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The Hospital Physician Emergency Medicine Board Review Manual is a peer-reviewed study guide for residents and practicing physicians preparing for board examinations in emergency medicine. Each quarterly manual reviews a topic essential to the current practice of emergency medicine.

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Cover Illustration by Christie Grams

EMERGENCY MEDICINE BOARD REVIEW MANUAL

Management of Electrolyte Emergencies

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Table of Contents

Introduction .................................................. 2
Disorders of Sodium Imbalance ...................... 2
Disorders of Potassium Imbalance ................... 5
Disorders of Calcium Imbalance ..................... 8
Disorders of Magnesium Imbalance ................. 10
Disorders of Phosphorous Imbalance ............... 11
Summary Points ........................................... 12
References ................................................... 12

Cover Illustration by Christie Grams
INTRODUCTION

Electrolyte panels are frequently ordered and often show results outside of normal ranges. Although most electrolyte abnormalities do not require specific treatment, some are emergent. Emergency medicine physicians should be familiar with common electrolyte imbalances as well as when and how to manage them.

DISORDERS OF SODIUM IMBALANCE

HOMEOSTASIS OF BODY WATER AND SODIUM

The kidneys have evolved to conserve water and salt in order to maintain a "private ocean" bathing the body cells. As the most abundant extracellular cation, plasma sodium is the major determinant of osmotic forces in the extracellular fluid (ECF). Thus, sodium regulation must be considered in conjunction with body water regulation. Antidiuretic hormone (ADH) and aldosterone enable the kidney to conserve water by concentrating urine. The healthy kidney is also able to excrete large volumes of excess water in order to maintain a constant plasma osmolality despite dietary variations.

ADH is the main regulator of water homeostasis. ADH enhances water permeability in the kidney’s collecting duct, increasing water reabsorption. ADH is secreted in response to hypovolemia and high plasma osmolality. ADH and aldosterone will maintain intravascular volume, even at the expense of electrolyte balance. The renin-angiotensin system is the main regulator of sodium homeostasis. Renin is produced in the kidney in response to decreased intravascular volume and via angiotensin stimulates adrenal production of aldosterone. Aldosterone increases sodium resorption and potassium excretion by the kidney. Hypothalamic cells regulate thirst in response to hyperosmolality and body fluid volume deficit.

Because of the complex interrelationship between sodium and water homeostasis, sodium disturbances are linked to water imbalances. Changes in total body sodium and water are usually proportionate and do not cause either hyponatremia or hypernatremia. Sodium imbalances require severe and disproportionate loss or gain of total body sodium or total body water (TBW).

Symptoms of hypernatremia and hyponatremia result primarily from compartmental fluid shifts. Both disorders cause similar pictures of altered level of consciousness, coma, and seizures. The severity of the symptoms depends on the rapidity and the degree of the imbalance. Patients at the extremes of age have more severe symptoms at any given sodium level.

HYPONATREMIA

Hyponatremia, defined as a plasma sodium concentration less than 130 mEq/L, is the most common electrolyte disturbance seen in the hospital population. Although most patients with hyponatremia are stable and do not require emergent therapy, acute, severe hyponatremia and its treatment can result in serious morbidity or death. Hyponatremia can cause cerebral edema secondary to the movement of water from the hypotonic extracellular space into the intracellular space, resulting in increased intracerebral pressure and decreased cerebral blood flow. Hyponatremia is a leading cause of febrile seizures in infants.

Etiology

Low or high plasma sodium concentration can occur in different states of hydration, depending on the ratio of TBW to total body sodium.

Factious hyponatremia. Low or high plasma sodium concentration can be the result of how plasma sodium is measured. Pseudohyponatremia (isotonic hyponatremia; plasma osmolality, 280–295) can be due to a blood draw error or an excess of a nonosmotic substance in the ECF (eg, hyperlipidemia, hyperproteinemia). Errors occur because some laboratory techniques for measuring sodium concentration consider the entire plasma volume as plasma water, resulting in a false increase in the ECF volume.

Redistributive hyponatremia occurs when there is an increase of osmotic particles in the ECF (hypertonic hyponatremia; plasma osmolality > 295). This form of hyponatremia can occur with hyperglycemia or when hyperosmolar substances, such as mannitol, are administered.
Water flows out of the relatively hypo-osmotic cells into the ECF, causing apparent hyponatremia. Initially, this redistribution of TBW occurs without an alteration in total body sodium. The presence of an extraneous osmotically active substance in plasma can be recognized when the calculated osmolality differs from the measured osmolality by more than 10 mOsm/L.

In situations of hyperglycemia, the sodium concentration falls by approximately 1.5 mEq/L for every 100 mg rise in serum glucose. The apparent hyponatremia will usually resolve once the underlying disorder is treated. Care should be taken to prevent the patient from becoming dehydrated secondary to osmotic diuresis.

True hyponatremia occurs when there is depletion of both water and sodium but the loss of sodium is greater. Hyponatremia with hypovolemia occurs when there is modest ECF volume excess. True hyponatremia should include measurement of basic electrolytes, urinary electrolytes, and a renal panel. Urinary sodium concentration of less than 20 mEq/L is expected if losses are extrarenal. If the urine sodium and chloride concentrations are high (sodium > 20 mEq/L), the kidney is wasting sodium and chloride.

The most common category of hyponatremia in the adult ED patient population is hypovolemic hyponatremia. Adult patients develop hypovolemic hyponatremia secondary to overuse of thiazide diuretics and in congestive heart failure (CHF).

Hyponatremia with euvolemia occurs with the syndrome of inappropriate ADH secretion (SIADH). SIADH has been recognized in association with a variety of pathologic processes, including malignancies, central nervous system (CNS) disorders (eg, infections), bleeding, trauma, acute psychosis, and pulmonary disorders. Although the normal kidney is able to excrete up to 25 L of excess water intake, in cases of extreme polydipsia or in infants, water intoxication can cause hyponatremia secondary to overuse of thiazide diuretics and in congestive heart failure (CHF).

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In situations of hyperglycemia, the sodium concentration falls by approximately 1.5 mEq/L for every 100 mg rise in serum glucose. The apparent hyponatremia will usually resolve once the underlying disorder is treated. Care should be taken to prevent the patient from becoming dehydrated secondary to osmotic diuresis.

True hyponatremia. “True hyponatremia” (plasma osmolality < 280) occurs with hypovolemia and hypervolemia, depending on the imbalance of TBW in conjunction with total body sodium concentration (Table 1). Hyponatremia with hypovolemia occurs when there is depletion of both water and sodium but the loss of sodium is greater. Hyponatremia with euvolement is a misnomer, since there is actually a modest increase in TBW. However, the TBW increase is equally distributed across all fluid compartments. In situations of hypervolemic hyponatremia, total body sodium is increased but TBW is increased even more.

Initial laboratory tests in the assessment of hyponatremia should include measurement of basic electrolytes, urinary electrolytes, and a renal panel. Urinary sodium concentration of less than 20 mEq/L is expected if losses are extrarenal. If the urine sodium and chloride concentrations are high (sodium > 20 mEq/L), the kidney is wasting sodium and chloride.

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Table 1. Categories of True Hyponatremia

<table>
<thead>
<tr>
<th>Category/Volume Status</th>
<th>Mechanism</th>
<th>Urinary Sodium</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypovolemic hyponatremia (ECF volume depletion)</td>
<td>Renal losses: excess diuretic use, osmotic diuresis, renal tubular acidosis, salt-losing nephritis, adrenal insufficiency, metabolic alkalosis</td>
<td>&gt; 20 mEq/L</td>
<td>Isotonic saline, volume expansion</td>
</tr>
<tr>
<td></td>
<td>Extrarenal losses: vomiting, diarrhea, fistulas, tubes, burns, effusions, pancreatitis, ascites, muscle trauma, intestinal obstruction, systemic infections</td>
<td>&lt; 10 mEq/L</td>
<td>Isotonic saline, volume expansion</td>
</tr>
<tr>
<td>Euvolemic hyponatremia (modest ECF volume excess)</td>
<td>Excess ADH: SIADH, drugs Glucocorticoid deficiency Water intoxication: IV therapy, psychogenic polydipsia, inappropriately diluted formula, excessive water feeding Hypothyroidism Reset osmostat</td>
<td>&gt; 20 mEq/L</td>
<td>Water restriction</td>
</tr>
<tr>
<td>Hypervolemic hyponatremia (ECF volume excess)</td>
<td>Edema-forming states: congestive heart failure, liver failure, nephrotic syndrome Acute or chronic renal failure</td>
<td>&lt; 10 mEq/L</td>
<td>Sodium and water restriction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 20 mEq/L</td>
<td>Sodium and water restriction, dialysis</td>
</tr>
</tbody>
</table>


*Most common cause of hyponatremia in adult emergency department patients.
they actually have volume retention and more or less normal total body sodium.

Hyponatremia with hypervolemia occurs in patients with renal failure, advanced CHF, hepatic cirrhosis, and nephrotic syndrome. Total body sodium is increased, but TBW is increased even more. Patients are relatively intravascularly depleted (cirrhosis, nephrosis) or have circulatory compromise (CHF). The kidneys interpret this apparent intravascular insufficiency as hypovolemia and act to retain water. Treatment is complex and involves sodium and water restriction in addition to treatment of the underlying disease. In situations of renal failure, dialysis may be necessary.

**Figure 1.** Calculation of volume of hypertonic saline for correcting hyponatremia.

\[
\text{Sodium to be infused (mEq/L)} = \frac{(\text{total body water}) \times (\text{desired } [Na] – \text{actual } [Na])}{513 \text{ mEq/L}} \\
\text{Volume of 3% saline to be infused in 1 hour} = \frac{(\text{total body water}) \times (\text{desired } [Na] – \text{actual } [Na])}{513 \text{ mEq/L}} \\
\text{ } = \frac{(0.6 \times 50 \text{ kg})(107–105 \text{ mEq/L})}{513 \text{ mEq/L}} \\
\text{ } = 0.117 \text{ L or 117 mL}
\]

Correct at this rate for a maximum of 24 hours.

**HYPERNATREMIA**

Hypernatremia is defined as a sodium concentration of more than 145 mEq/L. The normal response to elevation of plasma osmolality is increased thirst and release of ADH. The thirst mechanism is exquisitely sensitive to hyperosmolarity, so severe hypernatremia is rare in conscious, mobile patients. Hypernatremia occurs primarily in infants, the elderly, and debilitated patients secondary to inadequate access to and intake of water, often in conjunction with excessive water loss. Thus, because it occurs in a vulnerable population, hypernatremia has the worst prognosis of any electrolyte abnormality and dramatically increases the mortality for any coexisting disease.

Hypernatremia causes cerebral cellular dehydration. In situations of acute hypernatremia, water flows out of the intracellular fluid into the ECF. The loss of brain volume puts mechanical traction on the cerebral vessels, which may tear. In situations of chronic hypernatremia, the brain creates small intracellular proteins to combat cellular dehydration (idiogenic osmoles). Hypernatremia may develop in the setting of low, normal, or high (rarely) total body sodium. (Table 2).

The initial assessment of hypernatremia and its causes should include an electrolyte panel and urinary electrolytes. In hypovolemic states in the absence of renal disease, urinary sodium should be concentrated. In cases where there is renal dysfunction, and then renal failure, dialysis may be administered. In cases where there is renal dysfunction in water regulation, urinary electrolytes are variable and not helpful in diagnosis.

**Etiology**

Hypovolemic hypernatremia is the most common form of hypernatremia. The presence of hypernatremia in this setting indicates severe TBW depletion. Patients display signs of severe volume contraction, including flat neck veins, orthostatic hypotension, tachycardia, poor skin turgor, and dry mucous membranes.

Euvolemic hypernatremia occurs with water deficit in the absence of solute loss. It does not lead to overt signs of hypovolemia since only 8% of negative water
balance is at the expense of the intravascular volume. Renal water losses occur with diabetes insipidus (DI). DI occurs when the kidney is unable to concentrate urine because of a lack of ADH secretion (central or neurogenic DI) or the kidney fails to respond to ADH (nephrogenic DI). Central DI can occur after neurosurgical procedures, head trauma, stroke, and CNS infections. In nephrogenic DI, renal response to ADH or renal medullary interstitial hypertonicity is decreased, so the release of ADH does not result in increased water resorption.

Hypervolemic hypernatremia is the least common form of hypernatremia. It is infrequently seen in patients with normal renal function since the kidney is generally able to excrete any amount of excess sodium ingested. It is usually iatrogenic secondary to the administration of hypertonic sodium-containing solutions. Treatment includes water replacement and furosemide therapy. Those with renal failure may need dialysis.

**Table 2. Categories of Hypernatremia**

<table>
<thead>
<tr>
<th>Category</th>
<th>Sodium Status</th>
<th>Mechanism</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypovolemic hypernatremia</td>
<td>Low total body sodium</td>
<td>Extrarenal losses: excess sweat, diarrhea in children Renal losses: osmotic diuresis</td>
<td>Hypotonic saline Hypotonic saline</td>
</tr>
<tr>
<td>Euvolemic hypernatremia</td>
<td>Normal total body sodium</td>
<td>Renal losses: nephrogenic DI, acute and chronic renal failure, hypercalcemia, hypokalemia, central DI, sickle cell anemia, drugs Hypodipsia Extrarenal losses: insensible respiratory and dermal losses</td>
<td>Water replacement</td>
</tr>
<tr>
<td>Hypervolemic hypernatremia</td>
<td>Increased total body sodium</td>
<td>Iatrogenic sodium administration Primary hyperaldosteronism Cushing’s syndrome Acute renal failure; hypertonic dialysis</td>
<td>Diuretics and water replacement</td>
</tr>
</tbody>
</table>


**DISORDERS OF POTASSIUM IMBALANCE**

**POTASSIUM HOMEOSTASIS**

Potassium is the major intracellular cation. Normal ICF potassium concentration is 140 to 155 mEq/L. Only 2% of body potassium is extracellular, with the extracellular concentration of potassium ranging from 3.5 to 5.5 mEq/L. The large ratio of intracellular to extracellular potassium is the primary determinant of cell membrane potential and is maintained by the Na+,K+-ATPase pump. Alteration of this ratio has profound effects on excitable tissue, namely muscle and nerve. Despite the vital function of potassium in the body, potassium imbalances can be asymptomatic or nonspecific, with dysrhythmia being the first definitive manifestation.

Regulation of extracellular potassium concentration can be divided into the maintenance of external potassium balance, defined as the overall amount of potassium in the body, and internal potassium balance, the distribution of potassium between the ICF and the ECF. In an individual with normal renal function, approximately 90% of the daily potassium load is excreted by the kidneys. The remainder is excreted in the feces. Aldosterone enhances sodium and water conservation and potassium excretion into the urine. Acid-base status also modulates renal potassium handling. Acidemia
inhibits renal tubular potassium secretion, whereas alkalosis stimulates it.

Distribution of potassium between the intracellular and extracellular compartments is a rapid and dynamic process responsible for the moment-to-moment maintenance of plasma potassium concentration. Insulin, independent of its glucose regulatory role, promotes Na⁺/K⁺-ATPase activity to pump potassium into the cell. Catecholamines also modulate internal potassium balance. β₂-adrenergic stimulation facilitates cellular potassium uptake, while α-adrenergic stimulation releases potassium from cells. In acidemia, hydrogen ions move into cells in exchange for potassium ions in order to maintain plasma pH.

HYPOKALEMIA

Etiology

Hypokalemia is defined as a plasma potassium level less than 3.5 mEq/L. Although hypokalemia is common, life-threatening hypokalemia (potassium < 2.5 mEq/L) is unusual. In hypokalemia, the cell membrane is hyperpolarized secondary to an increase in the ratio of intracellular to extracellular potassium, causing decreased membrane excitability and delayed conduction of the action potential.

The 2 most common causes of hypokalemia in the ED setting are diuretic use and malnutrition associated with alcohol abuse. Other causes include inadequate intake (rare if other homeostatic mechanisms are not affected), renal potassium wasting, increased extrarenal potassium losses, and transcellular shifts of potassium. Often, a combination of factors contributes to the hypokalemic state. Etiologies of renal potassium wasting include osmotic diuresis, renal tubular acidosis (RTA), nephrotoxic drugs, and magnesium deficiency. Hyperaldosteronism and Cushing’s syndrome can result in potassium depletion due to increased action of aldosterone on the kidney. Common causes of increased extrarenal potassium losses are cutaneous (sweating and burns) and gastrointestinal (GI) losses. Vomiting also contributes to hypokalemia by causing elevated aldosterone and alkalosis, which favors potassium excretion in the urine in exchange for HCO₃⁻ and sodium.

Alkalemia, insulin excess, catecholamine excess, and cellular proliferation can cause hypokalemia by shifting potassium into the cells. The rare familial syndrome of hypokalemic periodic paralysis causes a transient change in the internal balance of potassium.

Diagnosis

Mild hypokalemia (plasma potassium, 3–3.5 mEq/L) is rarely symptomatic. In severe hypokalemia, symptoms are usually nonspecific and include weakness, fatigue, muscle pain, and palpitations. Hypokalemia can affect the smooth muscle of the intestines, causing an ileus. It should not cause mental status changes. The most serious manifestations of hypokalemia are cardiac dysrhythmias and rhabdomyolysis. Atrial and ventricular premature contractions and supraventricular tachycardia can develop. Underlying heart disease and digoxin use predispose patients with hypokalemia to more severe dysrhythmias; likewise, hypokalemia exacerbates digoxin toxicity.

Severe hypokalemia can cause a classic pattern of electrocardiograph (ECG) changes, including flattened T waves, development of the U wave and a depressed ST segment, flat or inverted T wave, and prominent U wave (Figure 2). Workup of hypokalemia should include an electrolyte panel to assess for acidosis, anion gap, and renal function. Measurement of urinary potassium is also helpful. Acidosis suggests lower GI losses, RTA, or diabetic ketoacidosis (DKA). A urine potassium level less than 20 mEq suggests diarrheal losses, while urine potassium more than 20 mEq suggests RTA, DKA, diuretic use, hyperaldosteronism, and vomiting. A low urinary chloride level suggests decreased renal perfusion and secondary hyperaldosteronism. Plasma magnesium and calcium levels should also be evaluated since regulation of potassium is affected by plasma levels of these electrolytes.

Treatment

Treatment should focus on first addressing the ABCs, correcting the potassium deficit, and addressing the underlying disorder. Hypokalemia with ventricular dysrhythmia is a medical emergency. Hypokalemia should also be treated aggressively in patients taking digoxin and in patients with angina or myocardial infarction. A rule of thumb is that each potassium deficit of 0.3 mEq/L reflects a total body potassium deficit of 100 mEq. It is preferable to administer potassium orally. Intravenous infusions can cause hyperkalemia and dysrhythmias. If potassium is administered at a rate of more than 20 mEq/hr, cardiac monitoring is needed to check for dysrhythmias. The maximum IV potassium replacement rate should be 0.3 to 1 mEq/kg/hr to a maximum of 40 mEq/hr. Potassium should be administered through a large vein, as it burns and is sclerosing.

Treatment for patients with a potassium deficit to 2.5 mEq/L is 20–40 mEq KCL orally. For those with a potassium level less than 2.5 mEq/L or less than 3 mEq/L and on digoxin, treatment is 20 mEq KCL/hr IV. If a patient is acidic and hypokalemic, it is advisable to first replace potassium before treating the
acidosis since treatment of acidosis will exacerbate hypokalemia. Hypokalemia recalcitrant to treatment can be secondary to concurrent hypomagnesemia.

**HYPERKALEMIA**

Hyperkalemia is defined as plasma potassium greater than 5.5 mEq/L. It is the most deadly electrolyte disturbance. The first manifestation of hyperkalemia may be a life-threatening cardiac arrhythmia. Hyperkalemia decreases the ICF/ECF potassium concentration ratio, depolarizing excitable tissues, decreasing conduction velocity, and increasing the rate of repolarization.8

**Etiology**

Causes of hyperkalemia can be divided into artifact, problems with external balance, and problems with internal balance. The number one cause of hyperkalemia is hemolysis after the patient’s blood has been drawn. Thrombocytosis and leukocytosis can also manifest as artifactual hyperkalemia.

Problems with external potassium balance can result from increased intake or decreased excretion of potassium. Mild or transient hyperkalemia can result from increased dietary intake or iatrogenic administration of potassium, but sustained hyperkalemia is usually indicative of underlying impaired renal function (acute and chronic renal failure or problems in tubular secretion of potassium [eg, sickle cell disease, interstitial nephritis, and chronic pyelonephritis]). Aldosterone-deficient conditions such as Addison’s disease and hyporeninemic hypoaldosteronism also cause hyperkalemia. Drugs account for up to one third of cases of hyperkalemia, with 75% of these cases secondary to potassium chloride supplements or potassium-sparing diuretics (Table 3).

Acidemia can cause and be caused by hyperkalemia. Insulin deficiency is the major cause of hyperkalemia in patients with diabetes mellitus. Acute cellular lysis caused by rhabdomyolysis, intravascular hemolysis, burns, and tumor lysis syndrome causes hyperkalemia by releasing intracellular contents, including potassium, into the ECF. Hyperkalemia in these situations worsens when renal function is impaired, as is often the case.

**Diagnosis**

Neuromuscular symptoms of hyperkalemia include paresthesias and weakness. In patients with acute hyperkalemia, symptoms mimicking hypocalcemia, including tetany, may develop. Sensory involvement is minimal, and the CNS should not be affected.

Classic ECG changes of hyperkalemia are tall, peaked waves (potassium, 5.5–6 mEq/L) followed by PR prolongation and loss of P wave (potassium > 6.0–6.5 mEq/L) and ultimately widening of the QRS (Figure 2). Virtually any conduction disturbance can develop in the setting of hyperkalemia, especially AV nodal, fascicular, and bundle branch blocks.5 The serum potassium levels at which these ECG changes develop are not hardfast.

**Treatment**

Treatment should be based on laboratory values and ECG findings. Emergent therapy should be started if
the potassium level is more than 6 mEq/L and ECG manifestations of hyperkalemia are present. An asymptomatic patient with a laboratory test result showing severe hyperkalemia should have a blood sample retested and a simultaneous ECG.

Initial treatment of severe hyperkalemia is aimed at preventing or reversing the deleterious effects of hyperkalemia on the myocardium. If ECG changes are present, calcium is given intravenously as a temporizing measure for membrane stabilization. Sodium bicarbonate, insulin (glucose is given simultaneously to prevent hypoglycemia), and high-dose inhaled albuterol are also used to shift potassium intracellularly. Kayexalate and diuretics actually correct the hyperkalemia by increasing potassium excretion (Table 4).

**DISORDERS OF CALCIUM IMBALANCE**

**CALCIUM HOMEOSTASIS**

Plasma and intracellular calcium are strictly regulated because plasma and intracellular calcium mediate vital functions such as muscular contractility, neurotransmission, and hormonal secretion. The majority (99%) of body calcium is complexed to hydroxyapatite in bone, serving as a dynamic reservoir of available calcium. Dietary calcium is absorbed actively and passively in the gastrointestinal tract. Approximately 90% of plasma calcium is filtered through the kidneys and passively resorbed.

Minute-to-minute plasma calcium levels are regulated by 3 hormonal mechanisms: vitamin D, parathyroid hormone (PTH), and calcitonin. These hormones influence intestinal absorption, renal resorption and excretion, and internal mobilization of body calcium from bone. PTH is released in response to a fall in serum calcium. It causes active renal resorption of calcium and stimulates bone resorption by osteoclastic activity. PTH and sunlight also mediate hydroxylation of dietary vitamin D into its active form, 1,25-dihydroxycholecalciferol (1,25-DHCC), in the kidney and liver. Activated vitamin D increases the intestinal absorption of calcium. Calcitonin is released when serum calcium rises; it causes deposition of calcium into the skeleton and suppresses PTH release.

Normal serum calcium levels range from 8.5 to 10.5 mg/dL; however, only 40% to 50% of serum calcium is ionized, or physiologically active. (The normal range of ionized calcium is 2.1–2.6 mEq/L [1.0–1.3 mmol/L]). The majority of plasma calcium is complexed to serum anions (phosphate, bicarbonate, citrate, lactate) and serum proteins (primarily albumin). Although ionized calcium levels remain unchanged, the ratio of bound serum calcium and ionized serum calcium is subject to change with decreased albumin states. Corrected serum calcium (in mg/dL) using serum albumin levels can be calculated with the following formula:

\[
\text{Corrected serum calcium (mg/dL)} = \frac{(\text{serum calcium [mg/dL]} + 0.8) \times (4 - \text{serum albumin [g/dL]})}{1}
\]

Acid-base status influences the ratio of bound and ionized serum calcium. Acidosis decreases and alkalosis increases calcium binding to albumin.

**HYPOCALCEMIA Etiology**

Acute hypocalcemia (ionized calcium level < 2.0 mEq/L [< 1.0 mmol/L]) is rare in ambulatory patients. This disorder can result from decreased calcium intake, deficiency of the hormones that cause calcium release into the blood, or chelation of calcium to substances that render the calcium inert. Primary hypoparathyroidism is rare and is usually congenital. Typically, secondary hypoparathyroidism is an iatrogenic complication of surgical removal or vascular disruption during parathyroid,
thyroid, or carotid surgery. Infiltration of the parathyroid gland by metastasis or by infiltrative disorders destroys parathyroid tissue. Hypomagnesemia and hypermagnesemia impair PTH release.

Vitamin D deficiency can cause hypocalcemia because of decreased absorption of dietary calcium but is rare in the United States because of milk fortification. However, lack of sunlight exposure, small bowel or biliary disease, or pancreatic failure can decrease vitamin D absorption. Many drugs can cause hypocalcemia, including cimetidine, phosphates, dilantin, loop diuretics, and glucocorticoids. Renal disease can result in lack of activation of vitamin D.

Since calcium forms complexes with different substances, increased concentration of anions, proteins, and fatty acids in the plasma can result in ionized hypocalcemia. In hyperphosphatemia, the phosphate complexes with serum calcium to cause hypocalcemia. Citrate (found in blood products as a preservative and in contrast material), exogenous bicarbonate, and alkalosis enhance plasma binding of calcium. Hypocalcemia can occur in pancreatitis as a result of calcium complexing with free fatty acids. Fluoride forms complexes with calcium in cases of fluoride poisoning. Calcium can also move into cells as a result of cellular injury, as occurs in sepsis, shock, and burns.

Diagnosis

The clinical manifestations of hypocalcemia are protean. In the ED, patients will usually have neuromuscular and cardiovascular signs and symptoms. Decreased serum calcium causes neuromuscular hyperexcitability. Paresthesias, weakness, cramps, fasciculations, and tetany are some peripheral neuromuscular signs. Latent tetany elicited by Chvostek’s sign (spasm of the muscles of facial movement when tapping over the facial nerve) and Trousseau’s sign (carpal spasm after inflation of a blood pressure cuff to 20 mm Hg above systolic blood pressure for 3 minutes) are signs of hypocalcemia. CNS manifestations of hypocalcemia include depression, confusion, and seizures. Psychiatric symptoms include depression, psychosis, and dementia. Bradycardia, hypotension, CHF, and cardiac arrest can result from decreased myocardial contractility.

Initial assessment should include measurement of serum electrolytes, serum calcium, ionized calcium, and phosphate and an ECG. The ECG may demonstrate a prolonged QT interval, although changes are nonspecific.

Treatment

Asymptomatic patients can be treated with oral calcium supplementation. Severe presentations (seizure, dysrhythmias, hypotension) with high clinical suspicion for hypocalcemia should be treated immediately. Symptomatic patients should be treated with elemental calcium 100 to 300 mg IV in a monitored setting. (10% calcium gluconate = 9.3 mg elemental calcium/mL and 10% calcium chloride = 27.2 mg elemental calcium/mL). Calcium is best administered through a central vein since it is sclerosing.

When treating hypocalcemia, serum magnesium should be checked and corrected if low, since hypomagnesemia can cause refractory hypocalcemia. When metabolic acidosis accompanies hypocalcemia, calcium must be replaced before acidosis is corrected because calcium and hydrogen compete for protein-binding sites and an increase in pH could result in a rapid decrease in ionized calcium and cardiac arrest. Patients on digoxin should be monitored carefully because calcium can exacerbate digoxin toxicity. In hyperphosphatemia, soft tissue calcifications can result when the product of

<table>
<thead>
<tr>
<th>Table 4. Treatment of Hyperkalemia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Action</strong></td>
</tr>
<tr>
<td>Membrane stabilization</td>
</tr>
<tr>
<td>Redistribution of potassium into cells</td>
</tr>
<tr>
<td>Insulin and glucose</td>
</tr>
<tr>
<td>Albuterol</td>
</tr>
<tr>
<td>Enhanced excretion</td>
</tr>
<tr>
<td>Diuretics/furosemide</td>
</tr>
<tr>
<td>Dialysis</td>
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</tbody>
</table>

*Use as a bolus only if QRS is widened.

IV = intravenous.
HYPERCALCEMIA

Etiology

The diagnosis of hypercalcemia is often more important as an indication of an underlying medical disorder than as a disorder that needs to be treated. Hypercalcemic crisis occurs in patients with severe hypercalcemia (> 14 mg/dL) and is generally associated with severe signs and symptoms. Ninety percent of cases are due to primary hyperparathyroidism or malignancy. Patients with primary hyperparathyroidism typically develop a constellation of problems such as hypercalcemia, hypophosphatemia, hyperchloremic metabolic acidosis, and phosphaturia. Hypercalcemia is the most common paraneoplastic complication of cancer, resulting from production of parathyroid hormone–related protein (PTHrP) by the tumor. Adrenal insufficiency can also cause hypercalcemia. Drugs are a less common etiology. Thiazide diuretics (increase renal absorption of calcium), lithium, estrogens, vitamin D toxicity, and calcium ingestion can result in hypercalcemia. Granulomatous disorders cause hypercalcemia when activated macrophages activate vitamin D.

Diagnosis

Clinical manifestations are nonspecific, and the severity of symptoms is a function of serum calcium level and rapidity of serum calcium rise. Hypercalcemia decreases neuronal conduction and causes CNS depression. Symptoms include fatigue, weakness, confusion, lethargy, stupor, and coma. Hypercalcemia impedes renal reabsorption of fluid and electrolytes and promotes dehydration, which can culminate in oliguric renal failure. Anorexia, vomiting, constipation, ileus, and abdominal pain are nonspecific GI symptoms. Chronic hypercalcemia and volume depletion predispose a patient to renal stones and calcium-induced interstitial nephritis.

The cardiovascular system is affected on many levels. Although hypercalcemia usually is associated with hypovolemia, blood pressure can be deceptively normal due to increased arterial smooth muscle vascular tone. ECG changes are not consistent but can include shortening of the QT interval, prolongation of the PR interval, and QRS widening. Hypercalcemia exacerbates digoxin toxicity.

Treatment

The 4 steps in the treatment of hypercalcemia are shown in Table 5. Patients with severe hypercalcemia or with significant dehydration should be treated immediately. Glucocorticoids to treat adrenal insufficiency should be considered.

DISORDERS OF MAGNESIUM IMBALANCE

Magnesium is a key cofactor in many enzymatic processes and is an obligatory cofactor for adenosine triphosphate (ATP). Half of the body’s magnesium is present in bone, while only 1% to 2% is present in the serum. The normal range of serum magnesium is 1.8 to 3 mg/dL. Because magnesium is linked to the function, regulation, and homeostasis of other electrolytes, hypomagnesemia can cause electrolyte disturbances refractory to standard treatment, in particular, hypokalemia and hypocalcemia.

Magnesium is absorbed in the intestines and is usually conserved by the kidneys. In deficiency states, magnesium reabsorption is enhanced in the kidney under the influence of PTH. While renal excretion of magnesium protects against hypermagnesemia, renal conservation is limited and cannot protect against hypomagnesemia.6

HYPOMAGNESEMIA

Diuretics and alcohol abuse are the major causes of hypomagnesemia seen in an ED population. Diuretics increase magnesium excretion by 25% to 50%. Significant hypomagnesemia usually occurs in conjunction with renal magnesium wasting. Hypomagnesemia also occurs in 50% to 60% of ICU patients.
Clinical manifestations of hypomagnesemia are non-specific, inconsistent, and variable in severity and do not correlate with plasma magnesium levels. Patients are usually symptomatic at magnesium levels less than 1.2 mg/dL. Neuromuscular (muscle weakness, tremor, hyperreflexia, and tetany) and cardiovascular (supraventricular and ventricular dysrhythmias, including ventricular tachycardia, ventricular fibrillation, and torsades de pointes) symptoms are the manifestations of hypomagnesemia seen in the ED. Patients with CHF on diuretics are especially prone to hypomagnesemia and vulnerable to its effects. Digoxin-induced dysrhythmias are more likely with hypomagnesemia. Hypomagnesemia also complicates digoxin toxicity since magnesium is an essential cofactor for the Na⁺,K⁺-ATPase pump, which is inhibited by digoxin.

Serum electrolytes and calcium level should be assessed. Hypomagnesemia can cause hypocalcemia since magnesium is required for normal synthesis and release of PTH. It can also result in refractory hypokalemia since it is a cofactor in the Na⁺,K⁺-ATPase pump. Electrocardiography should be done, although findings are nonspecific.

Because the serum magnesium level is an inaccurate representation of intracellular magnesium, it should not be used to guide therapy. If hypomagnesemia is suspected and the patient is symptomatic, treatment should be determined by severity of symptoms. Oral magnesium can be given when symptoms are not severe. In patients who are symptomatic, ABCs must first be addressed. A patient with dysrhythmia or seizures should be given IV magnesium. In patients with normal renal function, 25 to 50 mg/kg can be given initially. Bolus administration can cause bradycardia, hypotension, and heart block; therefore, magnesium should be administered with caution in patients with heart block or renal insufficiency. Because most magnesium is excreted in the urine, restoring total body magnesium to normal levels can take days.

**DISORDERS OF PHOSPHOROUS IMBALANCE**

Phosphorus is found in the body in the form of phosphate. It forms an essential component of nucleic acids, ATP, and hydroxyapatite in bone. In the serum, phosphate serves a vital function as an acid-base buffer. Phosphate abnormalities are rarely diagnosed in the ED, although they are not uncommon in very sick hospitalized patients.

Phosphate is absorbed by the intestines and kidney, stored in bone, and renally excreted. It is regulated by PTH and vitamin D hormones. Vitamin D coregulates phosphate, causing increased intestinal absorption of phosphate and calcium. Approximately 90% of serum phosphate is passively reabsorbed in the proximal tubule of the kidney. PTH inhibits further absorption of phosphate in the distal tubules while increasing calcium absorption. PTH also regulates calcium and phosphate activation from bone.

**HYPOPHOSPHATEMIA**

This disorder is classified as mild (2.5–2.8 mg/dL), moderate (1.0–2.5 mg/dL), and severe (< 1 mg/dL). Malnutrition is an uncommon cause of hypophosphatemia because phosphate is ubiquitous in the diet. However, up to 50% of alcohol abusers are hypophosphatemic. Important risk factors include DKA, malnutrition, diuretic or antacid therapy, sepsis, and alcoholism. Causes can be categorized as disorders that increase renal excretion, decrease GI absorption, or shift phosphate from the serum into the cells (Table 6).

Manifestations of hypophosphatemia are usually hematologic and neuromuscular, resulting from impaired energy metabolism and production of ATP. Mild hypophosphatemia is usually asymptomatic. With severe hypophosphatemia, myocardial depression, hypotension, impaired responsiveness to vasoressors, and respiratory insufficiency are common. Other manifestations of hypophosphatemia include hemolysis, leukocyte dysfunction, and decreased oxygen delivery to the tissues.

Patients with mild to moderate hypophosphatemia can be treated with oral phosphate supplements. Those
with severe symptomatic hypophosphatemia can be treated with IV phosphate. Parenteral phosphate should be given under monitored conditions since it can cause hypocalcemia and hyperphosphatemia. Intravenous phosphate should be given with caution in patients with impaired renal function.

**HYPERPHOSPHATEMIA**

Hyperphosphatemia is rare in patients with normal renal function, since the kidneys readily excrete excess phosphate. The major causes of hyperphosphatemia are renal failure and cellular injury (eg, rhabdomyolysis, tumor lysis syndrome, and hemolysis). It can occur with increased phosphate intake (eg, phosphate enemas or IV phosphate) and in conditions associated with hypocalcemia and hypomagnesemia.

Clinical signs of hyperphosphatemia reflect associated hypocalcemia (secondary to phosphate binding with calcium and precipitating into the tissues). Treatment includes supportive care, restriction of phosphate intake, treatment of the underlying cause, and treatment of symptomatic hypocalcemia.

**SUMMARY POINTS**

- Rapidity of development of electrolyte imbalance affects symptoms.
- Sodium regulation and imbalance occurs in conjunction with water regulation and imbalance.
- Sodium disorders cause CNS symptoms; treatment can cause CNS complications.
- Hypernatremia has the worst prognosis of any electrolyte abnormality because it occurs in the very young or very old or in patients with multiple comorbidities. It is always the result of TBW deficit in an adult.
- Hyperkalemia can be asymptomatic until dysrhythmias occur.
- Potassium disorders are the most life-threatening, secondary to dysrhythmias and neuromuscular symptoms.
- The number one cause of hyperkalemia is hemolysis secondary to laboratory error.
- Consider hypomagnesemia in cases of refractory hypokalemia and hypocalcemia.
- Normal magnesium levels do not preclude hypomagnesemia.
- Treat hypokalemia and hypocalcemia first when they occur in conjunction with acidemia.

**REFERENCES**


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