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

BODY WATER COMPARTMENTS

Body weight
70 kg

Total body water (TBW) 42 L

Intracellular fluid (ICF) 28 L

Extracellular fluid (ECF) 14 L

Interstitial fluid (ISF) 10.5 L

Plasma - 3.5 L
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:
  o Oncotic pressure: albumin
  o Endothelial permeability

• Aldosterone & ADH -> Na & water retention
• ANP -> Na & water excretion
Normal water loss

<table>
<thead>
<tr>
<th></th>
<th>Volume (ml)</th>
<th>Na⁺ (mmol)</th>
<th>K⁺ (mmol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urine</td>
<td>2000</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Insensible losses</td>
<td>700</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>from skin and respiratory tract</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faeces</td>
<td>300</td>
<td>–</td>
<td>10</td>
</tr>
<tr>
<td>Less water created from metabolism</td>
<td>300</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>2700</td>
<td>80</td>
<td>70</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Weight Range</th>
<th>Fluid Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>First 10 kg</td>
<td>4ml/kg/hr</td>
</tr>
<tr>
<td>Next 10kg</td>
<td>2ml/kg/hr</td>
</tr>
<tr>
<td>Each kg over 20kg</td>
<td>1ml/kg/hr</td>
</tr>
</tbody>
</table>

Example: Calculate the fluid requirement of a 100kg man

- First 10 kg: 4x10 = 40
- Next 10 kg: 2x10 = 20
- Last 80 kg: 1x80 = 80
- Total: 40+20+80 = 140ml/hr = 3360ml/day
Normal daily fluid requirement (maintenance)

• Method 2:
  - \(35 \times 100 = 3500 \text{ ml/kg/day} = 145 \text{ ml/hr}\)

• Method 3:
  - \(100 + 40 = 140 \text{ ml/hr}\)
Assessing fluid/electrolytes in surgical patient

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

### Table 1.8 Sources of fluid loss in surgical patients

<table>
<thead>
<tr>
<th>Typical losses per 24 hrs</th>
<th>Factors modifying volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insensible losses</td>
<td>↑ Losses associated with pyrexia, sweating and use of non-humidified oxygen</td>
</tr>
<tr>
<td>Urine</td>
<td>↓ With aldosterone and ADH secretion; ↑ With diuretic therapy</td>
</tr>
<tr>
<td>Gut</td>
<td>↑ Losses with obstruction, ileus, fistulae and diarrhoea (may increase substantially)</td>
</tr>
<tr>
<td>Third-space losses</td>
<td>↑ Losses with greater extent of surgery and tissue trauma</td>
</tr>
</tbody>
</table>
Assessing fluid/electrolytes in surgical patient

• Effect of Surgery:
  o Stress response:
    • Increased ADH, Aldosteron >> urinary retention + oliguria
  o Third space loss:
    • Surgical manipulation resulting in fluid sequestration within the tissues (extravascular)
  o 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
### Table 1.9 The approximate daily volumes (ml) and electrolyte concentrations (mmol/l) of various gastrointestinal fluids*

<table>
<thead>
<tr>
<th></th>
<th>Volume</th>
<th>Na⁺</th>
<th>K⁺</th>
<th>Cl⁻</th>
<th>HCO₃⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma</td>
<td></td>
<td>140</td>
<td>5</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Gastric secretions</td>
<td>2500</td>
<td>50</td>
<td>10</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Intestinal fluid (upper)</td>
<td>3000</td>
<td>140</td>
<td>10</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Bile and pancreatic secretions</td>
<td>1500</td>
<td>140</td>
<td>5</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Mature ileostomy</td>
<td>500</td>
<td>50</td>
<td>5</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Diarrhoea (inflammatory)</td>
<td></td>
<td>110</td>
<td>40</td>
<td>100</td>
<td>40</td>
</tr>
</tbody>
</table>
**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:
  o Dextrose solutions
  o NaCl solutions
    • 0.9% normal saline
    • ½ normal saline
    • ¼ normal saline
    • Hypertonic saline
  o Ringer’s Lactate (Hartmann’s solution)

• Colloids:
  o Natural: albumin
  o Synthetic: Gelatins, Hetastarch, Dextran
Crystalloids

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

  o 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:
  o Natural: albumin 5%, 20%
  o 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:
  o Not widely available
  o Take time to prepare and administer
  o Albumin is a blood product (stored in the blood bank)
  o Expensive
  o Can cause allergic reactions, pruritus, coagulopathy
## Composition of IV fluid

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Na⁺ (mmol/l)</th>
<th>K⁺ (mmol/l)</th>
<th>Cl⁻ (mmol/l)</th>
<th>HCO₃⁻ (mmol/l)</th>
<th>Ca²⁺ (mmol/l)</th>
<th>Mg²⁺ (mmol/l)</th>
<th>Oncotic pressure (mmH₂O)</th>
<th>Typical plasma half-life</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% dextrose</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>4.0</td>
</tr>
<tr>
<td>0.9% NaCl</td>
<td>154</td>
<td>0</td>
<td>154</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>5.0</td>
</tr>
<tr>
<td>Ringer’s lactate (Hartmann’s solution)</td>
<td>131</td>
<td>5</td>
<td>112</td>
<td>29*</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>-</td>
<td>6.5</td>
</tr>
<tr>
<td>Haemaccel (succinylated gelatin)</td>
<td>145</td>
<td>5.1</td>
<td>145</td>
<td>0</td>
<td>6.25</td>
<td>370</td>
<td>5 hours</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td>Gelofusine (polygeline gelatin)</td>
<td>154</td>
<td>0.4</td>
<td>125</td>
<td>0</td>
<td>0.4</td>
<td>0.4</td>
<td>465</td>
<td>4 hours</td>
<td>7.4</td>
</tr>
<tr>
<td>Hetastarch</td>
<td>154</td>
<td>0</td>
<td>154</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>310</td>
<td>17 days</td>
<td>5.5</td>
</tr>
<tr>
<td>Human albumin solution 4.5% (HAS)</td>
<td>150</td>
<td>0</td>
<td>120</td>
<td>0</td>
<td>0</td>
<td>275</td>
<td>-</td>
<td>7.4</td>
<td></td>
</tr>
</tbody>
</table>
## Composition of IV fluid

<table>
<thead>
<tr>
<th></th>
<th>Na (mEq/L)</th>
<th>K (mEq/L)</th>
<th>Cl (mEq/L)</th>
<th>HCO3 (mEq/L)</th>
<th>Dextrose (gm/L)</th>
<th>mOsm/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>D5W</td>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>278</td>
<td></td>
</tr>
<tr>
<td>½ NS</td>
<td>77</td>
<td></td>
<td>77</td>
<td>50</td>
<td></td>
<td>143</td>
</tr>
<tr>
<td>D51/2NS</td>
<td>77</td>
<td>77</td>
<td></td>
<td>50</td>
<td></td>
<td>350</td>
</tr>
<tr>
<td>NS</td>
<td>154</td>
<td></td>
<td>154</td>
<td></td>
<td></td>
<td>286</td>
</tr>
<tr>
<td>D5NS</td>
<td>154</td>
<td>154</td>
<td></td>
<td>50</td>
<td></td>
<td>564</td>
</tr>
<tr>
<td>Ringers Lactate (RL)</td>
<td>130</td>
<td>4</td>
<td>109</td>
<td>28</td>
<td>50</td>
<td>272</td>
</tr>
</tbody>
</table>
• 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.’

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: 1 mEq/kg/day
  - Cl: 1-2 mEq/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**
  - $(4 \times 10) + (2 \times 10) + (1 \times 50) = 110 \text{ ml/hr}$
  - $2640 \text{ ml/day}$
- **Electrolytes:**
  - Na: $1-2 \times 70 = 70-140 \text{ mEq/day}$
  - K: $1 \times 70 = 70 \text{ mEq/day}$
- **Type of fluid:**
  - D5 1/2 NS is the best solution
  - **Why:**
    - If you give 0.9NS only = $400 \text{ mEq/day}$ of Na (too much)
    - If you give ½ NS only = $200 \text{ mEq/day}$ 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
Water depletion/ Dehydration

• Very common in surgical patients
• Usually water + Na
• Commonly caused by:
  o Decreased intake
  o Increased GI loss (diarrhea, vomiting, NGT loss, high stoma output)
• Signs of dehydration:
  o Decreases skin turgor
  o Dry mucous membranes
  o Tachycardia
  o Oliguria <500ml/day (normal 0.5-1ml/kg/hr)
  o Hypotension
  o Decreased level of consciousness
• Treatment:
  o Rapid IV bolus of isotonic solution (0.9% NS or LR)
  o 250-1000ml over 30-60min
  o 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 hyponatremia
  - ↓ 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 on extracellular fluid volume status:
  - Normal or high: reduce water intake, Na will correct
  - Low: isotonic fluid administration

- Avoid rapid correction, brain damage
Hyperkalemia $K>5$mmol/l

- Can be life threatening

**Hyperkalemia**

- Decreased R wave amplitude
- Wide flat P wave
- Narrowed QRS
- Depressed ST segment
- Narrow, peaked T wave
- Prolonged PR interval

**Consequences**
- Arrhythmias (tented T waves, ↓ HR, heart block, broadened QRS, asystole)
- Muscle weakness
- Ileus

**Causes**

**Excess intravenous or oral intake**
- 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)

**Transcellular shift – efflux of potassium from cells**
- Acute renal failure*
- Chronic renal failure
- Drugs (ACE inhibitors, spironolactone, NSAIDs)
- Adrenal insufficiency (Addison’s disease).
**Hyperkalemia \( K > 5 \text{ mmol/l} \)**

<table>
<thead>
<tr>
<th>Table 1.13</th>
<th>Management of severe hyperkalaemia (( K^+ &gt; 7 \text{ mmol/l} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Identify and treat cause. Monitor ECG until potassium concentration controlled.</td>
</tr>
<tr>
<td>2.</td>
<td>10 ml 10% calcium gluconate iv over 3 mins, repeated after 5 min if no response. Antagonizes the membrane actions of ( \uparrow K^+ ) reducing the risk of ventricular arrhythmias.</td>
</tr>
<tr>
<td>3.</td>
<td>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.</td>
</tr>
<tr>
<td>4.</td>
<td>Regular salbutamol nebulizers. Increases transcellular shift of ( K^+ ) of into cells.</td>
</tr>
<tr>
<td>5.</td>
<td>Consider oral or rectal calcium resinum (ion exchange resin). Facilitates ( K^+ ) clearance across gastrointestinal mucosa. More effective in non-acute cases of hyperkalaemia.</td>
</tr>
<tr>
<td>6.</td>
<td>Renal replacement therapy. Haemodialysis is the most effective medical intervention to lower ( K^+ ) rapidly.</td>
</tr>
</tbody>
</table>
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)

**Table:**

<table>
<thead>
<tr>
<th>Hypokalaemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>- ECG changes (flattened T-waves, U-waves, ectopics)</td>
</tr>
<tr>
<td>- Muscle weakness and myalgia</td>
</tr>
</tbody>
</table>

**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:
  o pH: 7.35-7.45
  o PCo2: 35-45 mmHg
  o HCo3: 22-26

• Acidosis:
  o pH <7.35
  o Can be respiratory or metabolic

• Alkalosis:
  o pH >7.45
  o 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
## ABG result

<table>
<thead>
<tr>
<th>Blood Gas Values</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.956</td>
<td>[7.350 - 7.450]</td>
</tr>
<tr>
<td>pCO₂</td>
<td>155 mmHg</td>
<td>[35.0 - 45.0]</td>
</tr>
<tr>
<td>pO₂</td>
<td>35.0 mmHg</td>
<td>[75.0 - 100]</td>
</tr>
<tr>
<td>Acid Base Status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cHCO₃⁻(P₅0₂)ₜₜ</td>
<td>22.5 mmol/L</td>
<td></td>
</tr>
<tr>
<td>cBase(B rout)</td>
<td>-1.5 mmol/L</td>
<td></td>
</tr>
<tr>
<td>Electrolyte Values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cK⁺</td>
<td>5.7 mmol/L</td>
<td>[3.4 - 5.5]</td>
</tr>
<tr>
<td>cNa⁺</td>
<td>144 mmol/L</td>
<td>[136 - 148]</td>
</tr>
<tr>
<td>cCa²⁺</td>
<td>1.30 mmol/L</td>
<td>[1.15 - 1.30]</td>
</tr>
<tr>
<td>? cCa²⁺(7.4)ₜₜ</td>
<td>107 mmol/L</td>
<td>[94 - 107]</td>
</tr>
<tr>
<td>Metabolite Values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cGlu</td>
<td>10.2 mmol/L</td>
<td>[3.9 - 5.8]</td>
</tr>
<tr>
<td>cLac</td>
<td>1.2 mmol/L</td>
<td>[0.5 - 2.0]</td>
</tr>
<tr>
<td>Oxygen Status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cHb</td>
<td>81 g/L</td>
<td>[130 - 180]</td>
</tr>
<tr>
<td>sO₂</td>
<td>46.0 %</td>
<td>[95.0 - 100.0]</td>
</tr>
<tr>
<td>pS0₂</td>
<td>37.16 mmHg</td>
<td></td>
</tr>
<tr>
<td>pO₂(satA)ₜₜ</td>
<td>6.3 %</td>
<td></td>
</tr>
<tr>
<td>FMetHb</td>
<td>0.1 %</td>
<td>[0.0 - 1.5]</td>
</tr>
<tr>
<td>FCOHb</td>
<td>1.2 %</td>
<td>[0.0 - 1.5]</td>
</tr>
<tr>
<td>pS0₂(sat)ₜₜ</td>
<td>22.64 mmHg</td>
<td></td>
</tr>
<tr>
<td>FShunt</td>
<td>59.4 %</td>
<td></td>
</tr>
<tr>
<td>FO₂Hb</td>
<td>45.4 %</td>
<td></td>
</tr>
<tr>
<td>Hct</td>
<td>25.2 %</td>
<td></td>
</tr>
</tbody>
</table>


How to read blood gas?

**Arterial Blood Gas Interpretation**

- **pH**
  - Low
  - Normal
  - High

- **Acidemia**
  - Low
  - Acidemia
    - No Abnormality or Mixed Acid-Base Disorder
    - Respiratory Acidosis
    - Metabolic Acidosis

- **Alkalemia**
  - High
  - Alkalemia
    - Respiratory Alkalosis
    - Metabolic Alkalosis

**Primary Process**

- Compensation
  - Metabolic Alkalosis
  - Respiratory Alkalosis
  - Metabolic Acidosis
  - Respiratory Acidosis
Table 9–3. Changes in $\text{HCO}_3^-$ and $\text{pCO}_2$ in primary acid-base disorders.

<table>
<thead>
<tr>
<th>Disorder</th>
<th>pH</th>
<th>$\text{HCO}_3^-$</th>
<th>$\text{Pco}_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic acidosis</td>
<td>↓</td>
<td>↓</td>
<td>↓ (compensatory)</td>
</tr>
<tr>
<td>Metabolic alkalosis</td>
<td>↑</td>
<td>↑</td>
<td>↑ (compensatory)</td>
</tr>
<tr>
<td>Respiratory acidosis</td>
<td>↓</td>
<td>↑ (compensatory)</td>
<td>↑</td>
</tr>
<tr>
<td>Respiratory alkalosis</td>
<td>↑</td>
<td>↓ (compensatory)</td>
<td>↓</td>
</tr>
</tbody>
</table>
# 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 $\uparrow$
- $P_CO_2$ $\leftrightarrow$
- Actual $HCO_3^-$ $\downarrow$
- Standard $HCO_3^-$ $\downarrow$
- Base deficit $< -2$

**With respiratory compensation (hyperventilation)**
- $H^+$ ions $\leftrightarrow$ (full compensation) $\uparrow$ (partial compensation)
- $P_CO_2$ $\downarrow$
- Actual $HCO_3^-$ $\downarrow$
- Standard $HCO_3^-$ $\downarrow$
# Metabolic alkalosis

## Metabolic alkalosis

### Common surgical causes

<table>
<thead>
<tr>
<th>Loss of sodium, chloride and water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vomiting</td>
</tr>
<tr>
<td>Loss of gastric secretions</td>
</tr>
<tr>
<td>Diuretic administration</td>
</tr>
</tbody>
</table>

### Hypokalaemia

### Acid–base findings

#### Acute uncompensated

- $\text{H}^+ \text{ ions} \downarrow$
- $P_a\text{CO}_2 \leftrightarrow$
- Actual $\text{HCO}_3^- \uparrow$
- Standard $\text{HCO}_3^- \uparrow$
- Base excess $> + 2$

#### With respiratory compensation (hypoventilation)

- $\text{H}^+ \text{ ions} \leftrightarrow$ (full compensation), $\downarrow$ (partial compensation)
- $P_a\text{CO}_2 \uparrow$
- Actual $\text{HCO}_3^- \uparrow$
- Standard $\text{HCO}_3^- \uparrow$
# Respiratory Acidosis

## Respiratory Acidosis

<table>
<thead>
<tr>
<th>Common surgical causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central respiratory depression</td>
</tr>
<tr>
<td>- Opioid drugs</td>
</tr>
<tr>
<td>- Head injury or intracranial pathology</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pulmonary disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Severe asthma</td>
</tr>
<tr>
<td>- COPD</td>
</tr>
<tr>
<td>- Severe chest infection</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acid-base findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute uncompensated</td>
</tr>
<tr>
<td>- $H^+$ ions $\uparrow$</td>
</tr>
<tr>
<td>- $P_{a}CO_2$ $\uparrow$</td>
</tr>
<tr>
<td>- Actual $HCO_3^-$ $\leftrightarrow$ or $\uparrow$</td>
</tr>
<tr>
<td>- Standard $HCO_3^-$ $\leftrightarrow$</td>
</tr>
<tr>
<td>- Base deficit $&lt;-2$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>With metabolic compensation (renal bicarbonate retention)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- $H^+$ ions $\leftrightarrow$ (full compensation), $\uparrow$ (partial compensation)</td>
</tr>
<tr>
<td>- $P_{a}CO_2$ $\uparrow$</td>
</tr>
<tr>
<td>- Actual $HCO_3^-$ $\uparrow$</td>
</tr>
<tr>
<td>- Standard $HCO_3^-$ $\uparrow\uparrow$</td>
</tr>
</tbody>
</table>
Respiratory alkalosis

<table>
<thead>
<tr>
<th>Common surgical causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Pain</td>
</tr>
<tr>
<td>• Apprehension/hysterical hyperventilation</td>
</tr>
<tr>
<td>• Pneumonia</td>
</tr>
<tr>
<td>• Central nervous system disorders (meningitis, encephalopathy)</td>
</tr>
<tr>
<td>• Pulmonary embolism</td>
</tr>
<tr>
<td>• Septicaemia</td>
</tr>
<tr>
<td>• Salicylate poisoning</td>
</tr>
<tr>
<td>• Liver failure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acid–base findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute uncompensated</td>
</tr>
<tr>
<td>• $H^+$ ions $\downarrow$</td>
</tr>
<tr>
<td>• $P_a CO_2 \downarrow$</td>
</tr>
<tr>
<td>• Actual $HCO_3^- \leftrightarrow$ or $\downarrow$</td>
</tr>
<tr>
<td>• Standard $HCO_3^- \leftrightarrow$</td>
</tr>
<tr>
<td>• Base excess $&gt; +2$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>With metabolic compensation (renal bicarbonate excretion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• $H^+$ ions $\leftrightarrow$ (full compensation), $\downarrow$ (partial compensation)</td>
</tr>
<tr>
<td>• $P_a CO_2 \downarrow$</td>
</tr>
<tr>
<td>• Actual $HCO_3^- \downarrow$</td>
</tr>
<tr>
<td>• Standard $HCO_3^- \downarrow$</td>
</tr>
</tbody>
</table>
THANK YOU

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