Fluids and Electrolytes

Disorders affecting the body fluids and electrolytes are treated by supplying maintenance requirements, correcting volume and electrolyte deficits, and by replacing ongoing abnormal losses.

I. **Dehydration**

A. **Maintenance Fluid and Electrolytes**

1. Sensible losses, primarily urinary, account for approximately 50% of daily fluid requirements. Urinary fluid losses are included in maintenance water requirements provided that total daily urine output is not more than 50% of the calculated water maintenance.
2. Caloric requirements for growth can be estimated as equivalent on a kcal-for-mL basis to water requirements.
3. Factors that increase the requirements for calories and for water are fever (10% for each degree), physical activity, ongoing gastrointestinal losses, hyperventilation, and hypermetabolic states. Anuria, oliguria, and congestive heart failure may reduce the requirements for water.

Maintenance Requirements for Fluid and Electrolytes, Based on Body Weight			
Body Weight	**0 to 10 kg**	**10 to 20 kg**	**>20 kg**
Water Volume	100 mL/kg	1000 mL + 50 mL/kg for each kg >10 kg	1500 mL + 20 mL/kg for each kg >20 kg
Sodium	3 mEq/kg	3 mEq/kg	3 mEq/kg
Potassium	2 mEq/kg	2 mEq/kg	2 mEq/kg
Chloride	5 mEq/kg	5 mEq/kg	5 mEq/kg

4. Abnormal losses, such as those arising from nasogastric aspiration, prolonged diarrhea, or burns, should be analyzed, measured, and replaced on a volume for volume basis.

B. **Estimation of Deficit**

1. Assessment of volume depletion should assess fever, vomiting and/or diarrhea, and urine output. The type and amount of fluid loss are determined. Recent feeding, including type and volume of food and drink, and weight change are determined.

2. The physical examination aids in estimating the extent of dehydration.

Estimation of Dehydration			
Degree of Dehydration	**Mild**	**Moderate**	**Severe**
Weight Loss--Infants	5%	10%	15%
Weight Loss--Children	3-4%	6-8%	10%
Pulse	Normal	Slightly increased	Very increased
Blood Pressure	Normal	Normal to orthostatic, >10 mm Hg change	Orthostatic to shock
Behavior	Normal	Irritable	Hyperirritable to lethargic
Thirst	Slight	Moderate	Intense
Mucous Membranes	Normal	Dry	Parched
Tears	Present	Decreased	Absent tears, sunken eyes
Anterior Fontanelle	Normal	Normal to sunken	Sunken
External Jugular Vein	Visible when supine	Not visible except with supraclavicular pressure	Not visible even with supraclavicular pressure
Skin	Capillary refill <2 sec	Delayed capillary refill, 2-4 sec (decreased turgor)	Very delayed capillary refill (>4 sec), tenting; cool, acrocyanotic, or mottled skin
Urine Specific Gravity (SG)	>1.020	>1.020; oliguria	Oliguria or anuria

3. The percent dehydration is used to calculate the milliliters of body water deficit per kilogram of body weight.

C. **Isonatremic Dehydration**

1. The most common cause of dehydration in infants is diarrhea.
2. Children who have a brief illness and anorexia usually present with proportional water and electrolyte losses, and isotonic dehydration.

3. Oral Rehydration

a. Moderate volume depletion should be treated with oral fluids. The majority of patients who have gastroenteritis and moderate dehydration can be treated with oral rehydration therapy.

b. Small aliquots of oral hydration solution (Ricelyte, Pedialyte, Resol, Rehydralyte) are given as tolerated to provide 50 mL/kg over 4 hours in mild dehydration and up to 100 mL/kg over 6 hours in moderate dehydration. Once rehydration is accomplished, maintenance fluid is given at 100 mL/kg per day.

c. Clear-liquid beverages, such as broths, juices, sodas, and tea, are inappropriate for the treatment of diarrheal dehydration.

4. **Parenteral Rehydration**

a. Parenteral fluids should be given for severe volume depletion, with altered states of consciousness, intractable vomiting, and abdominal distention or ileus. For infants weighing less than 4.5 kg or who are younger than 3 months, parenteral therapy is advised.

b. The first phase of treatment rapidly expands the vascular volume, in order to prevent shock and improve renal function. Intravenous normal saline or Ringers lactate (10-20 mL/kg) should be given over 1 hour. This infusion should be subtracted from the proposed total volume for the day. Five percent albumin, 10 mL/kg, is needed only in neonates, malnourished infants, and hypernatremic patients in shock.

c. The next phase of treatment is aimed at correcting the deficit, providing maintenance, and replacing ongoing abnormal losses. In severe depletion, half of the calculated deficit is given over the first 8 hours and the second half over the next 16 hours; maintenance needs are provided at a steady rate. Five percent glucose should be used as the stock solution and NaCl is added according to the estimated need. Children who have isonatremic dehydration require 8 to 10 mEq of Na^+ per kg of body weight for repletion of deficit and 3 mEq/kg per day for maintenance. This Na^+ is given in a volume consisting of the calculated maintenance for water and the estimated water deficit. Once urine flow occurs, KCl is added at a concentration of 20 mEq/L.

d. Intravenous K^+ administration should not be greater than 4 mEq/kg per day to avoid exceeding the capacity for cellular uptake of K^+.

e. If diarrhea continues, stool volumes should be measured to maintain an appropriate intake relative to output; losses should be replaced volume for volume. Normal saline or two-thirds normal saline with 20 mMol/L of KCl may be used to replace most gastric or intestinal fluid losses.

f. Metabolic acidosis may result from diarrhea; however, it is usually mild and resolves once renal function is restored. In severe metabolic acidosis, bicarbonate administration may be required.

D. **Hyponatremia and Hyponatremic Dehydration**

1. The signs and symptoms of hyponatremia correlate with the rapidity and extent of the fall in serum Na^+ concentration. Symptoms include apathy, nausea, vomiting, cramps, weakness, headache, seizures, and coma.
2. If the correction of fluid and electrolyte losses is excessively rapid, the brain may sustain injury caused by dehydration. In severe hyponatremia, plasma Na^+ concentration should be corrected at no more than 10-12 mEq/L/day.
3. **Differential Diagnosis of Hyponatremia**
   a. **Hypovolemia**
      (1) The most frequent cause of hypovolemic hyponatremia is viral gastroenteritis, with vomiting, diarrhea, or both. Other causes of hypovolemic hyponatremia include percutaneous losses or third space sequestration of fluid (ascites, burns, peritonitis).
      (2) Renal loss (urinary Na^+ >20 mEq/L) also can cause hypovolemic hyponatremia. This may be caused by diuretics, salt-wasting nephropathy, proximal renal tubular acidosis, and lack of or resistance to mineralocorticoid.
   b. **Euvolemia.** The most common cause of euvolemic hyponatremia is the syndrome of inappropriate antidiuretic hormone (ADH) secretion, which is caused by water retention (urinary Na^+ is usually >20 mEq/L).
      (1) Causes include tumors, pulmonary disorders, CNS infection, and certain drugs.
      (2) Euvolemic hyponatremia may also occur in infants fed excessively diluted infant formula.
   c. **Hypervolemia.** Hypervolemic hyponatremia, associated with edema, may result from water retention and excess Na^+, as in nephrosis, congestive heart failure, cirrhosis, or renal failure.
4. **Management of Hyponatremia**
   a. Hypovolemic patients who have hyponatremia first require volume repletion with normal saline, then a solution containing salt is given to correct the Na^+ deficit (10 to

12 mEq/kg of body weight or 15 mEq/kg in severe hyponatremia) and to provide the Na^+ maintenance needs (3 mEq/kg per day) in 5% dextrose solution.

b. For a serum Na^+ concentration of 120 to 130 mEq/L, this amount should be given over a 24-hour period. For a serum Na^+ concentration <120 mEq/L, the rehydration should be spread out over the number of days it takes to raise the Na^+ concentration to 130 mEq/L at a rate of 10 mEq/day, along with the daily maintenance requirement.

c. **Symptomatic hyponatremia** (headache, lethargy, disorientation) requires urgent therapy to prevent seizures or coma.

(1) Hypertonic saline (3% saline solution), with or without a loop diuretic and water restriction, should be used to raise the serum Na^+ by 1 to 2 mEq/L per hour or halfway toward normal during the first 8 hours. A correction using 3% saline over 4 hours can be calculated according to the following formula:

Sodium deficit in mEq = (125 - observed [Na*]) x body weight in kg x 0.6

d. The presence of high urinary Na^+ and low urinary K^+ excretion indicates the need for mineralocorticoid replacement in addition to fluids.

e. Euvolemic patients who have hyponatremia require restriction of water intake. Edematous patients require restriction of both water and Na^+, along with furosemide (Lasix).

f. Hypervolemic patients who have hyponatremia, require water and sodium restriction. The hypervolemic state may be accompanied by edema and evidence of fluid overload. In patients whose renal failure is mild, water restriction is effective, but dialysis is required in those who have oliguria or anuria.

E. **Hypernatremia and Hypernatremic Dehydration**

1. The hypernatremic patient is usually also dehydrated, with a greater loss of water relative to solute. Total body Na^+ most commonly is decreased. Affected patients frequently exhibit lethargy or confusion, muscle twitching, hyperreflexia, or even convulsions. Fever is common, and the skin may feel thickened or doughy or velvet-soft.

2. **Differential Diagnosis**

a. Diarrhea, which usually results in isonatremic or hyponatremic dehydration, may cause hypernatremia in the presence of persistent fever, anorexia, vomiting, and decreased fluid intake.

b. Other causes of hypernatremia include water and Na^+ deficit from skin losses or renal losses and water losses from central or nephrogenic diabetes insipidus (DI) or drugs

(lithium, cyclophosphamide, cisplatin).

3. **Management**
   a. Initial therapy requires administration of normal saline or Ringers lactate to restore circulating plasma volume.
   b. Hypovolemic patients who have hypernatremia require a hypotonic solution containing salt to restore the Na^+ deficit (2-5 mEq/kg of body weight) and to provide the Na^+ maintenance (3 mEq/kg of Na^+) in a solution containing 20-40 mMol/L of KCl and 5% glucose.
   c. For a serum Na^+ concentration of 150-160 mEq/L, this volume should be given over a 24-hour period. An elevated serum Na^+ concentration should be corrected by no more than 10 mEq/L per day.
   d. For a serum Na^+ concentration >160 mEq/L, the rehydration should be spread out over the number of days necessary to lower the Na^+ concentration to 150 mEq/L by 10 mEq/day. Both the daily fraction of the deficit and the daily maintenance requirement is given.
   e. Euvolemic patients who have hypernatremia require water replacement and therapy for the management of the DI. Rehydration is accomplished by using hypotonic saline, aiming to correct the serum Na^+ concentration by no more than 10 mEq/L/day.

II. **Potassium Disorders**

A. Abnormalities of serum K^+ are potentially life-threatening, due to effects on cardiac function.

B. **Hypokalemia**

1. **Diagnosis**
   a. Hypokalemia (serum K^+ concentration <3 mEq/L) is most frequently caused by gastrointestinal K^+ losses or renal losses (nasogastric suction, protracted vomiting, diuretics, renal tubular disease).
   b. The most severe manifestations of hypokalemia are arrhythmias, neuromuscular excitability (hyporeflexia or paralysis, decreased peristalsis, ileus), and rhabdomyolysis.
   c. Intracellular K^+ concentration can be estimated from the electrocardiogram, which may reveal flattened T waves, shortened P-R interval and QRS complex, and eventually U waves.

2. **Management**
   a. In the presence of cardiac arrhythmias, extreme muscle weakness, or respiratory distress, patients should receive KCl intravenously with cardiac monitoring. Once the serum K^+ is stabilized, the oral route of administration is preferable.

b. If the patient is likely to be hypophosphatemic, a phosphate salt should be used. In metabolic alkalosis, KCl should be used; in renal tubular acidosis, a citrate salt should be used.

c. When hypokalemia is associated with depleted body stores or chronic K^+ wasting states, K^+ supplementation may be needed for weeks at 3 to 5 mEq/kg per day.

C. **Hyperkalemia**

1. **Differential Diagnosis**

a. The most common cause of hyperkalemia (serum K^+ concentration >5.5 mEq/L) is "pseudohyperkalemia" from hemolysis of the blood sample. This cause should be excluded by repeating the measurement on a free-flowing venous sample.

b. Children may display hyperkalemia in metabolic acidosis or tissue catabolism, or in acute or chronic renal failure, volume depletion, or hypoaldosteronism.

c. In salt-losing congenital adrenal hyperplasia, due to complete deficiency of the enzyme 21-hydroxylase, the symptoms in affected male infants appear in the first weeks of life and include dehydration and failure to thrive together with low serum Na^+ and high K^+ concentrations. Affected female infants usually are diagnosed at birth because of ambiguous genitalia.

d. Angiotensin-converting enzyme inhibitors and nonsteroidal anti-inflammatory agents may induce hyperkalemia.

2. **Diagnosis**

a. Manifestations of hyperkalemia include cardiac arrhythmias, paresthesias, muscle weakness, or paralysis.

b. The electrocardiogram demonstrates narrow, peaked T waves and shortened QT intervals at K^+ concentrations >6 mEq/L and depressed ST segment and widened QRS complex at K^+ concentrations >8 mEq/L.

3. Management

a. Cardiac monitoring is initiated, and emergent therapy to antagonize potentially life-threatening hyperkalemia consists of intravenous calcium. The onset of action is rapid and the duration is less than 30 minutes.

b. Emergent administration of glucose will cause K^+ to redistribute to the intracellular space. Glucose, 0.5 gm/kg, can be given over 30-60 minutes when EKG changes are present.

c. Sodium polystyrene sulfonate (Kayexalate) (1 gm/kg) can be given by high rectal enema or orally.

d. Severe hyperkalemia is treated with hemodialysis.

III. **Acid-Base Disorders**

A. The pH of the body fluids normally is between 7.35 and 7.45.

B. Acid-base disturbances can result from alterations in either Pco_2 or HCO_3^- due to changes in acid production, acid buffering, and acid excretion. A deviation in HCO_3^- causes a metabolic alkalosis or acidosis; a deviation in Pco_2 causes a respiratory alkalosis or acidosis.

C. **Metabolic Acidosis**

1. Acidosis results from the addition of acid or the removal of alkali from body fluids, and it causes a compensatory response consisting of increased ventilation (respiratory alkalosis) and a fall in Pco_2.
2. The clinical manifestations of acidosis include depressed myocardial contractility, arrhythmias, arteriolar dilatation, hypotension, and pulmonary edema.
3. **Diagnosis**
   a. Addition of a fixed acid to the extracellular fluid causes the formation of anions unmeasured in the routine laboratory determination. These unmeasured anions are referred to as the anion gap, which can be estimated as:

      $$\text{Anion gap} = Na^+ - (Cl + HCO_3^-) = 10\text{-}12 \text{ mEq/L}$$

   b. The anion gap can be either increased or normal in acidosis.
4. **Differential Diagnosis**
   a. **Normal Anion Gap (Hyperchloremic) Acidosis**
      (1) This disorder occurs when HCO_3^- is lost from the body, either through the gastrointestinal tract or the kidneys. Diarrheal fluid is high in HCO_3^-, high in K^+, and low in Cl^-. Thus, diarrhea causes hypokalemia and hyperchloremic acidosis.
      (2) Failure to excrete acid occurs in mild chronic renal insufficiency and RTA.
   b. **Increased Anion Gap Acidosis.** Common causes include DKA, lactic acidosis, ingestion of toxins (aspirin, ethylene glycol), and renal failure.
5. **Treatment**
   a. Sodium bicarbonate is the agent of choice in acute acidosis requiring intervention. No matter what the cause, bicarbonate should be given when plasma HCO_3^- is <5 mMol/L. Bicarbonate should be added to a hypotonic solution and given as a continuous infusion over 1 hour. The amount to infuse may be calculated by using the following formula:

Amount to infuse in mEq = body weight in kg (15 - observed [HCO_3^-]) x 0.5

b. With severe watery diarrhea, resulting in moderate-to-severe metabolic acidosis, volume replacement is the primary mode of therapy. It may be necessary to add HCO_3^- to the intravenous fluid.

c. Before giving HCO_3^-, the serum K^+ concentration must be determined. If it is normal or low, treatment with HCO_3^- may worsen hypokalemia and lead to neuromuscular complications.

d. For patients who have moderate-to-mild acidosis (HCO_3^- >10-15 mEq/L or pH >7.2), all that is required is to correct the dehydration and electrolyte losses so the kidney can correct the acidosis effectively.

e. In DKA, therapy with fluids and insulin allows for acid to be excreted by the kidneys. Therefore, administration of bicarbonate is not required for most cases.

f. In severe lactic acidosis, the primary treatment is correction of the underlying process.

g. Ethylene glycol ingestion is treated with gastric lavage, charcoal administration, and intravenous ethanol, and dialysis in severe cases.

D. **Metabolic Alkalosis**

1. Alkalosis results from a gain of base or a loss of acid. The common clinical manifestations are lethargy, confusion, neuromuscular irritability, arrhythmias, and seizures.

2. **Differential Diagnosis**

a. The causes of metabolic alkalosis include alkali administration, vomiting, and nasogastric aspiration. In patients with GI loss of acid from vomiting, urinary Cl^- concentration is usually below 20 mEq/L.

b. Cushing syndrome, Bartter syndrome or primary aldosteronism may cause metabolic alkalosis.

3. **Treatment**

a. Therapy consists of identifying and treating the underlying pathology.

b. In mild-to-moderate alkalosis, provision of Cl^- will allow the kidney to excrete the excess base. In severe alkalosis, hydrochloric acid administration may be necessary.

E. **Respiratory Acidosis**

1. Respiratory acidosis is induced by an increase in Pco_2, which lowers plasma pH.

Causes include airway obstruction, pulmonary disorders, and CNS depression.

2. Treatment consists of mechanical ventilation and correction of the underlying disorder; alkali administration is not indicated in the setting of pure respiratory acidosis.

F. **Respiratory Alkalosis**

1. Respiratory alkalosis is caused by a decrease in Pco_2, secondary to hyperventilation. Acute respiratory alkalosis from hyperventilation induces dizziness, confusion, and seizures.

2. The causes of respiratory alkalosis include those that can lead to hyperventilation, various CNS disorders, and panic disorder. Treatment involves correcting the underlying disorder. In acute hyperventilation, rebreathing into a bag will decrease the severity of symptoms. §