# Daily Water Requirements

<table>
<thead>
<tr>
<th>Weight, kg</th>
<th>Water, mL/kg/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>100 mL/kg/day</td>
</tr>
<tr>
<td>11-20</td>
<td>100 mL/kg/day for first 10 kg plus 50 mL/kg/day for each kilogram above 10 kg</td>
</tr>
<tr>
<td>21 and up</td>
<td>100 mL/kg/day for first 10 kg plus 50 mL/kg/day for next 10kg plus 20 mL/kg/day for each kilogram above 20 kg</td>
</tr>
<tr>
<td>BODY WEIGHT</td>
<td>FLUID PER DAY</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>0-10 kg</td>
<td>100 mL/kg</td>
</tr>
<tr>
<td>11-20 kg</td>
<td>1,000 mL + 50 mL/kg for each kg&gt;10 kg</td>
</tr>
<tr>
<td>&gt;20 kg</td>
<td>1,500 mL + 20 mL/kg for each kg&gt;20 kg*</td>
</tr>
</tbody>
</table>
Hourly Maintenance Water Rate

- For body weight of 0-10 kg: 4 mL/kg/hr
- For body weight of 10-20 kg: 40 mL/hr + 2 mL/kg/hr x (wt – 10 kg)
- For body weight of >20: 60 mL/hr + 1 L/kg/hr x (wt – 20 kg)
## Adjustments in Maintenance Water

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>CAUSES OF INCREASED WATER NEEDS</th>
<th>CAUSES OF DECREASED WATER NEEDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>Radiant warmer</td>
<td>Incubator (premature infant)</td>
</tr>
<tr>
<td></td>
<td>Phototherapy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fever/Sweat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Burns</td>
<td></td>
</tr>
<tr>
<td>Lungs</td>
<td>Tachypnea</td>
<td>Humidified ventilator</td>
</tr>
<tr>
<td></td>
<td>Tracheostomy</td>
<td></td>
</tr>
<tr>
<td>Gastrointestinal tract</td>
<td>Diarrhea</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emesis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nasogastric suction</td>
<td></td>
</tr>
<tr>
<td>Renal</td>
<td>Polyuria</td>
<td>Oliguria/anuria</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Surgical drain</td>
<td>Hypothyroidism</td>
</tr>
<tr>
<td></td>
<td>Third spacing</td>
<td></td>
</tr>
</tbody>
</table>
## Factors modifying fluid requirements

<table>
<thead>
<tr>
<th>Factors increasing water requirements</th>
<th>Factors decreasing water requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase in metabolic rate.</td>
<td>1. Decrease in metabolic rate</td>
</tr>
<tr>
<td>a) Fever (increase fluid intake by 12% per °C rise above 37.5°C).</td>
<td>2. Hypothermia (decrease fluid intake by 12% per °C below 37°C).</td>
</tr>
<tr>
<td>b) Hypermetabolic states e.g. salicylism, hyperthyroidism (Increase requirements by 25%).</td>
<td>3. Hypometabolic states e.g. hypothyroidism (Decrease requirement by 10%).</td>
</tr>
<tr>
<td>3. High ambient temperature</td>
<td>5. Extreme inactivity.</td>
</tr>
<tr>
<td>5. Any other abnormal fluid losses.</td>
<td>7. Fluid retention (cardiac failure), oliguria, anuria.</td>
</tr>
</tbody>
</table>
HISTORICAL DATA REQUIRED IN ESTIMATING MAGNITUDE AND TYPES OF DEFICIT AND IN PLANNING DEFICIT THERAPY

- Intake - during period of illness
  - Quantity and how given
  - Kind: water, electrolyte, protein, drugs

- Output – during period of illness
  - Quantity
  - Kind: urine, vomiting, diarrhea, sweat, drainage

- Balance
  - Weight change

- General medical
  - Age
  - Cardiovascular, respiratory, renal, or central nervous system
(Expected or recent weight) - (Current weight)

Percent dehydration = Expected weight \times 100
<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body fluid lost (ml/kg)</td>
<td>&lt;50</td>
<td>50-100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Weight loss (%)</td>
<td>&lt;5</td>
<td>5-10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Stage of stock</td>
<td>Impending</td>
<td>Compensated</td>
<td>Uncompensated</td>
</tr>
</tbody>
</table>

**Vital Signs**

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate</td>
<td>Slight ↑</td>
<td>↑ (orthostasis)</td>
<td>↑↑</td>
</tr>
<tr>
<td>Respiratory</td>
<td>Normal</td>
<td>Normal</td>
<td>↑(Hyperpnea)</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>Normal</td>
<td>Normal</td>
<td>↓</td>
</tr>
</tbody>
</table>

**Skin**

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capillary refill (finger)</td>
<td>&lt;2 sec</td>
<td>2-3 sec</td>
<td>&gt;3 sec</td>
</tr>
<tr>
<td>Elasticity (&lt;2 yrs)</td>
<td>Normal</td>
<td>↓</td>
<td>↓↓ (Tenting)</td>
</tr>
<tr>
<td>Anterior fontanel</td>
<td>Normal</td>
<td>Depressed</td>
<td>Depressed</td>
</tr>
<tr>
<td>Mucous membranes</td>
<td>Normal/dry</td>
<td>Dry</td>
<td>Dry</td>
</tr>
</tbody>
</table>
## CLINICAL ESTIMATION OF DEGREE OF DEHYDRATION

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNS</td>
<td>Normal</td>
<td>Altered</td>
<td>Depressed</td>
</tr>
<tr>
<td>Mental status</td>
<td>Normal</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Eyes</td>
<td>Normal/absent</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Tearing</td>
<td>Normal</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Appearance</td>
<td>Normal</td>
<td>Sunken</td>
<td>Sunken</td>
</tr>
<tr>
<td>Laboratory Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>Small</td>
<td>Oliguria</td>
<td>Oliguria-anuria</td>
</tr>
<tr>
<td>Osmolarity</td>
<td>600</td>
<td>800</td>
<td>Maximal</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.020</td>
<td>1.025</td>
<td>Maximal</td>
</tr>
<tr>
<td>Blood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood urea nitrogen</td>
<td>Upper normal</td>
<td>Elevated</td>
<td>High</td>
</tr>
<tr>
<td>pH</td>
<td>7.40-7.22</td>
<td>7.30-6.92</td>
<td>7.10-6.80</td>
</tr>
</tbody>
</table>
Deficit (mEq) = Body weight (kg) \times \\
\quad [\text{Desired concentration (mEq/L)} - \text{Actual concentration (mEq/L)}] \times \text{Distribution factor}
Clinical Evaluation of Dehydration

- Mild dehydration (<5% in an infant; <3% in an older child or adult): normal or increased pulse; decreased urine output; thirsty; normal physical finding.

- Moderate dehydration (5-10% in an infant; 3-6% in an older child or adult): tachycardia; little or no urine output; irritable/lethargic; sunken eyes and fontanel; decreased tears; dry mucous membranes; mild delay in elasticity (skin turgor); delayed capillary refill (>1.5 sec); cool and pale

- Severe dehydration (>10% in an infant; 6% in an older child or adult): rapid and weak or absent peripheral pulses; decreased blood pressure; no urine output; very sunken eyes and fontanel; no tears; parched mucous membranes; delayed elasticity (poor skin turgor); very delayed capillary refill (>3 sec); cold and mottled; limp, depressed consciousness
Fluid Management of Dehydration

- Restore intravascular volume
  - Normal saline: 20 mL/kg over 20 min
  - Repeat as needed
- Rapid volume repletion: 20 mL/kg normal saline or Ringer Lactate (maximum = 1L) over 2 hr
- Calculate 24-hr fluid needs: maintenance + deficit volume
- Subtract isotonic fluid already administered from 24 hr fluid needs
- Administer remaining volume over 24 hr using D5 ½ normal saline + 20 mEq/L KCl
- Replace ongoing losses as they occur
## Composition of Intravenous Solutions

<table>
<thead>
<tr>
<th>FLUID</th>
<th>[Na(^+)]</th>
<th>[Cl(^-)]</th>
<th>[K(^+)]</th>
<th>[Ca(^{2+})]</th>
<th>[Lactate]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal saline (0.9% NaCl)</td>
<td>154</td>
<td>154</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>½ normal saline (0.45% NaCl)</td>
<td>77</td>
<td>77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2 normal saline (0.2% NaCl)</td>
<td>34</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ringer lactate</td>
<td>130</td>
<td>109</td>
<td>4</td>
<td>3</td>
<td>28</td>
</tr>
</tbody>
</table>
Monitoring Therapy

VITAL SIGNS
  Pulse
  Blood pressure

INTAKE AND OUTPUT
  Fluid balance
  Urine output and specific gravity

PHYSICAL EXAMINATION
  Weight
  Clinical signs of depletion or overload
## ORAL ELECTROLYTE SOLUTION COMPOSITION

<table>
<thead>
<tr>
<th></th>
<th>Sodium (mEq/L)</th>
<th>Potassium (mEq/L)</th>
<th>Chloride (mEq/L)</th>
<th>Carbohydrate (g/dl)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rehydration solutions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHO formation</td>
<td>90</td>
<td>20</td>
<td>80</td>
<td>2.0 (glucose)</td>
</tr>
<tr>
<td>Rehydralyte</td>
<td>75</td>
<td>20</td>
<td>65</td>
<td>2.5 (glucose)</td>
</tr>
<tr>
<td><strong>Maintenance solutions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedialyte</td>
<td>45</td>
<td>20</td>
<td>35</td>
<td>2.5 (glucose)</td>
</tr>
<tr>
<td>Lytren</td>
<td>50</td>
<td>25</td>
<td>45</td>
<td>2.0 (glucose)</td>
</tr>
<tr>
<td>Resol</td>
<td>50</td>
<td>20</td>
<td>50</td>
<td>2.0 (glucose)</td>
</tr>
<tr>
<td>Infalyte</td>
<td>50</td>
<td>20</td>
<td>40</td>
<td>2.0 (glucose)</td>
</tr>
<tr>
<td>Ricelyte</td>
<td>50</td>
<td>25</td>
<td>45</td>
<td>30 (glucose polymers)</td>
</tr>
<tr>
<td>Fluid</td>
<td>Sodium (mmol/L)</td>
<td>Potassium (mmol/L)</td>
<td>Carbohydrates (gm/100 mL)</td>
<td>Osmolarity (mmol/L)</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------</td>
<td>--------------------</td>
<td>---------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Beef broths</td>
<td>110-248</td>
<td>2.5-17</td>
<td>-</td>
<td>300-390</td>
</tr>
<tr>
<td>Chicken broths</td>
<td>140-251</td>
<td>1.5-8.2</td>
<td>-</td>
<td>380-500</td>
</tr>
<tr>
<td>Apple juice</td>
<td>0.1–3.5</td>
<td>24-92</td>
<td>12</td>
<td>650-734</td>
</tr>
<tr>
<td>Grape juice</td>
<td>0.8-2.8</td>
<td>31-44</td>
<td>15</td>
<td>1170-1190</td>
</tr>
<tr>
<td>Colas</td>
<td>1.3-1.7</td>
<td>0.1</td>
<td>10.4-11.3</td>
<td>390-750</td>
</tr>
<tr>
<td>Ginger ale</td>
<td>0.8-5.5</td>
<td>0.1-1.5</td>
<td>5.3</td>
<td>520-560</td>
</tr>
<tr>
<td>7-Up</td>
<td>5-5.5</td>
<td>1.0-2.0</td>
<td>7.4</td>
<td>520-550</td>
</tr>
<tr>
<td>Kool-Aid</td>
<td>0.5-1.2</td>
<td>0.1-1.8</td>
<td>10.6</td>
<td>250-590</td>
</tr>
<tr>
<td>Popsicles</td>
<td>4.7-5.6</td>
<td>0.5-2.0</td>
<td>NA</td>
<td>670-720</td>
</tr>
<tr>
<td>Jell-O</td>
<td>22-27</td>
<td>1.3-2.0</td>
<td>15.8</td>
<td>570-640</td>
</tr>
<tr>
<td>Tea (unsweetened)</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Gatorade</td>
<td>20</td>
<td>3</td>
<td>4.6</td>
<td>330</td>
</tr>
</tbody>
</table>
## Emergency Treatment of Hyperkalemia

<table>
<thead>
<tr>
<th>Techniques</th>
<th>Agent</th>
<th>Dose</th>
<th>Rate of Administration</th>
<th>Onset/Duration of Action</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversal of membrane effects</td>
<td>10% calcium gluconate</td>
<td>0.5 ml/kg</td>
<td>2-5 min IV</td>
<td>Min/30-60 min</td>
<td>ECG monitor; discontinue if pulse rate &lt;100</td>
</tr>
<tr>
<td>Movement of K into cells</td>
<td>Na bicarbonate, 7.5% (1 mEq)</td>
<td>2-3 ml/kg</td>
<td>30-60 min</td>
<td>30 min/1-4 hr</td>
<td>May use in the absence of acidosis</td>
</tr>
<tr>
<td></td>
<td>Glucose 50% plus insulin</td>
<td>1 unit for every 5-6 g glucose</td>
<td>Same</td>
<td>Same</td>
<td>Monitor blood glucose</td>
</tr>
<tr>
<td></td>
<td>(regular)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enchanced excretion of K</td>
<td>Kayexalate</td>
<td>1 g/kg</td>
<td>Can be given in 10% glucose (1 g in 4 ml) every 4-6 hr</td>
<td>Hours/variable</td>
<td>Can be given p.o. or by rectum</td>
</tr>
</tbody>
</table>
Complications of Alkali Therapy in Metabolic Acidosis

- Hypokalemia
  A. K⁺ losses as part of the disease process (e.g. renal tubular acidosis, diabetic ketoacidosis)
  B. K⁺ shifts into cells
- Alkalosis
  A. Overcorrection
  B. Persistent hyperventilation
  C. Endogenous manufacture of HCO₃⁻
- CSF Acidosis
  A. Delay in equilibration of HCO₃⁻ across the blood-brain barrier
- Sodium Overload
- Hypocalcemic Tetany
  A. Ca²⁺ binding to protein
  B. Ca²⁺ incorporation into bone
## Appropriate Compensation During Simple Acid-Base Disorders

<table>
<thead>
<tr>
<th>DISORDER</th>
<th>EXPECTED COMPENSATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic acidosis</td>
<td>PCO₂ = 1.5x [HCO₃⁻] + 8 ± 2</td>
</tr>
<tr>
<td>Metabolic alkalosis</td>
<td>PCO₂ increased by 7 mm Hg for each 10 mEq/L increase in serum [HCO₃⁻]</td>
</tr>
<tr>
<td>Respiratory acidosis</td>
<td></td>
</tr>
<tr>
<td>Acute</td>
<td>[HCO₃⁻] increased by 1 for each 10-mm Hg increase in PCO₂</td>
</tr>
<tr>
<td>Chronic</td>
<td>[HCO₃⁻] increased by 3.5 for each 10-mm Hg increase in PCO₂</td>
</tr>
<tr>
<td>Respiratory alkalosis</td>
<td></td>
</tr>
<tr>
<td>Acute</td>
<td>[HCO₃⁻] falls by 2 each 10-mm Hg decrease in PCO₂</td>
</tr>
<tr>
<td>Chronic</td>
<td>[HCO₃⁻] falls by 4 each 10-mm Hg decrease in PCO₂</td>
</tr>
<tr>
<td>Normal Values of Arterial Blood Gas</td>
<td></td>
</tr>
<tr>
<td>------------------------------------</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.35-7.45</td>
</tr>
<tr>
<td>$[\text{HCO}_3^-]$</td>
<td>20-25 mEq/L</td>
</tr>
<tr>
<td>$\text{PCO}_2$</td>
<td>35-45 mm Hg</td>
</tr>
</tbody>
</table>
Causes of Metabolic Acidosis

Increased Anion Gap

- Lactic acidosis
  - Tissue hypoxia (shock, hypoxemia, severe anemia)
  - Liver failure
  - Malignancy
  - Intestinal bacterial overgrowth
  - Inborn errors of metabolism
  - Medications (nucleoside analogues, metformin)

- Ketoacidosis
  - Diabetic ketoacidosis
  - Starvation ketoacidosis
  - Alcoholic ketoacidosis

- Kidney failure

- Poisoning
  - Ethylene glycol
  - Methanol
  - Salicylate
  - Toluene
  - Paraldehyde

- Inborn errors or metabolism
Causes of Respiratory Alkalosis

CENTRAL STIMULATION

- Central nervous system disease
  - Subarachnoid hemorrhage
  - Encephalitic or meningitis
  - Trauma
  - Brain tumor
  - Stroke
- Fever
- Pain
- Anxiety (panic attack)
- Psychogenic hyperventilation or anxiety
- Liver failure
- Sepsis
- Pregnancy
- Medications
  - Salicylate intoxication
  - Theophylline
  - Progesterone
  - Exogenous catecholamines
  - Caffeine
- Mechanical ventilation
- Hyperammonemia
- Extracorporeal membrane oxygenation or hemodialysis
Treatment of Hypernatremic Dehydration

- **RESTORE INTRAVASCULAR VOLUME**
  Normal saline: 20mL/kg over 20 min
  (Repeat until intravascular volume restored)

- **DETERMINE TIME FOR CORRECTION BASED ON INITIAL SODIUM CONCENTRATION**
  - $[\text{Na}]: 145-157 \text{ mEq/L}: 24 \text{ hr}$
  - $[\text{Na}]: 158-170 \text{ mEq/L}: 48 \text{ hr}$
  - $[\text{Na}]: 171-183 \text{ mEq/L}: 72 \text{ hr}$
  - $[\text{Na}]: 184-196 \text{ mEq/L}: 84 \text{ hr}$
Treatment of Hypernatremic Dehydration

- ADMINISTER FLUID AT CONSTANT RATE OVER TIME FOR CORRECTION
  Typical fluid: D5½ normal saline (with 20 mEq/L KCl unless contraindicated)
  Typical rate: 1.25-1.5 times maintenance

- FOLLOW SERUM SODIUM CONCENTRATION ADJUST FLUID BASED ON
  CLINICAL STATUS AND SERUM SODIUM CONCENTRATION
  Signs of volume depletion: administer normal saline (20 mL/kg)
  Sodium decrease too rapidly
    - Increase sodium concentration of intravenous fluid, or
    - Decrease rate of intravenous fluid
  Sodium decreases too slowly
    - Decrease sodium concentration of intravenous fluid, or
    - Increase rate of intravenous fluid

- REPLACE ONGOING LOSSES AS THEY OCCUR
## Emergency Treatment of Hyperkalemia

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<td>Hours/variable</td>
<td>Can be given p.o. or by rectum</td>
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</table>
ETIOLOGY OF DEHYDRATION

- Reduced intake
  - Anorexia
  - Coma
  - Fluid restriction

- Increased loss
  - Gastrointestinal
    - Vomiting
    - Diarrhea
    - Enterocutaneous fistula or drains
  - Renal
    - Osmotic diuresis
    - Diuretic administration
    - Adrenal insufficiency
    - Chronic renal failure
    - Salt-losing nephropathy
    - Post obstructive diuresis
    - Central or nephrogenic diabetes insipidus
  - Skin and respiratory
    - Heat exposure
    - Cystic fibrosis
    - Inflammatory skin disease
    - Burns
# Composition of Oral Rehydration Solutions

<table>
<thead>
<tr>
<th>Solution</th>
<th>Glucose (mmol/L)</th>
<th>Na (mEq/L)</th>
<th>K (mEq/L)</th>
<th>Cl (mEq/L)</th>
<th>BASE (mEq/L)</th>
<th>OSMOVLALILTY (mOsom/kg)</th>
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<tbody>
<tr>
<td>WHO solution</td>
<td>111</td>
<td>90</td>
<td>20</td>
<td>80</td>
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<tr>
<td>Rehydralyte</td>
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<td>75</td>
<td>20</td>
<td>65</td>
<td>30</td>
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<td>Pedialyte</td>
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<td>45</td>
<td>20</td>
<td>35</td>
<td>30</td>
<td>250</td>
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<tr>
<td>Pediatric Electrolyte</td>
<td>140</td>
<td>45</td>
<td>20</td>
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<td>250</td>
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<tr>
<td>Infalyte</td>
<td>70*</td>
<td>50</td>
<td>25</td>
<td>45</td>
<td>34</td>
<td>200</td>
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<tr>
<td>Naturalyte</td>
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<td>45</td>
<td>20</td>
<td>35</td>
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<td>238</td>
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# Symptoms and Signs of Hyponatremia

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lethargy, apathy</td>
<td>Abnormal sensorium</td>
</tr>
<tr>
<td>Disorientation</td>
<td>Depressed deep tendon reflexes</td>
</tr>
<tr>
<td>Muscle cramps</td>
<td>Chyne-Stokes respiration</td>
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<tr>
<td>Anoxeria, nausea</td>
<td>Hypothermia</td>
</tr>
<tr>
<td>Agitation</td>
<td>Pathological reflexes</td>
</tr>
<tr>
<td></td>
<td>Pseudobulbar palsy</td>
</tr>
<tr>
<td></td>
<td>Seizures</td>
</tr>
</tbody>
</table>
TREATMENT OF HYPERKALEMIA

- Membrane-reversing effects
  - 10% calcium gluconate, 0.5-1.0 mg/kg IV over 2-5 min
    1. May repeat in 5-10 min
    2. Duration of action 30-60 min
    3. EKG monitoring

- Transcellular shifting of potassium
  - Sodium bicarbonate, 1-2 mEq/kg IV over 5-10 min
    1. May repeat in 15 min
    2. Duration of action up to 2 hr
    3. EKG monitoring
  - Glucose, 0.5 to 1.0 gm/kg IV over 30 min
    1. May repeat as needed
    2. Duration of action 4-6 hr
    3. May administer regular insulin IV (1 unit/3 gm glucose of 1 unit/kg)
    4. Glucose monitoring

- Potassium elimination
  - Diuretics
  - Ion exchange resin (sodium polystyrene sulfonate) 1 gm/kg
    1. Retention enema, 0.5 to 1.0 gm/kg over 30-45 min
      (a) Sorbitol 20%-25% solution, 3 mL/gm resin
    2. Orally: 0.5 to 1.9 gm/kg
      (a) Water, 3-4ml/gm resin
      (b) Sorbitol 70% solution or dextrose 10% solution
  - Dialysis
    1. Preferably hemodialysis
    2. Peritoneal dialysis
Etiologies of Hyponatremia

- Normal Total Body Water and Na
  (Hyperosmolar Hyponatremia)
  A. Hyoerglycemia*
  B. Mannitol, glycerol therapy

- Increased Total Body, Water and Na
  (Edema-Forming States)
  A. Congestive heart failure
  B. Nephrosis
  C. Cirrhosis
  D. Acute renal failure
Etiologies of Hyponatremia

- Decreased Total Body Water and Na (Hypovolemic States)
  A. Gastrointestinal losses (vomiting, diarrhea, fistulas)
  B. Renal losses (diuretics, renal tubular acidosis, primary interstitial disease)
  C. Adrenal (mineralocorticoid deficiencies)
  D. Third-space losses (ascites, burns, pancreatitis, peritonitis)

- Increased Total Body Water but Normal Total Body Na
  A. Syndrome of inappropriate antidiuretic hormone secretion
  B. Water intoxication
  C. Miscellaneous (reset osmostat, hypothyroidism, glucocorticoid deficiency)

- Psedohyponatremia
  A. Extreme hyperlipidemia or hyperproteinemia
<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anorexia</td>
<td>Clouded sensorium</td>
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<tr>
<td>Nausea</td>
<td>Decreased tendon reflexes</td>
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<tr>
<td>Muscle cramps</td>
<td>Pathologic reflexes</td>
</tr>
<tr>
<td>Apathy</td>
<td>Hypothermia</td>
</tr>
<tr>
<td>Disorientation</td>
<td>Pseudobulbar palsy</td>
</tr>
<tr>
<td>Agitation</td>
<td>Seizures</td>
</tr>
<tr>
<td>Acute respiratory failure</td>
<td></td>
</tr>
</tbody>
</table>
Laboratory Evaluation of Hyponatremia

- **Blood**
  - A. Electrolytes (Na, K, Cl, HCO$_3^-$)
  - B. BUN, creatinine
  - C. Liver function tests
  - D. Osmolality

- **Urine**
  - A. Urinalysis, including specific gravity
  - B. Urine Na
  - C. Urine creatinine
  - D. Urine osmolality
Etiologies of Hypernatremia

- Increased Total Body Na or Increased Total Body Na Greater than Increased Total Body Water
  - A. Na poisoning (accidental: Na bicarbonate therapy)
  - B. Hyperaldosteronism (rare in children)
- Normal Total Body Na; “Pure” Water Loss
  - A. Insensible losses – respiratory and skin
  - B. Renal (central and nephrogenic diabetes insipidus)
  - C. Inadequate access to water
Etiologies of Hypernatremia

- Decreased Total Body Na Less than Decreased Total Body Water
  - A. Extrarenal (gastrointestinal)\(^a\)
  - B. Renal (osmotic diuretics; glucose, mannitol, urea)
  - C. Obstructive uropathy

- Normal Total Body Na and Water with Abnormal Central Osmotic Regulation of Water Balance
  - A. Essential hypernatremia
Etiologies of Hypokalemia

- Apparent K Deficit (transcellular shifts)
  - A. Alkalosis
  - B. Familial hypokalemic periodic paralysis
  - C. Insulin
  - D. $\beta_2$ catecholamine

- Decreased Intake
  - A. Anorexia nervosa
  - B. Unusual diets (rate in pediatrics)

- Extra renal Losses
  - A. Protracted vomiting (e.g., pyloric stenosis or gastric suction)
  - B. Protracted diarrhea
  - C. Ureterosigmoidostomy
  - D. Laxative abuse (rare in pediatrics)
  - E. Increased sweating (cystic fibrosis)
Etiologies of Hypokalemia

- Renal Losses
  - A. Diuretic abuse (naturetic, osmotic agents)
  - B. Renal tubular acidosis
  - C. Diabetic ketoacidosis
  - D. Excessive mineral corticoid effect
    1. Primary/secondary hyperaldosteronism
    2. Bartter’s syndrome
    3. Licorice abuse (rare in pediatrics)
    4. Cushing’s syndrome (rare in pediatrics)
  - E. Excessive administration of “impermeant anions” (carbenicillin)
Pathophysiologic (Clinical) Consequences of Hypokalemia

- Muscle cell dysfunction (rhabdomyolysis)
- Cardiac cell dysfunction (myocardiopathy, arrhythmias)
- Neuromuscular dysfunction (weakness-paralysis, ileus, tetany, encephalopathy with underlying liver disease)
- Renal (polydipsia, polyuria, concentration defect)
Laboratory Evaluation of Hypokalemia

- **Blood**
  - A. Electrolytes (Na, K, Cl, HCO₃⁻)
  - B. BUN, creatinine
  - C. Glucose
  - D. Arterial blood gas
  - E. Creatine phosphokinase

- **Urine**
  - A. Urinalysis
  - B. Urine Na, K, Cl
  - C. Urine pH
  - D. Urine osmolality

- **Other**
  - A. ECG
  - B. Plain abdominal x-ray
  - C. Upper gastrointestinal series or ultrasound
Etiologies of Hyperkalemia

- Pseudohyperkalemia (*Hemolysis, extreme leukocytosis, or thrombocytosis*)
- Apparent K Excess (Transcellular shifts)
  - A. Acidosis
- Increased Intake
  - A. Endogenous (rhabdomyolysis, massive hemolysis)
  - B. Exogenous (suicide attempt with K salts)
- Decreased Excretion
  - A. Acute or chronic renal failure (oliguria)
  - B. Adrenal corticoid deficiency (acute adrenal insufficiency, hyporeninemic hypoaldosteronism)
  - C. Use of K-sparing diuretics in renal failure or in conjunction with dietary K supplements
  - D. B-Blockers, converting enzyme inhibitors
Laboratory Evaluation of Hyperkalemia

- **Blood**
  - A. Electrolytes (Na, K, Cl, HCO₃⁻)
  - B. BUN, creatinine
  - C. Glucose
  - D. Arterial blood gas
  - E. Creatine phosphokinase

- **Urine**
  - A. Urinalysis
  - B. Urine Na, K, Cl
  - C. Urine pH
  - D. Urine osmolality

- **Other**
  - A. ECG
Etiologies of Metabolic Acidosis

- Elevated Anion Gap Acidosis
  A. Diarrhea dehydration
  B. Diabetic ketoacidosis
  C. Renal failure (acute or chronic)
  D. Inborn errors of metabolism
  E. Poisons (e.g. salicylates, ethanol, ethylene glycol)
  F. Kactic acidosis (e.g. hypoxia, sepsis, idiopathic)

- Normal Anion Gap Acidosis
  A. Hypernatremic dehydration (older children)
  B. Renal tubular acidosis
  C. Hyper alimentation
  D. Enteric fistulas (e.g. pancreatic) or enterostomies
  F. Drugs (e.g., Sulfamylon, ammonium chloride, amphotericin, acetazolamide)
  G. Early renal failure (chronic interstitial nephritis)
  H. Dilution (rapid volume expansion)
Laboratory Evaluation of Metabolic Acidosis

- **Blood**
  - A. Electrolytes (Na, K, Cl, HCO$_3$)$_a$
  - B. Arterial blood gases
  - C. BUN, creatinine
  - D. Glucose
  - E. Toxic screen$^b$
  - F. Lactate, pyruvate$^c$

- **Urine**
  - A. Dipstick (pH, glucose, protein)
Causes of Metabolic Acidosis

Normal Anion Gap

- Diarrhea
- Renal tubular acidosis (RTA)
  - Distal (type 1) RTA (MIM: 179800/602722/267300)*
  - Proximal (type 11) RTA (MIM: 604278)†
  - Hyperkalemia (type IV) RTA (MIM: 201910/264350/177735/145260) †
- Urinary tract diversion
- Posthypocapnia
- Ammonium chloride intake
Causes of Metabolic Alkalosis

CHLORIDE RESPONSIVE (URINARY CHLORIDE < 15 mEq/L)

- Gastric losses (emesis or nasogastric suction)
- Diuretics (loop or thiazide)
- Chloride-losing diarrhea (MIM 214700)
- Chloride-deficient formula
- Cystic fibrosis (MIM 219700)
- Post-hypercapnia
Causes of Metabolic Alkalosis

CHLORIDE RESISTANT (URINARY CHLORIDE > 20 mEq/L)

- High blood pressure
  - Adrenal adenoma or hyperplasia
  - Glucocorticoid-remedial aldosteronism (MIM 103900)
- Renovascular disease
- Renin-secreting tumor
- 17α-hydroxylase deficiency (MIM 202110)
- 11β-hydroxylase deficiency (MIM 202010)
- Cushing syndrome
- 11β—hydroxysteroid dehydrogenase deficiency (MIM 218030)
- Licorice ingestion
- Liddle syndrome (MIM 177200)
Causes of Metabolic Alkalosis

- Normal blood pressure
- Gitelman syndrome (MIM 263800)
- Bartter syndrome (MIM 602023/607364/602522/241200/601678)
- Autosomal dominant hypoparathyroidism (MIM 146200)
- Base administration
Causes of Respiratory Acidosis

CENTRAL NERVOUS SYSTEM DEPRESSION

- Encephalitis
- Head trauma
- Brain tumor
- Central sleep apnea
- Primary pulmonary hypoventilation (Ondine curse)
- Stroke
- Hypoxic brain damage
- Obesity-hypoventilation (Pickwickian syndrome)
- Increased intracranial pressure
- Medications
  - Narcotics
  - Barbiturates
  - Anesthesia
  - Benzodiazepines
  - Propofol
  - Alcohols
Causes of Respiratory Acidosis

DISORDERS OF THE SPINAL CORD, PERIPHERAL NERVES, OR NEUROMUSCULAR JUNCTION

- Diaphragmatic paralysis
- Guillain-Barré syndrome
- Poliomyelitis
- Spinal muscular atrophies
- Tick paralysis
- Botulism
- Myasthenia
- Multiple sclerosis
- Spinal cord injury
- Medications
  - Vecuronium
  - Aminoglycosides
  - Organophosphates (pesticides)
Causes of Respiratory Acidosis

RESPIRATORY MUSCLE WEAKNESS

- Muscular dystrophy
- Hypothyroidism
- Malnutrition
- Hypokalemia
- Hypophosphatemia
- Medications
  - Succinycholine
  - Corticosteroids
Causes of Respiratory Acidosis

PULMONARY DISEASE

- Pneumonia
- Pneumothorax
- Asthma
- Bronchiolitis
- Pulmonary edema
- Pulmonary hemorrhage
- Adult respiratory distress syndrome
- Respiratory distress syndrome, neonatal
- Cystic fibrosis
- Bronchopulmonary dysphasia
- Hypo plastic lungs
- Meconium aspiration
- Pulmonary thromboembolus
- Interstitial fibrosis
Causes of Respiratory Acidosis

UPPER AIRWAY DISEASE
- Aspiration
- Laryngospasm
- Angiodema
- Obstructive sleep apnea
- Tonsillar hypertrophy
- Vocal cord paralysis
- Extrinsic tumor
- Extrinsic or intrinsic hemangioma
Causes of Respiratory Acidosis

MISCELLANEOUS

- Flail chest
- Cardiac arrest
- Kyphoscoliosis
- Decreased diaphragmatic movement due to ascites or peritoneal disease.
Causes of Respiratory Alkalosis

HYPOXEMIA OR TISSUE HYPOXIA

- Pneumonia
- Pulmonary edema
- Cyanotic heart disease
- Congestive heart failure
- Asthma
- Severe anemia
- High altitude
- Laryngospasm
- Aspiration
- Carbon monoxide poisoning
- Pulmonary embolism
- Interstitial lung disease
- Hypotension
Causes of Respiratory Alkalosis

LUNG RECEPTOR STIMULATION

- Pneumonia
- Pulmonary edema
- Asthma
- Pulmonary embolism
- Hemothorax
- Pneumothorax
- Respiratory distress syndrome (adult or infant)
Causes of Respiratory Alkalosis
Goals of Maintenance Fluids

- Prevent dehydration
- Prevent electrolyte disorders
- Prevent ketoacidosis
- Prevent protein degradation
Sources of Water Loss

Urine: 60%
Insensible losses: ~ 35% (skin and lungs)
Stool: 5%
Replacement Fluid for Diarrhea

AVERAGE COMPOSITION OF DIARRHEA

- Sodium: 55 mEq/L
- Potassium: 25 mEq/L
- Bicarbonate: 15 mEq/L

APPROACH TO REPLACEMENT OF ONGOING LOSSES

Solution: D5 0.2 normal saline + 20 mEq/L sodium bicarbonate + 20 mEq/L KCl

Replace stool mL/mL every 1-6 hr
Replacement Fluid for Emesis or Nasogastric Losses

AVERAGE COMPOSITION OF GASTRIC FLUID

- Sodium: 60 mEq/L
- Potassium: 10 mEq/L
- Chloride: 90 mEq/L

APPROACH TO REPLACEMENT OF ONGOING LOSSES

- Solution: normal saline + 10 mEq/L KCl
- Replace output mL/mL every 1-6 hr
Adjusting Fluid Therapy for Altered Renal Output

OLIGURIA/ANURIA

Place patient on insensible fluids (25-40% of maintenance)
Replace urine output mL/mL with ½ normal saline

POLYURIA

Place patient on insensible fluids (25-40% of maintenance)
Measure urine electrolytes
Replace urine output mL/mL with solution based on measured urine electrolytes
Conversions and Estimates

Temperature
➢ To convert centigrade to Fahrenheit:
   \[(9/5 \times \text{temperature}) + 32\]
➢ To convert Fahrenheit to centigrade:
   \[(\text{temperature} - 32) \times \frac{9}{5}\]
Conversions and Estimates

Weight
To change pounds to grams, multiply by 454
To change kilograms to pounds, multiply by 2.2

Growth Patterns
Birth weight (average): 3.3 kg (7 lb 5 oz)
A new born loses up to 10% of birth weight but should be up to birth weight again by 10 days.

An infant gains 30 g (1 oz) day for the first 1-2 month
5 month: birth weight should be doubled
12 month: birth weight should be tripled
2 yr: birth weight should be quadrupled

Estimates of Weight
4 to 8-year-old: 6 x age + 12 = Weight (lb)
8 to 12-year-old: 7 x age + 5 = Weight (lb)
Conversions and Estimates

Length

To convert inches to centimeters, multiply by 2.54
To convert centimeters to inches, multiply by 0.394

- Growth Patterns
  - Birth length (average): 50 cm (20 in)
  - 12 month: birth length should be doubled
Conversions and Estimates

Head Circumference

- Growth Patterns
  - Birth head circumference (average): 35 cm (14 in)
  - 12 month head circumference (average): 47 cm (19 in)
  - Head circumference grows 1 cm/month during first 9 months
Conversions and Estimates

Blood Pressure (estimate)

Systolic BP (mm Hg) = 2 x Age (yr) + 80
Diastolic BP (mm Hg) = 2/3 systolic
## Conversions and Estimates

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<thead>
<tr>
<th>To convert</th>
<th>To</th>
<th>Multiply by</th>
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<tbody>
<tr>
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<td>PSI</td>
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<tr>
<td>1 cm H₂O</td>
<td>Mm Hg</td>
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<td>1 mm Hg</td>
<td>Cm H₂O</td>
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<td>Cm</td>
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<tr>
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<td>Pound</td>
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<tr>
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<td>Kg</td>
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</tr>
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## Composition of Oral Rehydration Salts Solution for Severely Malnourished Children (ReSoMal)

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>CONCENTRATION (mmol/L)</th>
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<tr>
<td>Glucose</td>
<td>125</td>
</tr>
<tr>
<td>Sodium</td>
<td>45</td>
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<tr>
<td>Potassium</td>
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<tr>
<td>Chloride</td>
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<tr>
<td>Magnesium</td>
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</tr>
<tr>
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<tr>
<td>Copper</td>
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