–30 = **1,750–2,100 mL/day** (about 75–85 mL/h)
2. Na^+ about 70 mmol, K^+ about 70 mmol, glucose 50–100 g
3. One practical regimen: 2 L of 4% dextrose / 0.18% NaCl with 20 mmol KCl in each litre (+ oral or extra K^+ as needed) → water 2,000 mL, Na^+ 60 mmol, K^+ 40 mmol, glucose 80 g. Check sodium daily: hypotonic fluids after surgery can cause hyponatraemia because ADH is high.
4. Add **replacement** for ongoing losses (NG aspirate, drains, fistula, diarrhoea) separately, measured and charted.

Maintenance — children (Holliday-Segar)

Body weight	Per day	Per hour ("4-2-1 rule")
First 10 kg	100 mL/kg	4 mL/kg/h

Body weight	Per day	Per hour ("4-2-1 rule")
Next 10 kg (11–20 kg)	50 mL/kg	2 mL/kg/h
Each kg above 20 kg	20 mL/kg	1 mL/kg/h

Worked example — 18 kg child

- Per day: (10 × 100) + (8 × 50) = 1,000 + 400 = **1,400 mL/day**
- Per hour: (10 × 4) + (8 × 2) = 40 + 16 = **56 mL/h** (1,400 ÷ 24 ≈ 58; the two methods agree closely)
- Use an isotonic fluid such as 0.9% NaCl with 5% dextrose (or Plasma-Lyte with glucose) per current paediatric guidance, and consider restricting to 50–80% if there is a risk of ADH excess (post-op, meningitis, pneumonia). Check sodium and glucose at least daily.

Caution: applying the 4-2-1 rule to adults overestimates water needs (70 kg → 110 mL/h, 2,640 mL/day). In adults, the 25–30 mL/kg/day rule is safer.

> **Remember:** Resuscitate with balanced crystalloids or 0.9% saline, never with dextrose. Maintain at 25–30 mL/kg/day with about 1 mmol/kg/day of Na^+ and K^+. Replace measured losses separately.

Chapter 6: Deficits, Resuscitation, Burns and Blood Transfusion

Assessing volume status at the bedside

Look for: thirst, dry tongue, sunken eyes, cold peripheries, capillary refill > 2 s, tachycardia, hypotension (late), low urine output (< 0.5 mL/kg/h), postural drop, raised lactate, and the fluid balance chart. A **passive leg raise** that increases blood pressure or stroke volume suggests the patient will respond to fluid.

Estimating a fluid deficit

$$\text{Deficit (mL)} = \% \text{ dehydration} \times \text{weight (kg)} \times 10$$

Degree	% body weight lost	Clinical signs
Mild	3–5%	Thirst, dry mucosa, normal pulse and BP
Moderate	6–9%	Tachycardia, oliguria, reduced skin turgor, sunken eyes

Degree	% body weight lost	Clinical signs
Severe	⩾ 10%	Hypotension, cold peripheries, confusion, shock

Worked example. A 60 kg man with intestinal obstruction, moderately dehydrated (about 8%): deficit = 8 × 60 × 10 = **4,800 mL**. Correct shock first with boluses, then give the remaining deficit over the next 24 hours **in addition to** maintenance (Chapter 5) and measured NG losses.

Resuscitation

- **Adults (NICE):** 500 mL balanced crystalloid or 0.9% NaCl over less than 15 minutes; reassess after each bolus; seek senior help if more than about 2,000 mL is needed.
- **Sepsis with hypotension or lactate ⩾ 4 mmol/L:** about **30 mL/kg** of crystalloid within the first 3 hours (Surviving Sepsis Campaign), then guided by repeated assessment. For 70 kg → 2,100 mL.
- **Children:** 10 mL/kg crystalloid bolus over less than 10 minutes, reassess and repeat as needed.
- **Haemorrhagic shock:** stop the bleeding; give blood early rather than large volumes of crystalloid; balanced blood components (RBC : FFP : platelets about 1 : 1 : 1); tranexamic acid 1 g IV over 10 minutes within 3 hours of injury, then 1 g over 8 hours; permissive hypotension (systolic about 80–90 mmHg) in penetrating trauma without head injury.

Estimated blood loss in haemorrhage (ATLS classes, 70 kg adult, approximate)

Class	Blood loss	Pulse	BP	Urine output	Mental state
I	< 15% (< 750 mL)	Normal	Normal	Normal	Slightly anxious
II	15–30% (750–1,500 mL)	Raised	Normal (narrow pulse pressure)	20–30 mL/h	Anxious
III	30–40% (1,500–2,000 mL)	Clearly raised	Low	5–15 mL/h	Confused
IV	> 40% (> 2,000 mL)	Very high	Very low	Negligible	Lethargic

Composition of GI losses (approximate, per litre) — replace losses with a fluid of similar composition.

Fluid	Volume/day	Na^+	K^+	Cl^-	HCO_3^-	Replace with
Gastric (NG, vomiting)	1.5–3 L	40–80	10–15	100–150	0	0.9% NaCl + 20 mmol KCl/L

Fluid	Volume/day	Na^+	K^+	Cl^-	HCO_3^-	Replace with
Bile	0.5–1 L	140–145	5	100–105	30–40	Ringer's lactate
Pancreatic	1–1.5 L	140	5	60–75	70–115	Ringer's lactate ± bicarbonate
Small bowel / ileostomy / fistula	1–3 L	100–140	5–10	100	20–30	Ringer's lactate or 0.9% NaCl + KCl
Diarrhoea	Variable	50–130	20–40	50–100	30–45	Ringer's lactate + KCl

Losing gastric juice causes **hypochloraemic, hypokalaemic metabolic alkalosis**; losing pancreatic, biliary or small bowel fluid causes **metabolic acidosis** (bicarbonate loss).

Burns — fluid resuscitation

Start formal resuscitation for burns over about 15% TBSA in adults or 10% in children. Count only partial- and full-thickness burns (not simple erythema). Estimate area by the **rule of nines** (adults) or Lund-Browder chart (children); the patient's palm with fingers ≈ 1% TBSA.

Parkland formula:

$$\text{Volume in first 24 h (mL)} = 4 \times \text{weight (kg)} \times \%\ \text{TBSA}$$

Give half in the first 8 hours **from the time of the burn**, and half over the next 16 hours, using Ringer's lactate. ATLS now suggests starting at 2 mL/kg/% TBSA in adults (3 mL in children, 4 mL in electrical burns). Whichever formula you use, it is only a starting point: **titrate to urine output** of 0.5 mL/kg/h in adults and 1 mL/kg/h in children under 30 kg. Children also need maintenance fluid with glucose.

Worked example. A 60 kg man with 40% burns at 10:00 arrives at 12:00.

1. Total (Parkland) = 4 × 60 × 40 = **9,600 mL** in 24 h
2. First half = 4,800 mL to be given by 18:00 (8 h from the burn). Two hours have already passed, so give 4,800 mL over 6 h = **800 mL/h**
3. Second half = 4,800 mL over the next 16 h = **300 mL/h**
4. Target urine output = 0.5 × 60 = **30 mL/h**; reduce the rate if output is much higher, increase if lower.

Blood and blood products

Product	Usual threshold / indication	Expected effect
Red cells	Hb < 7 g/dL in most stable patients; < 8 g/dL in cardiac disease or symptomatic; active bleeding guided by clinical state	1 unit raises Hb by about 1 g/dL in a 70 kg adult
Platelets	< 10 × 10⁹/L prophylactic; < 50 for surgery or active bleeding; < 100 for neurosurgery or eye surgery	1 adult dose raises count by about 20–40 × 10⁹/L
FFP	Bleeding with INR or APTT > 1.5 × normal; massive transfusion	12–15 mL/kg
Cryoprecipitate	Bleeding with fibrinogen < 150 mg/dL (1.5 g/L)	Adult dose (about 10 units / 2 pools) raises fibrinogen by about 100 mg/dL

Children — red cell volume:

$$\text{Volume (mL)} = \text{desired Hb rise (g/dL)} \times \text{weight (kg)} \times 4$$

Example: 10 kg child, raise Hb from 6 to 9 g/dL → 3 × 10 × 4 = **120 mL** (some protocols use a factor of 5; follow local policy).

Maximum allowable blood loss (planning major surgery):

$$MABL = EBV \times \frac{Hct_{initial} - Hct_{lowest\ acceptable}}{Hct_{initial}}$$

Example: 70 kg adult, EBV = 70 × 70 = 4,900 mL; Hct 40% → lowest acceptable 24%: MABL = 4,900 × (16 ÷ 40) = **1,960 mL**.

Massive transfusion (e.g. > 10 units in 24 h, or > 4 units in 1 h with ongoing bleeding): activate the protocol, warm all fluids, and watch for **hypocalcaemia** (citrate), **hyperkalaemia**, **hypothermia**, acidosis and coagulopathy.

> **Remember:** Burns formulas are a starting point; urine output decides the rate. In bleeding, replace blood with blood.

Chapter 7: Sodium Disorders

Serum sodium reflects **water balance** more than sodium balance. A low sodium usually means too much water; a high sodium usually means too little water.

Key formulas

Calculated serum osmolality:

$$Osm = 2 \times Na + \frac{\text{glucose (mg/dL)}}{18} + \frac{\text{BUN (mg/dL)}}{2.8}$$

(in SI units: 2 × Na + glucose + urea, all in mmol/L). Normal 275–295 mOsm/kg. **Osmolar gap** = measured − calculated; normal < 10. A high gap suggests toxic alcohols (methanol, ethylene glycol), mannitol or ethanol.

Sodium corrected for high glucose:

$$Na_{corrected} = Na_{measured} + 1.6 \times \frac{\text{glucose (mg/dL)} - 100}{100}$$

(some use 2.4 instead of 1.6 when glucose is above about 400 mg/dL). Example: Na 128, glucose 600 mg/dL → 128 + 1.6 × 5 = **136** — the true sodium is normal; the low reading is due to water drawn out of cells by glucose.

Adrogué-Madias formula — the expected change in serum Na after 1 litre of any fluid:

$$\Delta Na = \frac{(Na_{infusate} + K_{infusate}) - Na_{serum}}{TBW + 1}$$

TBW = weight × 0.6 (men), 0.5 (women and elderly men), 0.45 (elderly women).

Sodium deficit (for hyponatraemia):

$$\text{Na deficit (mmol)} = TBW \times (Na_{target} - Na_{current})$$

Free water deficit (for hypernatraemia):

$$\text{Free water deficit (L)} = TBW \times \left(\frac{Na_{current}}{140} - 1 \right)$$

Hyponatraemia (Na < 135 mmol/L)

Severity: mild 130–134, moderate 125–129, severe < 125 mmol/L. Symptoms depend on the speed of the fall: headache, nausea, confusion, seizures, coma.

Step-by-step approach:

1. **Check serum osmolality.** Normal or high → pseudohyponatraemia (lipids, protein) or hyperglycaemia/mannitol. Low → true hypotonic hyponatraemia.

2. **Assess volume status.**
3. **Check urine osmolality and urine sodium.**

Volume status	Urine Na < 30 mmol/L	Urine Na > 30 mmol/L
Hypovolaemic	GI losses (vomiting, diarrhoea, fistula), burns, third space (pancreatitis, obstruction)	Diuretics (thiazides), salt-wasting, adrenal insufficiency, cerebral salt wasting
Euvolaemic	Low solute intake, excess water drinking (urine osm < 100)	SIADH (post-op pain, nausea, opioids, pneumonia, CNS disease, drugs), hypothyroidism, glucocorticoid deficiency
Hypervolaemic	Heart failure, cirrhosis, nephrotic syndrome	Renal failure

Surgical classics: post-operative hyponatraemia from hypotonic fluids plus ADH release; TURP syndrome (absorption of glycine irrigation); hypovolaemia from NG losses.

Treatment

- **Severe symptoms (seizures, coma, vomiting, confusion):** 150 mL of 3% NaCl IV over 20 minutes; recheck Na; repeat up to 2–3 times until Na has risen by about 5 mmol/L or symptoms improve (European guideline approach; some protocols use 100 mL boluses). Admit to HDU/ICU.
- **Safe limit:** do not raise Na by more than **10 mmol/L in the first 24 hours** (8 mmol/L in high-risk patients: alcoholism, malnutrition, hypokalaemia, liver disease, Na < 105). Too-rapid correction causes **osmotic demyelination syndrome** (quadriparesis, dysarthria, "locked-in").
- **Hypovolaemic:** 0.9% NaCl (watch for rapid correction once ADH switches off and the patient starts to pass dilute urine).
- **SIADH:** fluid restriction (about 800–1,000 mL/day) first; treat the cause; further options per specialist advice.
- **Hypervolaemic:** fluid restriction, treat the underlying condition, diuretics.
- Monitor Na every 2–4 hours during active correction. If overcorrection occurs, senior help is needed (5% dextrose and/or desmopressin may be used to re-lower).

Worked example — hyponatraemia. A 60 kg woman, day 2 after surgery, Na 118 mmol/L, confused.

1. TBW = 60 × 0.5 = **30 L**

2. Effect of 1 L of 3% NaCl (Na 513): ΔNa = (513 − 118) ÷ (30 + 1) = 395 ÷ 31 = **12.7 mmol/L per litre**
3. One 150 mL bolus: 12.7 × 0.15 ≈ **1.9 mmol/L** rise (expected). Two or three boluses give about 4–6 mmol/L.
4. Daily ceiling: no more than 10 mmol/L rise in 24 hours (target Na ⩽ 128 by this time tomorrow).
5. Formulas often underestimate the real rise, especially when a water diuresis starts — check Na frequently.

Hypernatraemia (Na > 145 mmol/L)

Causes: inadequate water intake (elderly, unconscious, ICU patients), water loss (fever, burns, diarrhoea, osmotic diuresis from hyperglycaemia or mannitol, diabetes insipidus after head injury or pituitary surgery), and excess sodium (hypertonic saline, sodium bicarbonate).

Treatment:

- If shocked, first restore volume with isotonic fluid.
- Then replace free water: oral/NG water where possible, or IV 5% dextrose (or 0.45% NaCl).
- **Rate:** in chronic hypernatraemia (> 48 h), lower Na by no more than about **10–12 mmol/L per 24 hours** (about 0.5 mmol/L/h), to avoid cerebral oedema. Acute (hours) hypernatraemia can be corrected faster.
- Add ongoing losses (urine, fever, drains) to the calculated deficit.

Worked example — hypernatraemia. A 70 kg elderly man with Na 160 mmol/L.

1. TBW = 70 × 0.5 = **35 L**
2. Free water deficit = 35 × (160 ÷ 140 − 1) = 35 × 0.143 = **5 L**
3. To lower Na from 160 to 140 safely (⩽ 10 mmol/L/day) takes at least **2 days**.
4. Using Adrogué-Madias for 5% dextrose (Na 0): ΔNa per litre = (0 − 160) ÷ 36 = **−4.4 mmol/L**. To lower Na by 10 mmol/L in 24 h needs about 10 ÷ 4.4 ≈ **2.25 L of free water**, plus the patient's ongoing losses (often another 1–1.5 L/day).
5. Recheck Na every 4–6 hours and adjust.

> **Remember:** Correct chronic sodium disorders slowly — no more than about 10 mmol/L in 24 hours — and check sodium often. Severe symptoms need small, fast boluses of 3% saline, not a slow drip.

Chapter 8: Potassium, Calcium, Magnesium, Phosphate and Bicarbonate

Potassium (normal 3.5–5.0 mmol/L). Only about 2% of body potassium is in the blood, so a small change in serum K^+ means a large change in body stores.

Hypokalaemia (< 3.5 mmol/L) — mild 3.0–3.4, moderate 2.5–2.9, severe < 2.5.

- Causes: vomiting and NG suction, diarrhoea, fistula, diuretics, insulin, salbutamol, alkalosis, low magnesium, poor intake.
- Effects: weakness, paralytic ileus, arrhythmias (worse with digoxin). ECG: flat T waves, U waves, ST depression, prolonged QT.
- Approximate deficit: a fall of 1 mmol/L in serum K^+ represents about 200–400 mmol total body deficit.

Safe IV potassium rules

1. **Never give KCl as an IV bolus or push** — it can cause cardiac arrest.
2. Use pre-mixed bags whenever available.
3. Peripheral line: concentration up to **40 mmol/L**, rate up to **10 mmol/h** on a general ward.
4. Faster rates (up to about 20 mmol/h) or stronger solutions only via a central line with **continuous ECG monitoring** (ICU/HDU), per local protocol.
5. Correct magnesium too — hypokalaemia will not correct while Mg is low.
6. Mild cases: oral KCl 20–40 mmol two to three times daily.
7. Check K^+ again after every 40–60 mmol given IV, and check renal function and urine output.

Hyperkalaemia (> 5.0–5.5 mmol/L) — mild 5.5–5.9, moderate 6.0–6.4, severe ⩾ 6.5 mmol/L.

- First exclude a **haemolysed sample** (difficult venepuncture, delayed processing).
- Causes: AKI or CKD, ACE inhibitors/ARBs, spironolactone, NSAIDs, acidosis, rhabdomyolysis, tissue necrosis (ischaemic limb or bowel), massive transfusion, tumour lysis, Addison's disease.
- ECG (progressive): tall peaked T waves → prolonged PR, flattened P waves → widened QRS → sine wave → VF or asystole.

Emergency treatment of hyperkalaemia (⩾ 6.5 mmol/L or ECG changes)

Step	Drug and typical adult dose	Purpose	Onset
1. Protect the heart	10% calcium gluconate 30 mL IV over 5–10 min (or 10% calcium chloride 10 mL); repeat if ECG changes persist	Stabilises myocardium; does not lower K^+	Minutes; lasts 30–60 min
2. Shift K^+ into cells	10 units soluble insulin with 25 g glucose (e.g. 50 mL of 50% dextrose) IV over 15 min; monitor glucose hourly for at least 6 h (risk of hypoglycaemia)	Lowers K^+ by about 0.6–1.0 mmol/L	15–30 min; lasts 4–6 h
	Salbutamol 10–20 mg nebulised (adjunct, not alone; caution in heart disease)	Further shift	30 min
	Sodium bicarbonate only if metabolic acidosis is present		
3. Remove K^+ from the body	Potassium binders (sodium zirconium cyclosilicate, patiromer, calcium polystyrene sulphonate), loop diuretic if passing urine, dialysis if refractory or anuric	Lowers total body K^+	Hours
4. Prevent recurrence	Stop K^+ supplements and offending drugs; treat cause		

Calcium (total 8.5–10.5 mg/dL; ionised 1.12–1.32 mmol/L). Nearly half of calcium is bound to albumin, so total calcium must be **corrected** for low albumin, or ionised calcium measured on the blood gas.

$$Ca_{corrected}\ (mg/dL) = Ca_{measured} + 0.8 \times (4.0 - \text{albumin in g/dL})$$

(SI: corrected Ca = measured Ca + 0.02 × (40 − albumin in g/L), in mmol/L.)

Worked example. Ca 7.6 mg/dL, albumin 2.0 g/dL: corrected = 7.6 + 0.8 × (4.0 − 2.0) = 7.6 + 1.6 = **9.2 mg/dL** → normal; no calcium needed.

Hypocalcaemia — causes in surgery: after thyroidectomy or parathyroidectomy ("hungry bones"), acute pancreatitis, massive transfusion (citrate), hypomagnesaemia, vitamin D deficiency. Signs: perioral and finger tingling, Chvostek's and Trousseau's signs, tetany, laryngospasm, seizures, prolonged QT.

- Symptomatic or severe: 10–20 mL of 10% calcium gluconate in 50–100 mL 5% dextrose IV over about 10 minutes with ECG monitoring, followed by a calcium infusion per local protocol; correct magnesium; start oral calcium and activated vitamin D (e.g. alfacalcidol) after parathyroid surgery as advised.
- Mild: oral calcium.

Hypercalcaemia (> 10.5 mg/dL; severe > 14 mg/dL or 3.5 mmol/L) — mostly primary hyperparathyroidism or malignancy. "Bones, stones, abdominal groans and psychic moans"; polyuria, dehydration, short QT.

- Rehydrate with IV 0.9% NaCl (often 3–4 L in the first 24 h if heart and kidneys allow), aiming for good urine output.
- Bisphosphonate: zoledronic acid 4 mg IV over 15 minutes (adjust for renal function), effect in 2–4 days.
- Calcitonin for rapid short-term effect; loop diuretics only after rehydration.

Magnesium (1.7–2.4 mg/dL; 0.7–1.0 mmol/L). 1 g of magnesium sulphate ≈ 4 mmol Mg^{2+}.

- Low Mg causes: diarrhoea, fistula and high-output stoma, diuretics, PPIs, alcohol, refeeding.
- Effects: arrhythmias (including torsades de pointes), seizures, refractory hypokalaemia and hypocalcaemia.
- Treatment: torsades or severe symptoms — **2 g (8 mmol) $MgSO_4$ IV over 10–15 min**; otherwise about 20 mmol (5 g) IV over several hours (up to about 40 mmol in 24 h), with reduced doses in renal failure. Monitor reflexes and levels.

Phosphate (2.5–4.5 mg/dL; 0.8–1.45 mmol/L).

- **Low phosphate** — classically in **refeeding syndrome** (starting feeds after prolonged starvation), DKA treatment, alcohol, sepsis. Severe (< 1 mg/dL or 0.32 mmol/L) causes muscle weakness, respiratory failure and heart failure. IV replacement typically 0.25 mmol/kg (moderate) to 0.5 mmol/kg (severe) over 8–12 hours (maximum about 50 mmol), per local protocol.
- **Prevent refeeding syndrome:** identify at-risk patients (little or no intake for > 5–10 days, BMI < 16–18.5, alcohol), give **thiamine before feeding**, start feeds slowly (as low as 10 kcal/kg/day in high risk) and check K^+, Mg^{2+} and PO_4 daily.
- **High phosphate:** renal failure, tumour lysis, rhabdomyolysis.

Bicarbonate therapy

```
HCO_3\ \text{deficit (mmol)} = 0.5 \times \text{weight (kg)} \times (24 - HCO_3)
```

or, using base excess: $NaHCO_3$ (mmol) = 0.3 × weight (kg) × base deficit.

Worked example. 70 kg patient, base excess −15: 0.3 × 70 × 15 = **315 mmol**. Give about **half** (about 150 mmol = 150 mL of 8.4% $NaHCO_3$) slowly, then recheck the ABG.

Bicarbonate is **not** routine. Consider it in severe metabolic acidosis (pH < 7.1–7.2) with AKI, hyperkalaemia with acidosis, bicarbonate-losing (normal anion gap) acidosis, and some poisonings (tricyclic antidepressants, salicylates). In DKA it is generally not given unless pH < 6.9. Hazards: sodium and fluid overload, hypokalaemia, low ionised calcium, and a rise in CO_2 (the patient must be able to breathe it off).

> **Remember:** Never bolus potassium. Calcium first in hyperkalaemia with ECG changes. Correct calcium for albumin. Fix magnesium when potassium or calcium will not correct.

Chapter 9: ABG Basics — Normal Values and the Step-by-Step Method

An arterial blood gas (ABG) answers two questions: **Is the patient oxygenating and ventilating adequately?** and **What is the acid-base state?**

Normal arterial values (breathing room air, at sea level)

Parameter	Normal (mmHg units)	Normal (kPa)
pH	7.35–7.45	—
$PaCO_2$	35–45 mmHg	4.7–6.0 kPa
PaO_2	80–100 mmHg	10.7–13.3 kPa
HCO_3^-	22–26 mmol/L	—
Base excess (BE)	−2 to +2 mmol/L	—
SaO_2	95–100%	—
Lactate	< 2 mmol/L	—
Anion gap ($Na - [Cl + HCO_3]$)	8–12 mmol/L (lab-specific; 12–16 if K^+ is included)	—

Conversion: mmHg × 0.133 = kPa; kPa × 7.5 = mmHg.

Taking a good sample

- Radial artery is preferred; perform a modified Allen's test first.
- Use a heparinised syringe; expel air bubbles (they falsely raise PaO_2 and lower $PaCO_2$).
- Record the FiO_2 and the patient's temperature.
- Analyse within about 15 minutes (or keep on ice if there is a delay).
- A **venous gas (VBG)** is acceptable for pH, HCO_3^-, K^+, lactate and glucose: venous pH is about 0.03 lower and PCO_2 about 4–6 mmHg higher than arterial. It cannot assess oxygenation.

The Henderson-Hasselbalch idea in one line

```
pH \propto \frac{HCO_3^-\ (\text{kidneys, metabolic})}{PaCO_2\ (\text{lungs, respiratory})}
```

More HCO_3^- → higher pH (alkalosis). More CO_2 → lower pH (acidosis).

To check that a report is internally consistent: $[H^+]$ (nmol/L) = 24 × $PaCO_2$ ÷ HCO_3^-. Approximate pH equivalents: 7.60 = 25, 7.50 = 32, 7.40 = 40, 7.30 = 50, 7.20 = 63, 7.10 = 80 nmol/L.

The four primary disorders

Disorder	pH	Primary change	Compensation
Respiratory acidosis	↓	$PaCO_2$ ↑	HCO_3^- ↑ (kidneys; takes 3–5 days to complete)
Respiratory alkalosis	↑	$PaCO_2$ ↓	HCO_3^- ↓
Metabolic acidosis	↓	HCO_3^- ↓	$PaCO_2$ ↓ (lungs; within minutes to hours)
Metabolic alkalosis	↑	HCO_3^- ↑	$PaCO_2$ ↑ (limited by the need for oxygen)

Memory aid **ROME**: **R**espiratory **O**pposite (pH and $PaCO_2$ move in opposite directions), **M**etabolic **E**qual (pH and HCO_3^- move in the same direction).

The 7-step method for reading any ABG

1. **Look at the patient and the history.** What do you expect? (Vomiting → alkalosis; sepsis → lactic acidosis; COPD → CO_2 retention.)
2. **Oxygenation.** Is PaO_2 adequate for the FiO_2? Calculate the P/F ratio and, if needed, the A-a gradient (Chapter 10).

3. **pH.** Below 7.35 = acidaemia; above 7.45 = alkalaemia; normal pH does not exclude a disorder (mixed disorders or full compensation).
4. **Primary process.** Which value ($PaCO_2$ or HCO_3^-) explains the pH change?
5. **Compensation.** Is it appropriate? Use the formulas in Chapter 10. If not, there is a second (mixed) disorder.
6. **Anion gap** (in every metabolic acidosis, and usually in all ABGs). Correct it for albumin.
7. **Delta ratio** if the anion gap is high, to uncover a hidden second metabolic disorder. Then put it all together with the clinical picture and find the cause.

Oxygenation and respiratory failure

Term	Definition
Hypoxaemia	PaO_2 < 80 mmHg; mild 60–79, moderate 40–59, severe < 40 mmHg
Type 1 respiratory failure	PaO_2 < 60 mmHg (8 kPa) with normal or low $PaCO_2$ — a gas-exchange problem (pneumonia, ARDS, PE, pulmonary oedema, atelectasis)
Type 2 respiratory failure	PaO_2 < 60 mmHg with $PaCO_2$ > 45–50 mmHg (> 6 kPa) — a ventilation problem (COPD, opioids, exhaustion, neuromuscular weakness, chest wall injury)

Rough guide: expected PaO_2 (mmHg) on supplemental oxygen ≈ FiO_2 (%) × 5. On 40% oxygen, a PaO_2 of 90 mmHg is "normal-looking" but much lower than the expected ≈ 200 mmHg, showing significant lung disease.

> **Remember:** Patient first, then oxygenation, pH, primary process, compensation, anion gap, delta ratio.

Chapter 10: ABG Formulas — Compensation, Gaps and Oxygenation

Expected compensation (all values in mmHg and mmol/L)

Primary disorder	Expected compensation
Metabolic acidosis	$PaCO_2 = (1.5 \times HCO_3^-) + 8 \pm 2$ **(Winter's formula)**; also $PaCO_2$ ≈ last two digits of pH

Primary disorder	Expected compensation
Metabolic alkalosis	$PaCO_2$ = (0.7 × HCO_3^-) + 21 ± 2 (rarely above 55 mmHg)
Acute respiratory acidosis	HCO_3^- rises 1 for every 10 mmHg rise in $PaCO_2$ above 40; pH falls about 0.08 per 10 mmHg
Chronic respiratory acidosis	HCO_3^- rises 3.5 (3–4) for every 10 mmHg rise; pH falls about 0.03 per 10 mmHg
Acute respiratory alkalosis	HCO_3^- falls 2 for every 10 mmHg fall in $PaCO_2$ below 40
Chronic respiratory alkalosis	HCO_3^- falls 4–5 for every 10 mmHg fall

If the measured value lies outside the expected range, a **second disorder** is present:

- Metabolic acidosis with $PaCO_2$ **higher** than expected → additional respiratory acidosis (the patient is tiring — consider ventilation).
- Metabolic acidosis with $PaCO_2$ **lower** than expected → additional respiratory alkalosis (e.g. sepsis, salicylate poisoning).
- Compensation never over-corrects the pH back to (or beyond) the normal range in a single disorder.

Anion gap (AG)

$$AG = Na^+ - (Cl^- + HCO_3^-) \qquad \text{normal } 8\text{–}12\ \text{mmol/L}$$

Albumin is the main unmeasured anion, so a low albumin hides a high AG:

$$AG_{corrected} = AG + 2.5 \times (4.0 - \text{albumin in g/dL})$$

High anion gap metabolic acidosis (HAGMA) — GOLDMARK

Letter	Cause
G	Glycols (ethylene glycol, propylene glycol)
O	Oxoproline (chronic paracetamol use, especially in malnourished patients)
L	L-lactate — shock, sepsis, ischaemic bowel, hypoxia, metformin
D	D-lactate — short bowel syndrome
M	Methanol

Letter	Cause
A	Aspirin (salicylates)
R	Renal failure (uraemia)
K	Ketoacidosis — diabetic, alcoholic, starvation

Normal anion gap (hyperchloraemic) metabolic acidosis — causes

- GI bicarbonate loss: diarrhoea, pancreatic or small bowel fistula, ileostomy, ureterosigmoidostomy / ileal conduit
- Renal tubular acidosis; acetazolamide
- Large volumes of 0.9% saline (hyperchloraemia)
- Addison's disease

Urine anion gap (for normal AG acidosis): UAG = urine Na^+ + urine K^+ − urine Cl^-. **Negative** → kidneys are excreting acid normally (GI loss, e.g. diarrhoea). **Positive** → renal cause (RTA).

Delta ratio (delta-delta) — used when the AG is high, to detect a hidden second metabolic disorder:

```
\text{Delta ratio} = \frac{AG - 12}{24 - HCO_3^-}
```

Delta ratio	Interpretation
< 0.4	Pure normal-AG (hyperchloraemic) acidosis
0.4–0.8	Combined high-AG and normal-AG acidosis (e.g. DKA after much saline; diarrhoea with renal failure)
0.8–2.0	Pure high-AG acidosis (lactic acidosis often 1–2; DKA often near 1)
> 2.0	High-AG acidosis **plus metabolic alkalosis** (e.g. vomiting) or pre-existing high HCO_3^- (chronic CO_2 retention)

Metabolic alkalosis — causes by urine chloride

Urine Cl^- < 20 mmol/L (chloride-responsive; treat with 0.9% NaCl + KCl)	Urine Cl^- > 20 mmol/L (chloride-resistant)
Vomiting, NG suction, gastric outlet obstruction; previous (stopped) diuretics; post-hypercapnia	Current diuretic use; hyperaldosteronism (Conn's), Cushing's; severe hypokalaemia; excess alkali (bicarbonate, massive transfusion citrate)

Respiratory acidosis — causes: COPD, asthma exhaustion, opioids and sedatives, residual neuromuscular block, Guillain-Barré, myasthenia, flail chest, pain-limited breathing after upper abdominal surgery, abdominal compartment syndrome, obesity hypoventilation, inadequate ventilator settings.

Respiratory alkalosis — causes: pain, anxiety, hypoxaemia, pulmonary embolism, early sepsis, pneumonia, liver failure, pregnancy, salicylates (early), CNS lesions, over-ventilation on the ventilator.

Oxygenation formulas

Alveolar gas equation (sea level; Patm 760 mmHg, water vapour 47 mmHg, respiratory quotient 0.8):

```
P_AO_2 = F_iO_2 \times (760 - 47) - \frac{PaCO_2}{0.8}
```

On room air (FiO_2 0.21): $PAO_2 \approx 150 - PaCO_2 \div 0.8$.

```
\text{A-a gradient} = P_AO_2 - PaO_2
```

Normal A-a gradient ≈ (age ÷ 4) + 4 mmHg (about 5–15 mmHg in young adults, up to 20–25 in the elderly).

- **Normal A-a gradient with hypoxaemia** → hypoventilation (opioids, neuromuscular weakness) or low inspired oxygen (altitude). The lungs themselves are fine.
- **High A-a gradient** → V/Q mismatch, shunt or diffusion problem (pneumonia, ARDS, PE, atelectasis, pulmonary oedema).

P/F ratio ($PaO_2 \div FiO_2$) — the simplest bedside measure of oxygenation. Normal ≈ 400–500 (e.g. 100 ÷ 0.21 = 476).

P/F ratio (with PEEP ⩾ 5 cmH_2O)	Berlin ARDS severity
200–300	Mild ARDS
100–200	Moderate ARDS

P/F ratio (with PEEP ⩾ 5 cmH_2O)	Berlin ARDS severity
⩽ 100	Severe ARDS

ARDS also requires onset within 1 week, bilateral opacities on imaging, and respiratory failure not fully explained by heart failure or fluid overload.

> **Remember:** Winter's formula for every metabolic acidosis; correct the anion gap for albumin; calculate the delta ratio whenever the anion gap is high.

Chapter 11: ICU Clinical Scenarios

Each case is solved with the 7-step method (Chapter 9) and the formulas from Chapters 5–10. Cover the answer, try it yourself, then check.

Case 1: Abdominal pain and vomiting in a young diabetic

A 22-year-old, 60 kg, type 1 diabetic is referred to surgery with abdominal pain, vomiting and deep sighing respiration. Abdomen diffusely tender.

Results (room air): pH 7.14 · $PaCO_2$ 18 mmHg · HCO_3^- 6 · PaO_2 105 mmHg · Na^+ 134 · K^+ 5.6 · Cl^- 98 · glucose 450 mg/dL · urine ketones +++

1. Oxygenation adequate.
2. pH 7.14 → acidaemia; HCO_3^- low → **metabolic acidosis**.
3. Winter's: (1.5 × 6) + 8 = 17 ± 2 → expected 15–19; actual 18 → **appropriate respiratory compensation** (Kussmaul breathing).
4. AG = 134 − (98 + 6) = **30** → high AG.
5. Delta ratio = (30 − 12) ÷ (24 − 6) = 18 ÷ 18 = **1.0** → pure high-AG acidosis.
6. Corrected Na = 134 + 1.6 × 3.5 = **139.6** → true sodium normal.

Diagnosis: diabetic ketoacidosis. DKA itself commonly causes abdominal pain; avoid an unnecessary laparotomy, but re-examine after correction to exclude a true surgical cause that triggered DKA.

Management (adult protocol, e.g. JBDS): 0.9% NaCl 1 L over 1 hour, then 1 L over 2 h, 2 h, 4 h, 4 h and 6 h, adjusted to response · fixed-rate IV insulin 0.1 unit/kg/h = **6 units/h** · potassium: none if K^+ > 5.5; 40 mmol/L if 3.5–5.5; senior review if < 3.5 (insulin will drive K^+ down fast) · add 10% glucose when glucose falls below about 250 mg/dL (14 mmol/L) · no bicarbonate · monitor glucose hourly, ketones and VBG every 1–2 hours.

Case 2: Projectile vomiting for one week

A 55-year-old, 60 kg man with long-standing peptic ulcer disease vomits undigested food daily. Succussion splash present.

Results: pH 7.52 · $PaCO_2$ 48 · HCO_3^- 38 · Na^+ 132 · K^+ 2.8 · Cl^- 82 · urea 70 mg/dL · creatinine 1.5 mg/dL

1. pH 7.52 → alkalaemia; HCO_3^- high → **metabolic alkalosis**.
2. Expected $PaCO_2$ = (0.7 × 38) + 21 = 47.6 ± 2 → 46–50; actual 48 → **appropriate compensation**.
3. AG = 132 − (82 + 38) = 12 → normal.
4. Urea raised more than creatinine → pre-renal.

Diagnosis: gastric outlet obstruction with **hypochloraemic, hypokalaemic metabolic alkalosis** and dehydration. Loss of HCl causes the alkalosis; the kidney conserves Na^+ in exchange for K^+ and H^+, causing hypokalaemia and the classic **paradoxical aciduria**.

Management: NG decompression, measure aspirate · estimated deficit about 8% × 60 × 10 = **4,800 mL** · correct with **0.9% NaCl plus 20–40 mmol KCl per litre** (chloride is the key to correcting the alkalosis) over 24–48 hours, plus replacement of NG losses · check electrolytes 12-hourly · endoscopy with biopsy (exclude gastric cancer) before definitive surgery.

Case 3: Shock after bowel surgery

Day 5 after anterior resection, a 70 kg man is febrile with generalised abdominal tenderness. BP 80/45 mmHg, HR 125/min, urine 10 mL/h. On 40% oxygen.

Results (FiO_2 0.40): pH 7.18 · $PaCO_2$ 30 · HCO_3^- 11 · PaO_2 75 · lactate 6.0 · Na^+ 138 · Cl^- 106 · albumin 2.0 g/dL

1. Oxygenation: P/F = 75 ÷ 0.40 = **187** → significant impairment (evaluate for ARDS).
2. pH 7.18 with low HCO_3^- → **metabolic acidosis**.
3. Winter's: (1.5 × 11) + 8 = 24.5 ± 2 → 22.5–26.5; actual 30 → $PaCO_2$ **too high** → coexisting **respiratory acidosis** — the patient is tiring.
4. AG = 138 − (106 + 11) = 21; corrected for albumin = 21 + 2.5 × (4 − 2) = **26** → high AG.
5. Delta = (26 − 12) ÷ (24 − 11) = 14 ÷ 13 = **1.1** → pure high-AG acidosis (lactic).

Diagnosis: septic shock from anastomotic leak, with lactic acidosis, impending respiratory failure and AKI.

Management (within the first hour): blood cultures then broad-spectrum IV antibiotics · crystalloid 30 mL/kg = **2,100 mL** in the first 3 hours with reassessment · noradrenaline to keep MAP ⩾ 65 mmHg · repeat lactate within 2–4 hours · urgent **source control** (CT and

return to theatre) · ICU for ventilatory support · urinary catheter, hourly output.

Case 4: Drowsy COPD patient after laparotomy

A 68-year-old man with COPD, day 1 after open cholecystectomy, is drowsy on a 60% face mask. He received morphine for pain.

Results (FiO_2 0.60): pH 7.25 · $PaCO_2$ 75 · HCO_3^- 32 · PaO_2 110

1. Oxygenation: P/F = 110 ÷ 0.6 = 183 → impaired, though PaO_2 looks "normal".
2. pH 7.25 with high $PaCO_2$ → **respiratory acidosis**.
3. $PaCO_2$ is 35 mmHg above 40. Acute expected HCO_3^- = 24 + 3.5 = 27.5; chronic expected = 24 + (3.5 × 3.5) ≈ 36. Actual 32 lies **between** → **acute-on-chronic respiratory acidosis**.

Diagnosis: acute-on-chronic type 2 respiratory failure — worsened by high-flow oxygen, opioids, and pain-limited breathing.

Management: controlled oxygen via Venturi mask (24–28%) targeting SpO_2 **88–92%** (do not stop oxygen suddenly) · review opioids; naloxone if opioid toxicity · regional or non-opioid analgesia · bronchodilators, physiotherapy · **NIV** if pH < 7.35 and $PaCO_2$ > 45 mmHg persist after initial treatment · intubation if deteriorating.

Case 5: Sudden breathlessness on day 5

A 50-year-old woman, day 5 after abdominal hysterectomy, suddenly becomes breathless with pleuritic chest pain. HR 115/min, chest clear.

Results (room air): pH 7.50 · $PaCO_2$ 28 · HCO_3^- 21 · PaO_2 62

1. Oxygenation: PAO_2 = 150 − (28 ÷ 0.8) = 150 − 35 = 115; A-a gradient = 115 − 62 = **53 mmHg** → markedly raised.
2. pH 7.50 with low $PaCO_2$ → **respiratory alkalosis**.
3. Acute expected HCO_3^- = 24 − (2 × 1.2) = 21.6 → actual 21 → **acute, appropriately compensated**.

Diagnosis: hypoxaemia with a high A-a gradient and hyperventilation in a post-operative patient with a clear chest — **pulmonary embolism** until proven otherwise.

Management: oxygen · CT pulmonary angiography (or bedside echo if unstable) · therapeutic anticoagulation (e.g. LMWH) once bleeding risk has been discussed with the surgical team · thrombolysis or embolectomy only for massive PE with shock.

Case 6: High-output enterocutaneous fistula

A 45-year-old man with a small bowel fistula draining 1.8 L/day.

Results: pH 7.32 · $PaCO_2$ 30 · HCO_3^- 15 · Na^+ 136 · Cl^- 114 · K^+ 3.1 · Mg^{2+} 1.4 mg/dL

1. pH 7.32 with low HCO_3^- → **metabolic acidosis**.
2. Winter's: (1.5 × 15) + 8 = 30.5 ± 2 → actual 30 → appropriate.
3. AG = 136 − (114 + 15) = **7** → normal AG (hyperchloraemic).
4. Urine anion gap would be negative (GI cause).

Diagnosis: normal-AG metabolic acidosis from bicarbonate loss in fistula fluid, with hypokalaemia and hypomagnesaemia.

Management: measure and replace fistula output millilitre for millilitre with **Ringer's lactate or Plasma-Lyte plus KCl**, on top of maintenance · correct magnesium (otherwise K^+ will not correct) · reduce output: PPI, loperamide, restrict hypotonic oral drinks, and give a high-sodium oral rehydration solution · protect the skin · nutrition (often parenteral) · treat sepsis; plan definitive surgery later (SNAP approach: Sepsis, Nutrition, Anatomy, Procedure).

Case 7: The "almost normal" gas

A 60-year-old man with intestinal obstruction has vomited for 4 days and has become oliguric. Creatinine 5.2 mg/dL.

Results: pH 7.36 · $PaCO_2$ 40 · HCO_3^- 22 · Na^+ 140 · Cl^- 90 · K^+ 5.8

1. pH, $PaCO_2$ and HCO_3^- are all near normal — a careless reader would stop here.
2. AG = 140 − (90 + 22) = **28** → high AG metabolic acidosis is present (renal failure).
3. Delta ratio = (28 − 12) ÷ (24 − 22) = 16 ÷ 2 = **8** → far above 2 → a **coexisting metabolic alkalosis** (vomiting) is hiding the acidosis.
4. Winter's: (1.5 × 22) + 8 = 41 ± 2 → actual 40 → appropriate.

Diagnosis: mixed high-AG metabolic acidosis (AKI) and metabolic alkalosis (vomiting), with hyperkalaemia.

Lesson: always calculate the anion gap — a normal pH can hide two serious, opposite disorders.

Management: NG decompression, fluid resuscitation with 0.9% NaCl (no added K^+), treat hyperkalaemia, hourly urine output, relieve the obstruction once resuscitated, renal replacement therapy if the AKI does not respond.

Case 8: Confusion at the end of a TURP

A 70-year-old, 70 kg man becomes confused, nauseated and bradycardic towards the end of a prolonged transurethral resection of the prostate using glycine irrigation.

Results: Na^+ 117 mmol/L · measured osmolality 270 mOsm/kg (near normal because of absorbed glycine)

1. Severe, acute, symptomatic hyponatraemia from absorption of irrigation fluid (**TURP syndrome**).
2. TBW = 70 × 0.5 (elderly man) = **35 L**.
3. One litre of 3% NaCl changes Na^+ by (513 − 117) ÷ (35 + 1) = 396 ÷ 36 = **11 mmol/L**; a 150 mL bolus ≈ **1.65 mmol/L**.

Management: stop the procedure as soon as possible and secure haemostasis · oxygen, airway support · **150 mL of 3% NaCl over 20 minutes**, recheck Na^+, repeat up to 2–3 times aiming for a rise of about 5 mmol/L or resolution of symptoms · loop diuretic if fluid overloaded · do not exceed about 10 mmol/L rise in 24 hours · monitor Na^+ every 2–4 hours · prevention: limit resection time, keep irrigation bag height low, or use bipolar resection with saline irrigation.

Case 9: Hyperkalaemia with ECG changes

A 65-year-old, day 2 after aortic surgery, is oliguric. His ACE inhibitor was restarted yesterday.

Results: K^+ 7.1 mmol/L (non-haemolysed) · pH 7.25 · HCO_3^- 14 · creatinine 3.0 mg/dL · ECG: tall peaked T waves and widening QRS

Diagnosis: severe hyperkalaemia with ECG changes, due to AKI, ACE inhibitor and acidosis.

Management, in order:

1. Continuous ECG monitoring.
2. **10% calcium gluconate 30 mL IV** over 5–10 minutes; repeat if the ECG does not improve.
3. **10 units soluble insulin + 25 g glucose** (50 mL of 50% dextrose) IV over 15 minutes; check glucose hourly for at least 6 hours.
4. Nebulised salbutamol 10–20 mg as an adjunct.
5. Consider sodium bicarbonate because he is acidotic (with caution about sodium and fluid load).
6. Stop the ACE inhibitor and all potassium supplements; review any potassium-containing fluids.
7. Remove potassium: potassium binder; urgent renal referral for dialysis if K^+ stays high, the patient is anuric, or acidosis or fluid overload is severe.
8. Recheck K^+ at 1, 2, 4 and 6 hours, then regularly.

Case 10: Low urine output after laparotomy

A 70 kg man, 4 hours after a laparotomy, has passed 15 mL/h for the last 3 hours. HR 105/min, BP 105/70 mmHg, cool peripheries.

1. Target urine output = 0.5 × 70 = **35 mL/h** → he is oliguric.
2. **Exclude a blocked catheter first:** check the tubing, flush the catheter, bladder scan.
3. **Assess volume status:** HR, BP, capillary refill, lactate, fluid balance chart (intra-operative losses, third-space losses, drains, NG output).
4. **Exclude bleeding:** abdominal distension, drain output, repeat Hb.
5. If hypovolaemic: **500 mL crystalloid over less than 15 minutes**, then reassess; repeat if responding.
6. Check urea, creatinine and K^+; stop nephrotoxic drugs (NSAIDs, aminoglycosides).
7. If the abdomen is tense, measure bladder pressure: **intra-abdominal pressure > 20 mmHg with new organ dysfunction = abdominal compartment syndrome**, which needs decompression.
8. Do **not** give furosemide just to "improve the numbers" in a dry patient — it worsens kidney injury.

Case 11: Tingling after thyroidectomy

A 35-year-old woman, day 1 after total thyroidectomy, has perioral and fingertip tingling. Chvostek's sign is positive.

Results: Ca 6.8 mg/dL · albumin 3.6 g/dL · Mg^{2+} 1.4 mg/dL · ECG: QTc prolonged

1. Corrected Ca = 6.8 + 0.8 × (4.0 − 3.6) = 6.8 + 0.32 = **7.1 mg/dL** → true hypocalcaemia.
2. Magnesium is also low.

Diagnosis: symptomatic hypocalcaemia from parathyroid stunning or removal, with hypomagnesaemia.

Management: 10–20 mL of 10% calcium gluconate in 50–100 mL of 5% dextrose IV over 10 minutes with ECG monitoring, followed by a calcium infusion per local protocol · correct magnesium (magnesium sulphate IV) · start oral calcium and activated vitamin D (alfacalcidol or calcitriol) · check PTH · monitor calcium every 6–12 hours until stable · watch for laryngospasm.

Quick Reference Card

Item	Value / formula
Hb	Men 13.5–17.5; women 12.0–15.5 g/dL

Item	Value / formula
WBC / platelets	4–11 / 150–400 × 10^9/L
INR / APTT	0.8–1.2 / about 25–35 s
Na / K / Cl / HCO_3	135–145 / 3.5–5.0 / 98–107 / 22–28 mmol/L
Urea / creatinine	15–45 / 0.7–1.3 mg/dL
Ca / Mg / PO_4	8.5–10.5 / 1.7–2.4 / 2.5–4.5 mg/dL
Bilirubin / albumin	0.3–1.2 mg/dL / 3.5–5.0 g/dL
Fasting glucose / HbA1c	70–99 mg/dL / < 5.7%
Lactate	< 2 mmol/L
ABG	pH 7.35–7.45 · $PaCO_2$ 35–45 · PaO_2 80–100 mmHg · HCO_3 22–26 · BE −2 to +2
Maintenance (adult)	25–30 mL/kg/day water; Na^+, K^+, Cl^- about 1 mmol/kg/day
Maintenance (child)	4-2-1 mL/kg/h
Deficit	% dehydration × kg × 10 mL
Parkland	4 × kg × % TBSA; half in first 8 h from burn
Urine output target	Adult 0.5 mL/kg/h; child 1 mL/kg/h
Corrected Ca	Ca + 0.8 × (4 − albumin)
Corrected Na (glucose)	Na + 1.6 × (glucose − 100) ÷ 100
Adrogué-Madias	ΔNa = (infusate Na + K − serum Na) ÷ (TBW + 1)
Free water deficit	TBW × (Na ÷ 140 − 1)
Na correction limit	⩽ 10 mmol/L per 24 h (chronic)
IV K^+ (peripheral)	⩽ 40 mmol/L, ⩽ 10 mmol/h; never bolus
Anion gap	Na − (Cl + HCO_3); + 2.5 × (4 − albumin)
Winter's formula	$PaCO_2$ = 1.5 × HCO_3 + 8 ± 2
Metabolic alkalosis	$PaCO_2$ = 0.7 × HCO_3 + 21 ± 2
Respiratory acidosis	HCO_3 +1 (acute) / +3.5 (chronic) per 10 mmHg $PaCO_2$

Item	Value / formula
Respiratory alkalosis	HCO_3 −2 (acute) / −4 to 5 (chronic) per 10 mmHg $PaCO_2$
Delta ratio	(AG − 12) ÷ (24 − HCO_3)
A-a gradient (room air)	(150 − $PaCO_2$ ÷ 0.8) − PaO_2
P/F ratio	PaO_2 ÷ FiO_2; ARDS ⩽ 300

Self-Assessment Questions

Choose the single best answer.

1. ABG: pH 7.30, $PaCO_2$ 25 mmHg, HCO_3^- 12 mmol/L. The best interpretation is: A. Respiratory acidosis B. Metabolic acidosis with appropriate respiratory compensation C. Metabolic acidosis with respiratory acidosis D. Metabolic alkalosis E. Mixed respiratory and metabolic alkalosis
2. Na^+ 140, Cl^- 100, HCO_3^- 10 mmol/L, albumin normal. The anion gap is: A. 10 B. 20 C. 30 D. 40 E. 50
3. Total calcium 7.8 mg/dL with albumin 2.0 g/dL. The corrected calcium is: A. 6.2 B. 7.8 C. 8.6 D. 9.4 E. 10.2 mg/dL
4. An 80 kg man has 25% partial- and full-thickness burns. By the Parkland formula, the volume in the first 8 hours from the burn is: A. 2,000 mL B. 4,000 mL C. 6,000 mL D. 8,000 mL E. 10,000 mL
5. The hourly maintenance fluid for a 25 kg child by the 4-2-1 rule is: A. 45 mL/h B. 55 mL/h C. 65 mL/h D. 75 mL/h E. 100 mL/h
6. The maximum usual rate of IV potassium through a peripheral line on a general ward is: A. 5 mmol/h B. 10 mmol/h C. 20 mmol/h D. 40 mmol/h E. Any rate if diluted
7. K^+ 7.0 mmol/L with broad QRS complexes. The first drug to give is: A. Salbutamol B. Insulin-glucose C. Calcium gluconate D. Sodium bicarbonate E. Furosemide
8. In chronic hyponatraemia, serum sodium should not rise by more than about: A. 2 mmol/L in 24 h B. 10 mmol/L in 24 h C. 20 mmol/L in 24 h D. 30 mmol/L in 24 h E. Any rate is safe
9. Persistent vomiting from pyloric obstruction typically produces: A. Hyperchloraemic metabolic acidosis B. Hypochloraemic hypokalaemic metabolic alkalosis C. Respiratory alkalosis D. High anion gap acidosis E. Hyperkalaemic acidosis
10. A ventilated patient on PEEP 8 cmH_2O has PaO_2 75 mmHg on FiO_2 0.5 with bilateral infiltrates not due to heart failure. The ARDS severity is: A. None B. Mild C. Moderate D. Severe E. Cannot be graded

11. A 70 kg young man has Na^+ 154 mmol/L. His free water deficit is about: A. 1.2 L B. 2.5 L C. 4.2 L D. 7 L E. 10 L

Answers

Q	Answer	Working
1	B	Winter's: 1.5 × 12 + 8 = 26 ± 2; $PaCO_2$ 25 fits
2	C	140 − (100 + 10) = 30
3	D	7.8 + 0.8 × (4 − 2) = 9.4
4	B	4 × 80 × 25 = 8,000 mL in 24 h; half = 4,000 mL in first 8 h
5	C	40 + 20 + (5 × 1) = 65 mL/h
6	B	10 mmol/h peripherally
7	C	Calcium protects the myocardium first
8	B	⩽ 10 mmol/L in 24 h to prevent osmotic demyelination
9	B	Loss of HCl and K^+
10	C	P/F = 75 ÷ 0.5 = 150 → moderate (100–200)
11	C	TBW 42 L × (154 ÷ 140 − 1) = 42 × 0.1 = 4.2 L

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