Intravenous Fluid & Acid-base Balance for Surgical Patients

Dr. Abdullah F Alshehri, MBBS, FRCSC, MSc
Assistant professor, consultant pediatric surgeon

What is Intravenous fluid?

- Why is understanding IV fluid important for you?
  - The commonest order prescribed in every hospital
  - Needed for almost every patient
  - Always done by the junior doctors
  - Considered basic medical knowledge
  - Everyone expect you to know it
  - Incorrect prescription can be very dangerous
  - Usually the fluid is available in the floor, so no pharmacist to double check your orders

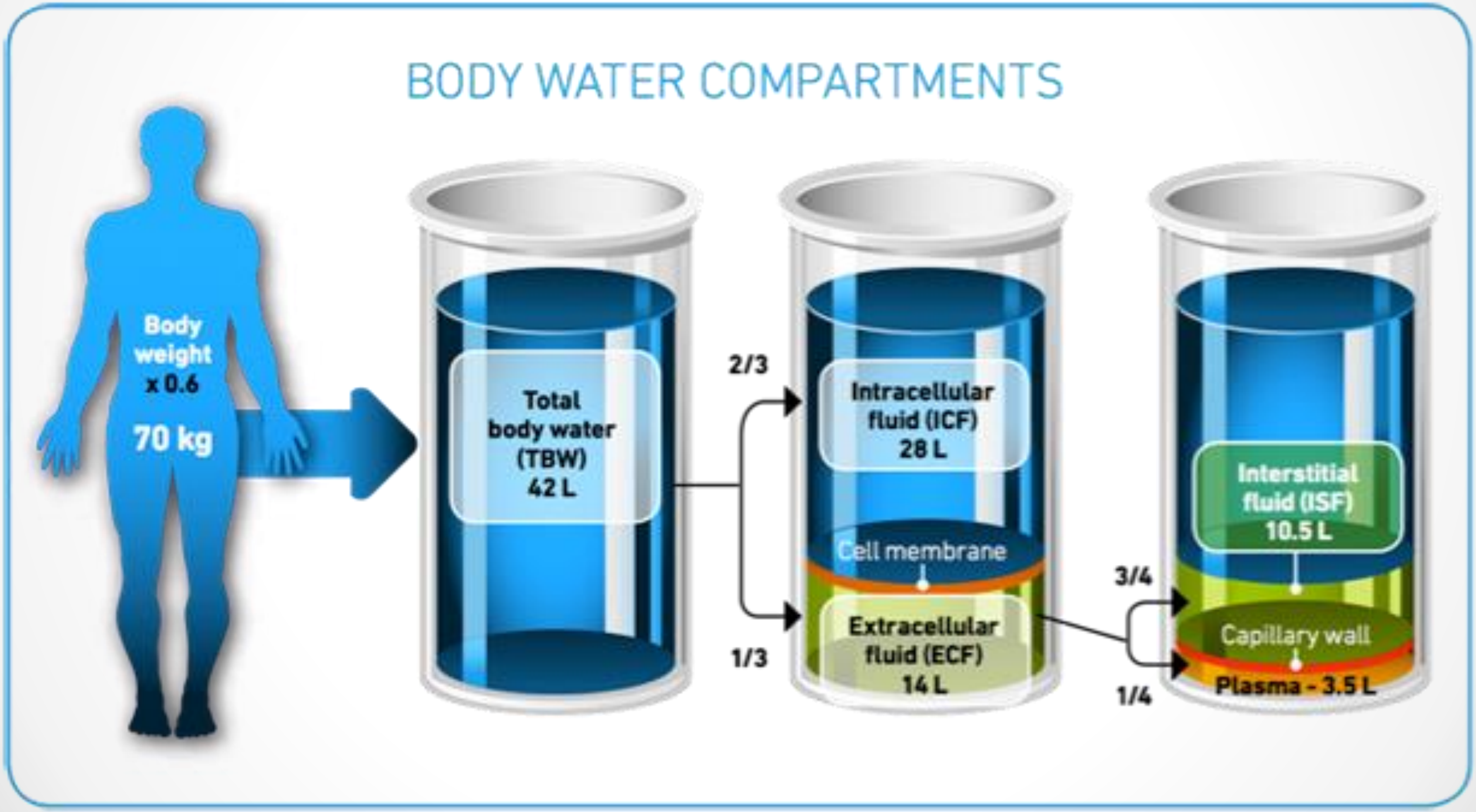
Objectives

- Review basics of fluid & electrolytes physiology in surgical patient
- Be familiar with different types of commonly used IV fluids
- Be able to calculate fluid & electrolytes requirement for a patient and choose the appropriate type of fluid
- Understand different types of electrolytes and fluid disturbance and its management
- Understand basics of acid-base physiology and common disorders

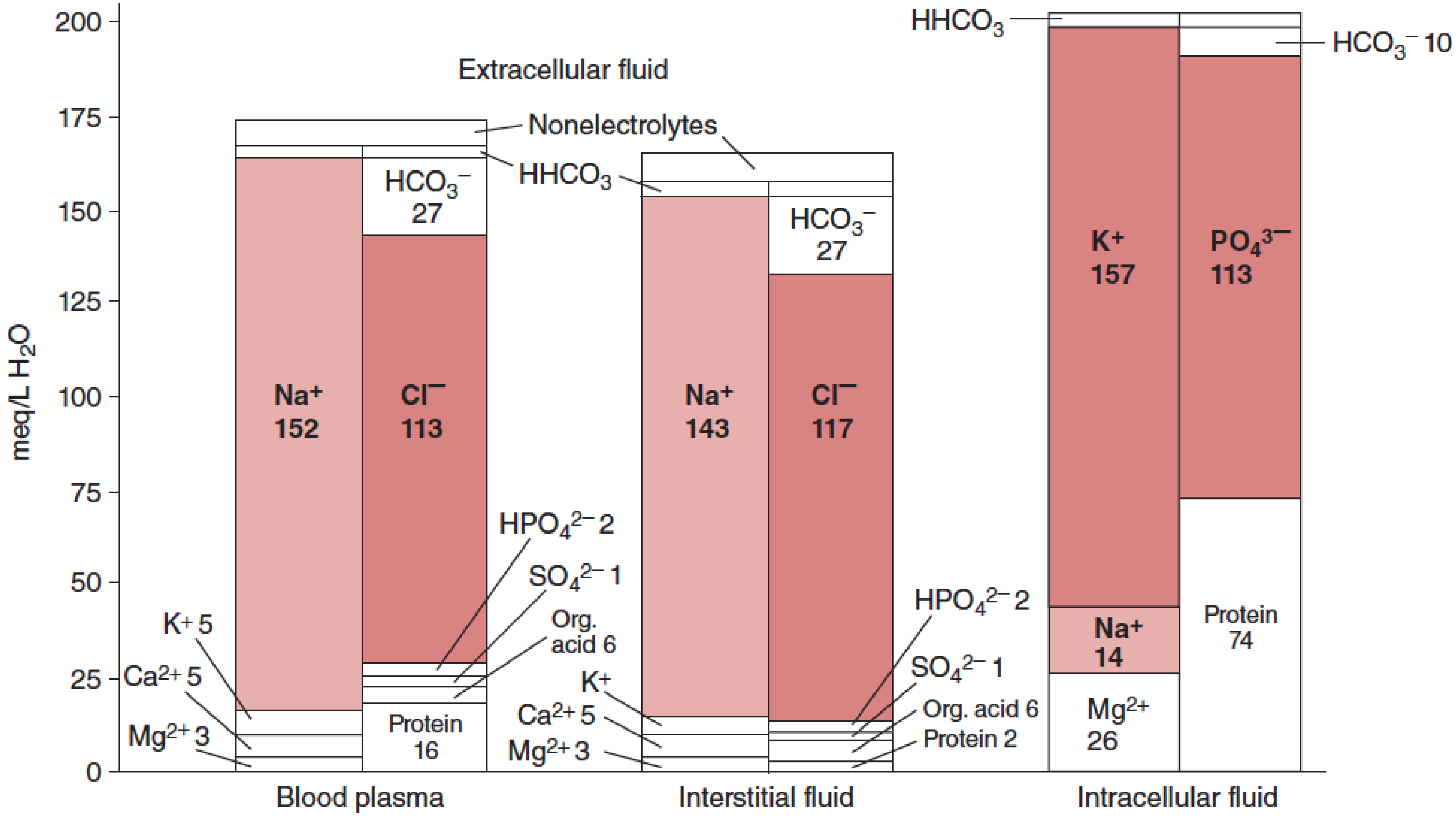
What are we discussing?

1. Intravenous fluids
2. Electrolytes
3. Acid-base balance

Water & electrolyte balance



Electrolyte composition of the body compartments



▲ **Figure 9–1.** Electrolyte composition of human body fluids. Note that the values are in mEq/L of water, not of body fluid. (From Leaf A, Newburgh LH: *Significance of the Body Fluids in Clinical Medicine*, 2nd ed. Thomas, 1955.)

- Distribution of fluid between intravascular and extravascular spaces depends on:
  - Oncotic pressure: albumin
  - Endothelial permeability

- Aldosteron & ADH-> Na & water retention
- ANP -> Na & water excretion

Normal water loss

Table 1.7 Normal daily losses and requirements for fluids and electrolytes

	Volume (ml)	Na^+ (mmol)	K^+ (mmol)
Urine	2000	80	60
Insensible losses from skin and respiratory tract	700	–	–
Faeces	300	–	10
Less water created from metabolism	300	–	–
Total	2700	80	70

Normal daily fluid requirement (maintenance)

- 3 methods:
  1. 4,2,1 formula (most commonly used)- ml/hr
  2. 35 ml/kg/day (rough estimate)
  3. Weight + 40 ml/hr

Normal daily fluid requirement (maintenance)

Method 1: 4,2,1 formula: based on body weight	
First 10 kg	4ml/kg/hr
Next 10kg	2ml/kg/hr
Each kg over 20kg	1ml/kg /hr

- Example: Calculate the fluid requirement of a 100kg- man
- First 10 kg: 4x10= 40
- Next 10kg: 2x10= 20
- Last 80kg: 1x80= 80
- Total: 40+20+80= 140ml/hr =3360ml/day

Normal daily fluid requirement (maintenance)

- Method 2:
  - 35 x 100= 3500 ml/kg/day = 145 ml/hr

- Method 3:
  - 100 + 40= 140 ml/hr

Assessing fluid/electrolytes in surgical patient

Table 1.8 Sources of fluid loss in surgical patients

	Typical losses per 24 hrs	Factors modifying volume
Insensible losses	700–2000 ml	↑ Losses associated with pyrexia, sweating and use of non-humidified oxygen
Urine	1000–2500 ml	↓ With aldosterone and ADH secretion; ↑ With diuretic therapy
Gut	300–1000 ml	↑ Losses with obstruction, ileus, fistulae and diarrhoea (may increase substantially)
Third-space losses	0–4000 ml	↑ Losses with greater extent of surgery and tissue trauma

- Fever:
  - -200ml/day for each 1 degree Celsius
- Sweating:
  - Up to -1L/hr
  - Na>K loss

Assessing fluid/electrolytes in surgical patient

- Effect of Surgery:
  - Stress response:
    - Increased ADH, Aldosteron >> urinary retention + oliguria
  - Third space loss:
    - Surgical manipulation resulting in fluid sequestration within the tissues (extravascular)
  - Loss of fluid from gastrointestinal tract:
    - Bowel obstruction: no fluid absorption
    - Paralytic ileus: loss of GI function after abdominal surgery for 2-3 days
    - Nasogastric tube fluid loss
    - Stoma or intestinal fistula fluid loss
    - Diarrhea

Volume + Electrolytes in GI fluid

Table 1.9 The approximate daily volumes (ml) and electrolyte concentrations (mmol/l) of various gastrointestinal fluids*

	Volume	Na^+	K^+	Cl^-	HCO_3^-
Plasma	–	140	5	100	25
Gastric secretions	2500	50	10	80	40
Intestinal fluid (upper)	3000	140	10	100	25
Bile and pancreatic secretions	1500	140	5	80	60
Mature ileostomy	500	50	5	20	25
Diarrhoea (inflammatory)	–	110	40	100	40

IVF administration

- Before ordering IVF, you should ask yourself:
  - How much maintenance fluid does the patient need?
    - 4,2,1 formula
  - Is there any fluid deficit I should add?
    - Dehydrated patient!
  - What fluid compartment I want to replace?
  - Does the patient have any electrolytes disturbance?
    - Na, K, Cl
  - What is the type of fluid appropriate for my patient?
    - Crystalloid vs. colloid
  - Does the patient need bolus or continuous fluid?

Types of IV fluids

- Crystalloids:
  - Dextrose solutions
  - NaCl solutions
    - 0.9% normal saline
    - ½ normal saline
    - ¼ normal saline
    - Hypertonic saline
  - Ringer's Lactate (Hartmann's solution)

- Colloids:
  - Natural: albumin
  - Synthetic: Gelatins, Hetastarch, Dextran

Crystalloids

- Dextrose fluids:
  - Different concentration: 5%, 10%, 20%, 50%
  - 5% Dextrose contain 5gm of glucose in every 100ml of water (50g/L)
  - No electrolytes
  - After administration:
    - 60% will go to intarcellular compartment
    - 30% will go to extracellular compartment (80% Interstitial , 20% intravascular)
  - Not good option for fluid resuscitation
  - > 12% dextrose can not be administered in peripheral vein (central venous line is needed)
  - Never bolus any dextrose containing solution !!! (hypotonic)

  - Which patient could benefit from this type of fluid?

Crystalloids

- Electrolytes solutions:
  - NaCl solutions (0.9% NS, ½ NS, ¼ NS)
  - LR solution (Hartmann's)
- Hypotonic fluid: 1/2NS, ¼ NS
  - Never bolus a hypotonic solution!!!
- Isotonic fluids:
  - 0.9%NS, LR (similar osmolality to plasma)
  - 25% will remain in the IVC
  - 75% will go to EVC
  - Best option for fluid resuscitation e.g. dehydration, trauma, perioperative
  - Can be given as bolus or continuous fluid
- Hypertonic solutions
  - E.g. 3% NS
  - Rarely used (for cerebral edema and management of brain injuries)

Colloids

- Examples:
  - Natural: albumin 5%, 20%
  - Synthetic: Gelatins, Hetastarch, Dextran
- Contain protein particles that exert oncotic pressure and cause fluid to remain in the intravascular compartment for ~ 6-24hrs
- Disadvantages of colloid:
  - Not widely available
  - Take time to prepare and administer
  - Albumin is a blood product (stored in the blood bank)
  - Expensive
  - Can cause allergic reactions, pruritus, coagulopathy

Composition of IV fluid

Table 1.10 Composition of commonly administered intravenous fluids

	Na^+ (mmol/l)	K^+ (mmol/l)	Cl^- (mmol/l)	HCO_3^- (mmol/l)	Ca^{2+} (mmol/l)	Mg^{2+} (mmol/l)	Oncotic pressure (mmH_2O)	Typical plasma half-life	pH
5% dextrose	–	–	–	–	–		0	–	4.0
0.9% NaCl	154	0	154	0	0		0	–	5.0
Ringer's lactate (Hartmann's solution)	131	5	112	29*	1	1	0	–	6.5
Haemaccel (succinylated gelatin)	145	5.1	145	0	6.25		370	5 hours	7.4
Gelofusine (polygeline gelatin)	154	0.4	125	0	0.4	0.4	465	4 hours	7.4
Hetastarch	154	0	154	0	0		310	17 days	5.5
Human albumin solution 4.5% (HAS)	150	0	120	0	0		275	–	7.4

Composition of IV fluid

	Na (mEq/L)	K (mEq/L)	Cl (mEq/L)	HCO3 (mEq/L)	Dextrose (gm/L)	mOsm/L
D5W					50	278
½ NS	77		77			143
D51/2NS	77		77		50	350
NS	154		154			286
D5NS	154		154		50	564
Ringers Lactate (RL)	130	4	109	28	50	272

- Is colloid better than crystalloid for fluid resuscitation?

EBM	1.1 Crystalloid vs colloid to treat intravascular hypovolaemia
	'There is no evidence that resuscitation with colloids reduces the risk of death, compared to resuscitation with crystalloids, in patients with trauma, burns or following surgery.'
	Perel P. et al., Cochrane Database Syst Rev. 2007 Oct 17;(4):CD000567
	'The use of 4% albumin for intravascular volume resuscitation in critically ill patients is associated with similar outcomes to the use of normal saline.'
	Finfer S. et al. The SAFE study. New Engl J Med 2004; 350:2247–2256.

Which goes to which?

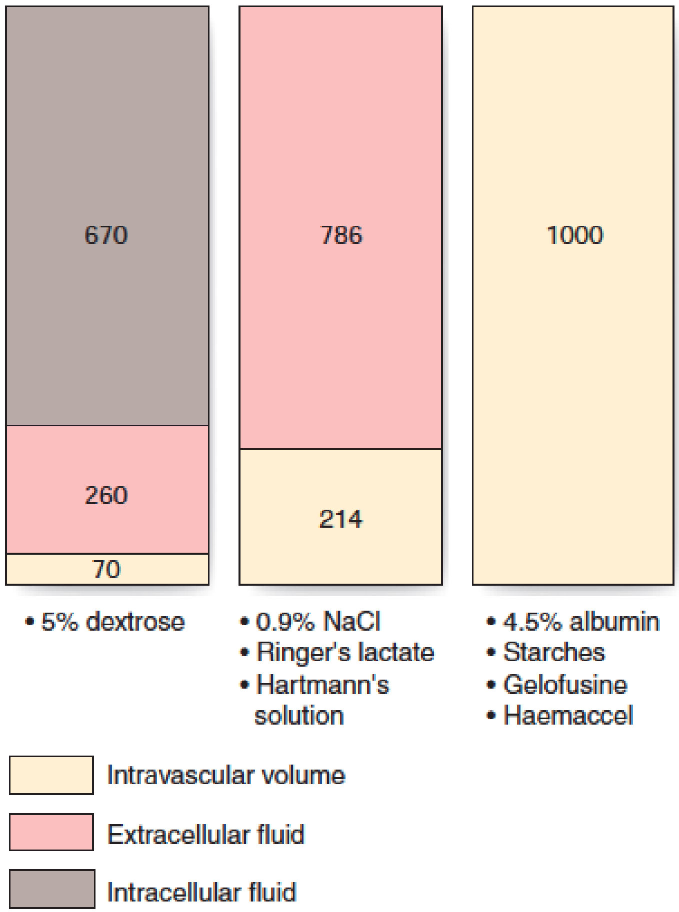


Fig. 1.6 Distribution of different fluids in the body fluid compartments 30–60 minutes after rapid intravenous infusion of 1000 ml.

Electrolyte requirement

- Adult:
  - Na: 1-2 mEq/kg/day
  - K: 1mEq/kg/day
  - Cl 1-2mEq/kg/day
- Children:
  - Na: 2-3 mEq/kg/day
  - K: 2-3 mEq/kg/day
  - Cl: 2-3 mEq/kg/day

Calculating fluid requirement for 70kg adult

- Assuming normal, well hydrated patient, normal electrolytes
- Volume: 4,2,1 formula
  - (4x10) + (2x10) + (1x50) = 110 ml/hr
  - 2640 ml/day
- Electrolytes:
  - Na: 1-2 x 70= 70-140 mEq/day
  - K: 1x70= 70 mEq/day
- Type of fluid:
  - D5 1/2 NS is the best solution
  - Why:
    - If you give 0.9NS only = 400mEq/day of Na (too much)
    - If you give ½ NS only = 200mEq/day of Na (acceptable)
    - But 1/2NS is hypotonic (150mOsmol/L) >> add D5 will raise osmolality to 400 mOsm (acceptable) also will prevent muscle catabolism
  - You should add 20mEq KCL/L to the solution = 52 mEq/day
  - Avoid Dextrose in diabetic patient (use ½ NS)

Your final order:
Start IV fluid D51/2 NS + 20mEq KCL/L @ 110ml/hr


STARBUCKS COFFEE
100 % French Roast

Water depletion/ Dehydration

- Very common in surgical patients
- Usually water + Na
- Commonly caused by:
  - Decreased intake
  - Increased GI loss (diarrhea, vomiting, NGT loss, high stoma output)m;987
- Signs of dehydration:
  - Decreases skin turgor
  - Dry mucous membranes
  - Tachycardia
  - Oliguria <500ml/day (normal 0.5-1ml/kg/hr)
  - Hypotension
  - Decreased level of consciousness
- Treatment:
  - Rapid IV bolus of isotonic solution (0.9% NS or LR)
  - 250-1000ml over 30-60min
  - Monitor response to rehydration

Water excess

- Due to excessive fluid administration (especially hypotonic fluid e.g. Dextrose solutions
- Can cause hyponatremia (dilutional)
- Water accumulate in ECC
- Difficult to detect clinically (edema, basal chest crackles, elevated JVP)
- Later stages >> tissue edema
- High risk patients:
    - Cardiac failure
    - Renal failure

Hypernatremia (Na >145mmol/l)

Causes

Hypovolaemic
- ↓ oral intake (e.g. fasting, ↓ conscious level) *
- Nausea and vomiting*
- Diarrhoea*
- ↑ Insensible losses (↑ sweating and/or ↑ respiratory tract losses)
- Severe burns*
- Diuresis (e.g. glycosuria, use of osmotic diuretics)

Euvolaemic
- Diabetes insipidus – central or nephrogenic

Hypervolaemic
- Excessive sodium load (hypertonic saline, TPN, sodium bicarbonate)
- ↑Mineralocorticoid activity (e.g. Conn's syndrome or Cushing's disease)

Treatment

- Hypovolemic hyponatremia is treated with isotonic saline
- Avoid rapid lowering Na (cerebral edema, permanent brain damage)

Hyponatremia (Na <135 mmol/L)

Causes

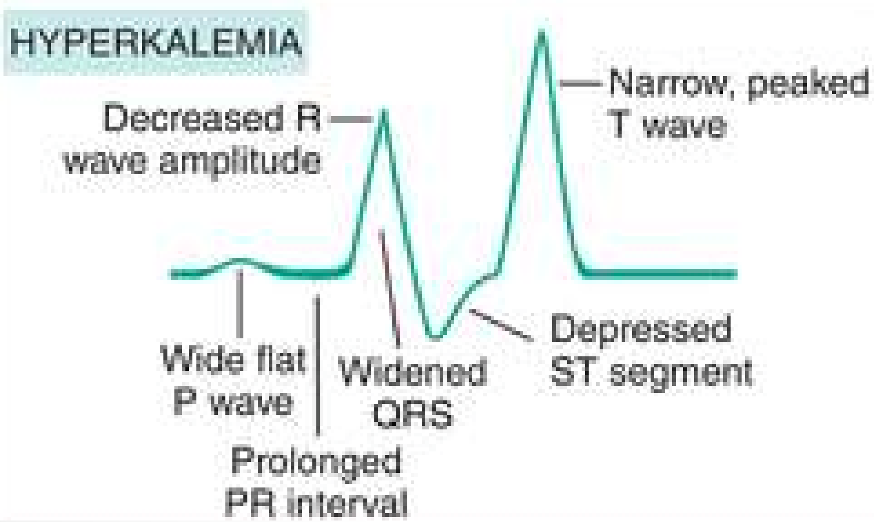
Low extracellular fluid volume
• Diarrhoea*
• Diuretic use*
• Adrenal insufficiency
• Salt-losing renal disease
Normal extracellular fluid volume
• Syndromes of inappropriate ADH secretion (SIADH)
• Hypothyroidism
• Psychogenic polydipsia
Increased extracellular fluid volume
• Excessive water administration*
• Secondary hyperaldosteronism (cirrhosis, cardiac failure)
• Renal failure.

Treatment

- Depends of extracellular fluid volume status:
  - Normal or high: reduce water intake> Na will correct
  - Low: isotonic fluid administration
- Avoid rapid correction >> brain damage

Hyperkalemia K>5mmol/l

- Can be life threatening



Hyperkalaemia
Consequences
• Arrhythmias (tented T waves, ↓ HR, heart block, broadened QRS, asystole) • Muscle weakness • Ileus
Causes
Excess intravenous or oral intake
Transcellular shift – efflux of potassium from cells
• Metabolic acidosis* • Massive blood transfusion* • Rhabdomyolysis (e.g. crush and/or compartment syndromes)* • Massive tissue damage (e.g. ischaemic bowel or liver)* • Drugs (e.g. digoxin, β-receptor antagonists)
Impaired excretion
• Acute renal failure* • Chronic renal failure • Drugs (ACE inhibitors, spironolactone, NSAIDs) • Adrenal insufficiency (Addison's disease).

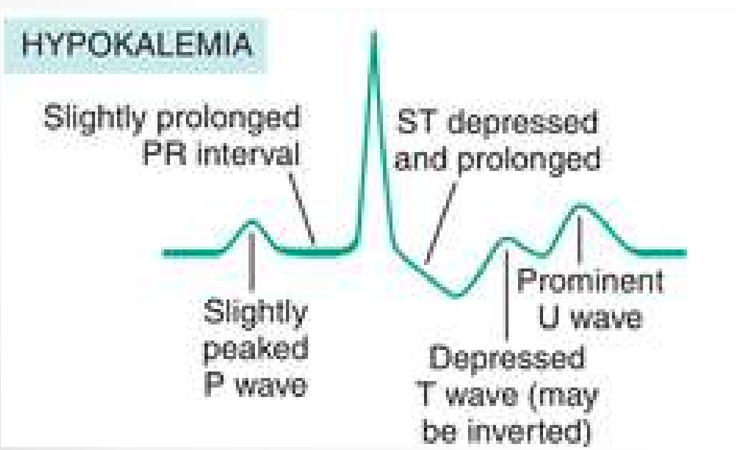
Hyperkalemia K>5mmol/l

Table 1.13 Management of severe hyperkalaemia (K^+ >7 mmol/l)

1. Identify and treat cause. Monitor ECG until potassium concentration controlled.	
2. 10 ml 10% calcium gluconate iv over 3 mins, repeated after 5 min if no response	Antagonizes the membrane actions of ↑ K^+ reducing the risk of ventricular arrhythmias
3. 50 ml 50% dextrose + 10 units short-acting insulin over 2–3 mins. Start infusion of 10–20% dextrose at 50–100 ml/h	Increases transcellular shift of K^+ of into cells
4. Regular salbutamol nebulizers	Increases transcellular shift of K^+ of into cells
5. Consider oral or rectal calcium resonium (ion exchange resin)	Facilitates K^+ clearance across gastrointestinal mucosa. More effective in non-acute cases of hyperkalaemia
6. Renal replacement therapy	Haemodialysis is the most effective medical intervention to lower K^+ rapidly

Hypokalemia K< 3mmol/l

- Very common in surgical patients
- Most K is lost via kidneys
- Rx:
    - Oral K
    - IV K for severe cases
    - Avoid K IV bolus (arrhythmia)



Hypokalaemia
• ECG changes (flattened T-waves, U-waves, ectopics) • Muscle weakness and myalgia
Inadequate intake*
Gastrointestinal tract losses
• Vomiting* • Gastric aspiration/drainage* • Fistulae* • Diarrhoea* • Ileus* • Intestinal obstruction* • Potassium-secreting villous adenoma*
Urinary losses
• Metabolic alkalosis* • Hyperaldosteronism* • Diuretics* • Renal tubular disorders (e.g. Bartter's syndrome, renal tubular acidoses, drug-induced)
Transcellular shift–influx of potassium into cells • Metabolic alkalosis* • Drugs* (e.g. insulin, β-agonists, adrenaline).

Acid-base balance

Introduction

- pH: measure of fluid acidity
- Normal plasma values:
  - pH: 7.35-7.45
  - PCo2: 35-45 mmHg
  - HCo3: 22-26
- Acidosis:
  - pH <7.35
  - Can be respiratory or metabolic
- Alkalosis:
  - pH >7.45
  - Can be respiratory or metabolic
- Arterial blood gas (ABG) is the method to analyze acid-base status through arterial blood sample from the radial artery

Fig. 1.7 A blood gas sample being taken from the radial artery under local anaesthesia.

ABG result

Blood Gas Values			
↓ pH	6.956		[7.350 - 7.450]
↑ pCO_2	155	mmHg	[35.0 - 45.0]
↓ pO_2	35.0	mmHg	[75.0 - 100]
Acid Base Status			
$cHCO_3^-(P,st)_c$	22.5	mmol/L	
$cBase(B)_c$	-1.5	mmol/L	[-3.0 - 3.0]
Electrolyte Values			
↑ cK^+	5.7	mmol/L	[3.4 - 5.5]
cNa^+	144	mmol/L	[136 - 146]
cCa^{2+}	1.30	mmol/l	[1.15 - 1.30]
? $cCa^{2+}(7.4)_c$		mmol/L	
↑ cCl^-	107	mmol/L	[94 - 107]
Metabolite Values			
↑ cGlu	10.2	mmol/L	[3.9 - 5.8]
cLac	1.2	mmol/L	[0.5 - 2.0]
Oxygen Status			
↓ ctHb	81	g/L	[130 - 180]
↓ sO_2	46.0	%	[95.0 - 100.0]
$p50_c$	37.16	mmHg	
$pO_2(a/A)_e$	6.3	%	
FMetHb	0.1	%	[0.0 - 1.5]
FCOHb	1.2	%	[0.0 - 1.5]
$p50(st)_c$	22.64	mmHg	
$FShunt_e$	59.4	%	
FO_2Hb	45.4	%	[-]
Hct_c	25.2	%	

How to read blood gas?

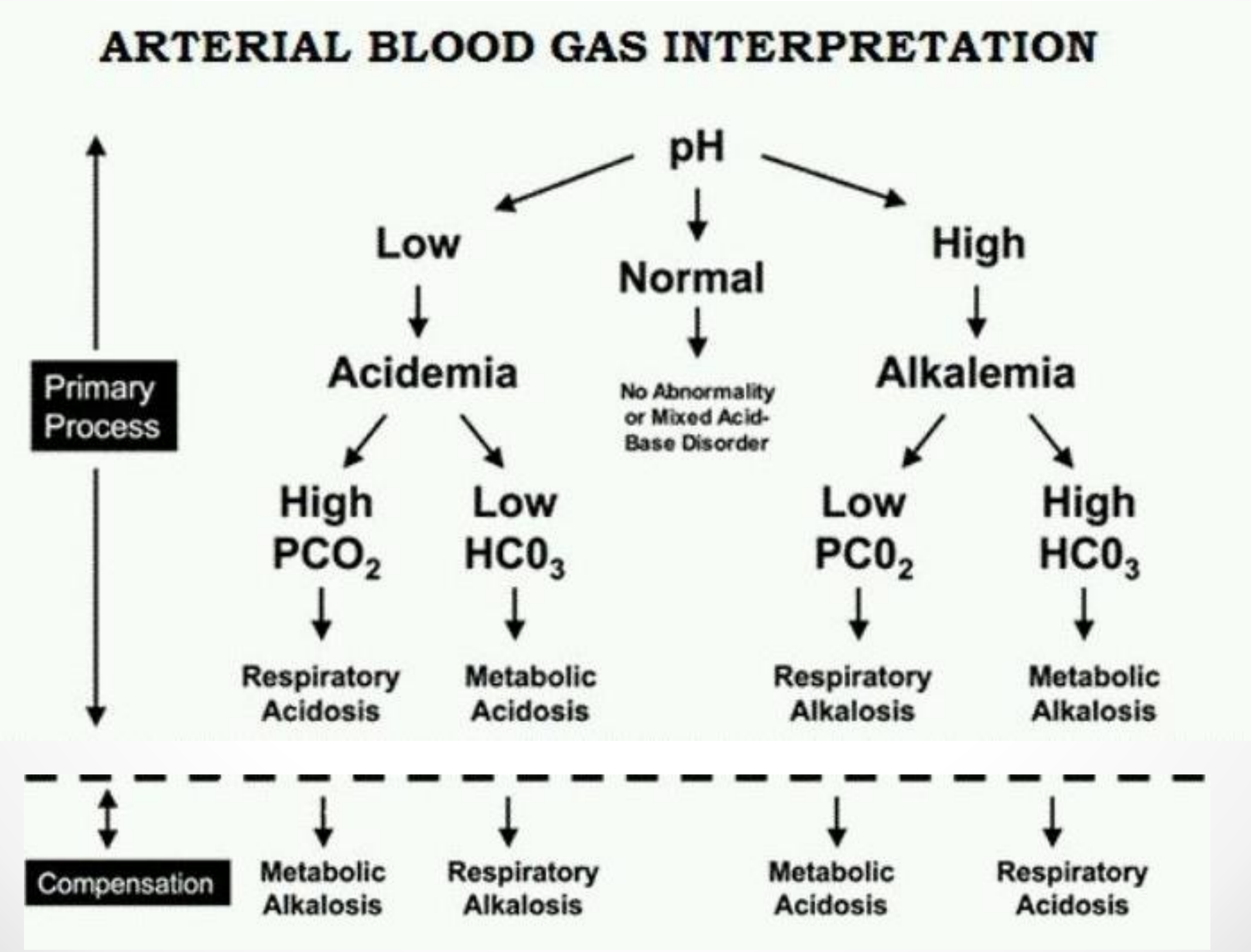


Table 9–3. Changes in HCO_3^- and pCO_2 in primary acid-base disorders.

Disorder	pH	HCO_3^-	P_{CO_2}
Metabolic acidosis	⇓	⇓	⇓ (compensatory)
Metabolic alkalosis	⇑	⇑	⇑ (compensatory)
Respiratory acidosis	⇓	⇑ (compensatory)	⇑
Respiratory alkalosis	⇑	⇓ (compensatory)	⇓

Metabolic Acidosis

Common surgical causes
Lactic acidosis
• Shock (any cause)
• Severe hypoxaemia
• Severe haemorrhage/anaemia
• Liver failure
Accumulation of other acids
• Diabetic ketoacidosis
• Starvation ketoacidosis
• Acute or chronic renal failure
• Poisoning (ethylene glycol, methanol, salicylates)
Increased bicarbonate loss
• Diarrhoea
• Intestinal fistulae
• Hyperchloraemic acidosis

Acid–base findings
Acute uncompensated
• H^+ ions ↑
• P_aCO_2 ↔
• Actual HCO_3^- ↓
• Standard HCO_3^- ↓
• Base deficit < −2
With respiratory compensation (hyperventilation)
• H^+ ions ↔ (full compensation) ↑ (partial compensation)
• P_aCO_2 ↓
• Actual HCO_3^- ↓
• Standard HCO_3^- ↓

Metabolic alkalosis

Metabolic alkalosis

Common surgical causes
Loss of sodium, chloride and water • Vomiting • Loss of gastric secretions • Diuretic administration **Hypokalaemia**
Acid–base findings
Acute uncompensated • H^+ ions ↓ • P_aCO_2 ↔ • Actual HCO_3^- ↑ • Standard HCO_3^- ↑ • Base excess > + 2
With respiratory compensation (hypoventilation) • H^+ ions ↔ (full compensation), ↓ (partial compensation) • P_aCO_2 ↑ • Actual HCO_3^- ↑ • Standard HCO_3^- ↑

Respiratory Acidosis

Respiratory acidosis

Common surgical causes
Central respiratory depression • Opioid drugs • Head injury or intracranial pathology
Pulmonary disease • Severe asthma • COPD • Severe chest infection
Acid–base findings
Acute uncompensated • H^+ ions ↑ • P_aCO_2 ↑ • Actual HCO_3^- ↔ or ↑ • Standard HCO_3^- ↔ • Base deficit < −2
With metabolic compensation (renal bicarbonate retention) • H^+ ions ↔ (full compensation), ↑ (partial compensation) • P_aCO_2 ↑ • Actual HCO_3^- ↑ • Standard HCO^- ↑↑

Respiratory alkalosis

Respiratory alkalosis

Common surgical causes

- Pain
- Apprehension/hysterical hyperventilation
- Pneumonia
- Central nervous system disorders (meningitis, encephalopathy)
- Pulmonary embolism
- Septicaemia
- Salicylate poisoning
- Liver failure

Acid–base findings

Acute uncompensated

- H^+ ions ↓
- P_aCO_2 ↓
- Actual HCO_3^- ↔ or ↓
- Standard HCO_3^- ↔
- Base excess > + 2

With metabolic compensation (renal bicarbonate excretion)

- H^+ ions ↔ (full compensation), ↓ (partial compensation)
- P_aCO_2 ↓
- Actual HCO_3^- ↓
- Standard HCO_3^- ↓

THANK YOU

- REMEMBER:
    - Formula to calculate fluid requirement
    - Comparing different types of fluid
    - Identifying and managing dehydrated patient
    - Composition of different intravenous solutions