Advances In Diagnosis And Management Of Hypokalemic And Hyperkalemic Emergencies

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Abstract

With up to 56% of individuals taking diuretics likely to develop hypokalemia, and comorbid disease and many other types of medications having the potential to induce hyperkalemia, potassium abnormalities are some of the most commonly seen electrolyte abnormalities in the emergency department (ED). Unless recognized and treated appropriately, they can also be some of the most deadly. Symptoms accompanying potassium abnormalities are often vague, involving multiple organ systems. This evidence-based review discusses the etiology, differential diagnosis, and diagnostic studies for detecting hypokalemia and hyperkalemia, including managing laboratory errors that lead to factitious potassium findings. Recognition and treatment of life-threatening dysrhythmias in hypokalemia and hyperkalemia are key to managing these potassium abnormalities. Electrocardiogram (ECG) findings, treatment algorithms, and controversies on treating potassium abnormalities in the ED are discussed, with recommendations on criteria for disposition.

CME Objectives

Upon completion of this article, you should be able to:

1. Describe the pathophysiology and complications of hypokalemia and hyperkalemia.
2. Distinguish key physical examination findings that may help identify hypokalemia or hyperkalemia.
3. Describe the treatment algorithms for hypokalemia and hyperkalemia.

Case Presentations

It is the beginning of a busy shift when EMS brings in a 64-year-old gentleman with a chief complaint of lethargy. On arrival, the patient is bradycardic at 40 beats per minute with a normal blood pressure. You ask the nurse to immediately move the man to the resuscitation bay, obtain intravenous access, draw a rainbow of labs, and obtain an ECG. The EMS report states that they found him at home alone, unable to ambulate without assistance. The patient tells you that he has missed dialysis for the past few sessions because he did not have the energy to make it to clinic. You obtain an ECG and immediately notice concerning abnormalities.

As you are preparing to assist the nurses with the resuscitation of the dialysis-dependent patient, a 54-year-old gentleman passes out and falls to the floor while standing at his wife's bedside. On arousal, he states that he has had a cold for several days and has been experiencing weakness that started in his legs and has now progressed up into his arm. His past history is positive for congestive heart failure, and his only medication is furosemide. You consider hypokalemia but are unsure if it causes an ascending paralysis…or are you missing something?

Introduction

Potassium abnormalities are some of the most common electrolyte abnormalities identified in the emergency department (ED); they can also be some of the most deadly if not identified rapidly and treated appropriately. The symptoms that accompany potassium abnormalities are often vague, but recognizing them may be life-saving. This issue of *Emergency Medicine Practice* presents a systematic review of the latest evidence regarding the pathophysiology, diagnosis, and treatment of potassium-related emergencies. Some of the enduring and longstanding treatments of potassium abnormalities will be challenged, and a new perspective on these very common electrolyte emergencies will be provided.

Critical Appraisal Of The Literature

An Ovid MEDLINE® search for randomized controlled trials (RCTs) was performed, using the search terms *hyperkalemia* and *hypokalemia,* to review trials published since 2009. Ovid MEDLINE® was also queried using the search terms *hyperkalemia* and *hypokalemia* and (*therapy* or *treatment)* to identify investigations that have not yet reached the RCT stage. A total of 129 articles were identified, of which 106 full texts were reviewed; 64 were used in this review. In addition, www.guidelines.gov and The Cochrane Library Database of Systematic Reviews for the treatment of hyperkalemia and hypokalemia were searched.

Etiology And Pathophysiology Of Potassium Abnormalities

Potassium (K^+) is a cation that plays a major role in human physiology.[1] Two percent of potassium is located extracelullarly, with the remaining 98% found intracellularly. Seventy-five percent of the intracellular potassium is found in muscle cells. Potassium is highly concentrated inside the cell (150 mmol/L); in the extracellular fluid, its concentration is only 4 mmol/L. This results in a large gradient that is responsible for setting the thresholds of cellular action potentials, such as those found in the cardiac cells.

Potassium is largely regulated by the renal system; the kidneys excrete 90% of the electrolyte, with the remaining excreted by the gastrointestinal system. The regulation of potassium occurs within narrow confines, with normal potassium levels ranging from 3.5-5.5 mEq/L in the extracellular fluid. This gradient helps to determine cell membrane electrical charge. Thus, minute changes to the extracellular concentration of potassium represent a significant change in the cell membrane electrical charge, mainly in the cardiac and neuromuscular cells.[2] The electric gradient is maintained by sodium-potassium adenosine triphosphatase (Na^+/K^+-ATPase) pumps in the cell membrane, which actively transport potassium into and sodium out of the cell.[3]

Etiology Of Hypokalemia

Hypokalemia, defined as a serum potassium level < 3.5 mEq/L, is one of the most common electrolyte abnormalities in clinical practice. Hypokalemia is found in over 20% of hospitalized patients and in 10% to 40% of patients treated with thiazide diuretics in the outpatient setting.[4] However, hypokalemia is clinically significant in only about 4% to 5% of these patients.[3] Patients that may be hypokalemic in the ED often present with diarrhea, vomiting, alcohol abuse, insulin therapy, or hyperventilation.

Hypokalemia is divided into the following 3 categories:

- Mild: K^+ 3.0-3.5 mEq/L
- Moderate: K^+ 2.5-3.0 mEq/L
- Severe: K^+ < 2.5 mEq/L

Symptoms from hypokalemia are more likely to occur with the severity as well as the rapidity of the drop in serum potassium concentrations. Patients typically become symptomatic when serum concentrations drop below 2.5 mEq/L, although their symptoms may appear earlier when there is a rapid decrease in concentration. The renal and gastrointestinal systems are the primary sites of excess potassium loss from the body. Organ systems affected by hypokalemia include the cardiac and neuromuscular systems. Cardiovascular manifestations of hypokalemia include palpitations, postural hypotension, ec-

topy, and dysrhythmias; however, patients without heart disease rarely demonstrate significant cardiac abnormalities due to hypokalemia. Hypokalemia impairs intestinal smooth muscle activity and may cause nausea, vomiting, abdominal distention, and ileus. Renal effects may manifest as polyuria, polydipsia, and impaired ability to concentrate urine or excrete an acid load. Severe hypokalemia can cause rhabdomyolysis, ascending paralysis, and eventually respiratory arrest.

The causes of hypokalemia fall into 3 basic categories: (1) inadequate potassium intake, (2) excessive loss of potassium, and (3) transcellular shift of potassium.

Inadequate Potassium Intake

Inadequate dietary intake of potassium alone is rarely a cause of hypokalemia. The kidneys are able to decrease potassium excretion in the urine to < 15 mEq/L per day, allowing for nearly 2-3 weeks of total potassium depletion before normal serum levels would be expected to decrease to approximately 3 mEq/L.[5] Nonetheless, low potassium intake may exacerbate hypokalemia from other causes. When poor potassium intake is combined with increased losses, severe hypokalemia can result, most commonly in alcoholic patients or severely malnourished patients.

Excessive Loss Of Potassium

Renal and gastrointestinal losses are the most common causes of hypokalemia. Losses from the skin are rare; however, in cases of burns and intense sweating, hypokalemia can become clinically significant. Increased mineralocorticoid activity can lead to increased potassium secretion in the urine.

Renal Losses

The most common cause of hypokalemia is increased potassium loss in the urine, namely potassium losses due to increased urinary flow or delivery of sodium to distal nephron. The use of diuretics is the most common drug-related cause of hypokalemia. Approximately 56% of patients taking diuretics develop hypokalemia at some point, with varying times of onset.[6] Both thiazide diuretics and loop diuretics increase sodium and chloride delivery to the distal collecting duct, which results in increased potassium secretion and chloride depletion. Fludrocortisone, an oral agent with mineralocorticoid activity, stimulates potassium secretion directly. Other steroids, such as glucocorticoids, indirectly promote potassium excretion.[7] Administration of high doses of some antibiotics, such as penicillin or its derivatives, also increases the delivery of sodium to the distal nephron and increases potassium secretion.[8]

Rare causes of hypokalemia due to increased distal sodium delivery include Type I and Type II renal tubular acidosis, Gitelman syndrome, and Bart-

ter syndrome. In these disorders, increased delivery of sodium to the distal nephron causes increased potassium secretion.[9] Renal tubular acidosis is one of the few disorders in which hypokalemia and metabolic acidosis occur simultaneously.

Gastrointestinal Losses

Hypokalemia associated with gastrointestinal losses is the second most common cause of clinical hypokalemia. Potassium excretion from the stool accounts for an extremely small percentage of normal potassium loss, amounting to approximately 10 mEq each day. However, in pathological states where stool volume increases, as in cases of diarrhea, patients can become potassium-deficient. In the cases of dehydration from diarrhea and vomiting, patients can become even more hypokalemic secondary to the activation of aldosterone. Increased aldosterone causes increased potassium excretion from the kidneys, causing varying levels of hypokalemia. An associated metabolic alkalosis will contribute to increased urinary potassium loss and transcellular shifting of extracellular potassium, contributing to the development of hypokalemia.

Increased Mineralocorticoid Activity

Aldosterone is the primary hormonal regulator of renal potassium secretion. Increased aldosterone levels leads to an increased number of open sodium pores and increased Na^+/K^+-ATPase activity in the nephrons, and, as a result, increased potassium secretion into the urine. Primary hyperaldosteronism may be the result of a unilateral adrenal adenoma, bilateral adrenal hyperplasia, or, rarely, an adrenocortical carcinoma.[8]

Transcellular Potassium Shifts

Transcellular shifts of potassium rarely cause clinically significant hypokalemia. Generally, total body potassium levels are normal despite a lowered serum potassium level. It is often unnecessary to correct hypokalemia when it is induced by transcellular shift. Most transcellular potassium shifts are due to medications, hyperventilation, or metabolic acidosis.

Drug-Induced Potassium Shifts

There are numerous medications that cause transcellular potassium shifts by stimulating cell membrane Na^+/K^+-ATPase and promoting potassium entry into cells.[8] **(See Table 1, page 4.)** The degree and duration of hypokalemia varies with the agent used. Hypokalemia may also occur in patients with a high level of circulating catecholamines. The administration of glucose or insulin may cause a decline in serum potassium, as insulin stimulates cellular uptake of potassium, leading to dangerous complications with intentional overdoses of insulin and during treatment of diabetic ketoacidosis. Albuterol-induced

hypokalemia can occur even at normal, therapeutic doses. A standard dose of nebulized albuterol reduces serum potassium by 0.2 to 0.4 mEq/L, and a second dose taken within 1 hour has the potential to reduce it by almost 1 mEq/L.

Nondrug-Induced Potassium Shifts

A variety of disorders can cause movement of potassium into cells. Both metabolic and respiratory alkalosis can contribute to hypokalemia, due to the exchange of extracellular potassium for intracellular hydrogen ions. Rare causes of severe hypokalemia with paralysis include familial periodic paralysis, thyrotoxic periodic paralysis, sporadic periodic paralysis, and hypernatremic hypokalemic paralysis. Hypokalemia due to transcellular shifts should remain in the differential diagnosis of paralysis or weakness when there are recurrent episodes of similar events, even when there is no evidence of a total body deficit of potassium.[9,10]

Etiology Of Hyperkalemia

Hyperkalemia, defined as serum potassium level ≥ 5.5 mEq/L, is the most dangerous acute electrolyte abnormality, potentially leading to life-threatening arrhythmias and death. Hyperkalemia is often caused by medications, most commonly occurs in patients with underlying comorbid conditions, and can be found in up to 8% of hospitalized patients.[1]

Hyperkalemia can be divided into the following 3 categories:
- Mild: K+ 5.5-6.5 mEq/L
- Moderate: K+ > 6.5-7.5 mEq/L
- Severe: K+ > 7.5 mEq/L

There are several important causes of hyperkalemia that should always be taken into consideration: cardiovascular disease, renal failure, and genetic predisposition.

In mild heart failure, potassium is usually unaffected; however, in severe heart failure, activation of the renin and aldosterone systems, as well as other adrenergic activation, induce water and sodium reabsorption, with a significant drop in intraluminal sodium concentration. As a result, no sodium exchange for potassium is available, resulting in the retention of potassium and subsequent hyperkalemia.[11]

In one retrospective study of 35 patients from a tertiary hospital center, hyperkalemia was diagnosed (in nondialysis patients) in 3.3% of the inpatient medicine service.[12] One case-control series of 938 patients admitted to 2 separate university-affiliated tertiary care centers for congestive heart failure (CHF) found that 8.5% (80) of these nondialysis patients had hyperkalemia and that, of these 80, 14% had severe hyperkalemia.[13] This same study demonstrated the contribution of diabetes and renal function in the development of hyperkalemia. Another study, a retrospective chart review conducted on a national level of all Veteran's Administration hospitals, found that patients with chronic kidney disease were at higher risk of hyperkalemia (n = 34,937/66,295 or 52.7%).[14] One prospective study of 251 adult end-stage renal disease patients on hemodialysis found that there were 367 episodes of hyperkalemia among this group during 1877 person-months of follow-up.[15]

Decreased mineralocorticoid activity can be caused by hyporeninemic-hypoaldosteronism most often seen in patients with moderate renal impairment from diabetic nephropathy or tubule-interstitial disease.

Hyperkalemic periodic paralysis is an autosomal-dominant point mutation on skeletal muscle sodium channels that predisposes to the development of hyperkalemia in association with fasting and exercise or the ingestion of high levels of potassium. The sodium falls and potassium rises, leading to depolarization of the membrane due to a mutation in the sodium channel that causes sodium to rush into the cells and potassium to be expelled.[11]

Mortality from hyperkalemia is primarily related to its effect on the cardiac system.[16] A study looking at sudden death in hemodialysis patients found that a majority of the 88 patients had comorbid disease, most likely CHF (55%), coronary artery disease (56.3%), and/or diabetes mellitus (57.5%).[17] In addition, medications that increase serum potassium, such as angiotensin II receptor blockers (ARBs) and angiotensin-converting enzyme inhibitors (ACEIs) can contribute to the risk of sudden death. A retrospective study of 1163 patients on ACEIs and 1168 patients on ARBs in a single Veteran's Affairs Medical Center found that hyperkalemia (≥ 5 mEq/L) was observed in 20.4% of patients on ACEIs and 31.0% on ARBs.[18]

The approach to evaluating a patient with elevated serum potassium requires consideration of 3 possible causes: (1) laboratory error and factitious hyperkalemia, (2) transcellular shifting of potassium, and (3) potassium excretion insufficiency.

Table 1. Common Medications That Cause Hypokalemia Through Transcellular Shifts

- Decongestants
- Bronchodilators
- Tocolytic agents
- Synthetic thyroid hormone
- Phosphodiesterase inhibitors (eg, theophylline and caffeine)
- Insulin
- Barium (in overdose)
- Verapamil (in overdose)

Laboratory Error And Factitious Hyperkalemia

Factitious hyperkalemia, or pseudohyperkalemia, is an important consideration in patients found to have an elevated serum potassium. All healthcare providers must remember that the number one cause of an elevated serum potassium on a test report is spurious elevation due to hemolysis during or after the blood draw. An ECG should always be used to assess for true hyperkalemia while another sample is analyzed. The most common cause of pseudohyperkalemia is cell lysis that often results from mechanical disruption of cells during the blood-drawing process or from disruption related to delay in laboratory analysis.[19] Lysis may be induced by the blood drawing, clenching and unclenching of the fist by the patient, or prolonged tourniquet use.[1] Leukocytosis (white blood cell count > 50-100 x 10 mm^3); thrombocytosis (500,000-1 million/mm^3), and polycythemia all increase the fragility of the red blood cells and predispose to factitious hyperkalemia.[20] In cases of isolated hyperkalemia, the assessment includes examining the rest of the chemistry panel, the acid-base status, and medication use. When factitious hyperkalemia is suspected, it is important to draw the specimen again, ensuring that it is drawn properly and processed quickly. However, do not allow a laboratory value to direct care in an unstable patient.

Transcellular Shifting Of Potassium

Transcellular shifting disorders are due to conditions that impact the acid base status or the Na^+/K^+-ATPase pumps. Factors that alter the integrity of the membrane by acting on the Na^+/K^+-ATPase pumps include insulin and beta-adrenergic catecholamines causing extracellular potassium to shift into the cell. These mechanisms are utilized in the treatment of hyperkalemia.[22] A patient's internal state may affect the potassium level, such as in acidosis, which will shift hydrogen ions into the cell and potassium out of the cell to allow the cell to remain neutral. Alkalemia and hypertonicity (eg, hyperglycemia) also cause potassium to move into cells.[3]

Potassium Excretion Insufficiency

In healthy kidneys, renal potassium excretion is increased when: (1) potassium concentration in the plasma is elevated, (2) plasma aldosterone level and effect is higher, and (3) delivery of water and sodium to the discollecting tubules is decreased. Hyperkalemia and states of low perfusion, hypovolemia, and decreased renal sodium cause renin and aldosterone release, which leads to sodium reabsorption and potassium excretion. **(See Figure 1.)**

While a kidney with normal perfusion can compensate for a wide range of potassium intake by increasing or decreasing urinary output, excretion disorders (where elimination of potassium is hindered) can lead to hyperkalemia. Ninety percent of potassium elimination occurs in the kidneys. The vast majority of cases of hyperkalemia occur from impaired renal function caused by an underlying medical condition or certain medications in a patient who has some degree of renal insufficiency.[3,6,9]

Medications That Induce Hyperkalemia

There are many medications that are capable of producing hyperkalemia. Many patients with a predisposition to renal insufficiency are prone to hyperkalemia when they are started on a new medication that interferes with potassium homeostasis.[22] **(See Table 2.)**

Figure 1. Regulation Of Extracellular Fluid Potassium Concentration
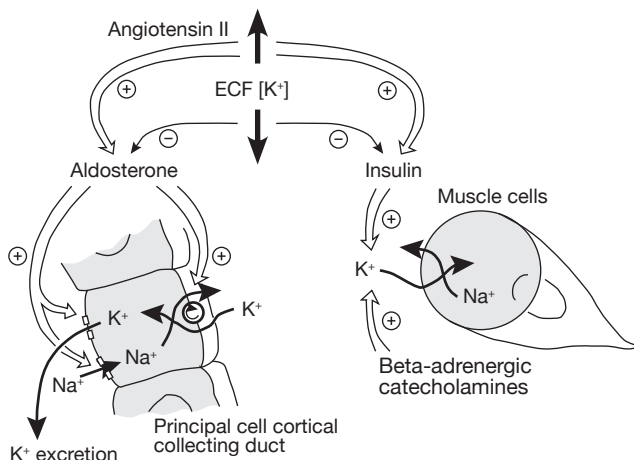
An increase in extracellular fluid potassium concentration (ECF [K$^+$]) stimulates both aldosterone and insulin secretion. Insulin stimulates K$^+$ entry into cells, and aldosterone secretion stimulates K$^+$ secretion into the collecting duct urine, promoting its excretion by the kidney.

Gennari FJ. Disorders of potassium metabolism. In: Suki WN, Massry SG, eds. *Therapy of Renal Diseases.* 3rd ed. Figure 1. Boston: Springer; 1997:53-84. With kind permission from Springer Science+Business Media B.V.

Table 2. Medications That Induce Hyperkalemia[23,24]

- ACEIs
- ARBs
- Beta-blockers
- Potassium-sparing diuretics
- Antibiotics (trimethoprim, penicillin G potassium)
- NSAIDs
- Succinylcholine
- Digoxin

Abbreviations: ACEIs, angiotensin-converting enzyme inhibitors; ARBs, angiotensin II receptor blockers; NSAIDs, nonsteroidal anti-inflammatory drugs.

Angiotensin-Converting Enzyme Inhibitors: ACEIs block conversion of angiotensin I to angiotensin II, leading to decreased aldosterone secretion, subsequently causing a decreased excretion of potassium and a decrease in the glomerular filtration rate (GFR). These effects are even more pronounced in patients with volume depletion, chronic renal insufficiency, and renal artery stenosis.[25] Up to 10% of patients on ACEIs develop hyperkalemia (≥ 5.5 mEq/L) within a year of starting the medication. The rate of hyperkalemia in low-risk patients is only 1.3%,[26] but the risk increases for patients on other hyperkalemia-inducing medications or in patients who have diabetes mellitus, chronic kidney disease, or CHF.

Angiotensin-II Receptor Antagonists: ARBs act as competitive inhibitors, binding to the angiotensin II receptor, decreasing the adrenal production of aldosterone. In general, the risk of hyperkalemia is the same for ACEIs as for ARBs.[27]

Potassium-Sparing Diuretics: Renal excretion is the major route of potassium loss, and blocking this process with potassium-sparing diuretics may result in hyperkalemia. This is the mode of action of the potassium-sparing diuretics.[28,29] These medications have been reported to increase the rate of hospitalization for hyperkalemia in patients on high doses or in patients who have compromised GFR.[29,30]

Beta-Blockers: Nonselective beta-blockers can produce hyperkalemia by decreasing renin secretion and the intracellular shift of potassium. This effect is seen predominantly in patients with renal comorbidities and it is controversial whether the effect is clinically relevant in other patient groups.[31,32]

Nonsteroidal Anti-Inflammatory Drugs: Nonsteroidal anti-inflammatory drugs (NSAIDs) may also induce hyperkalemia via 2 mechanisms: decreasing renin secretion and decreasing the GFR via prostaglandin inhibition. In one study, hyperkalemia was reported in 47% of high-risk patients on high doses of indomethacin.[33] Risk factors include advanced age, mild to moderate renal insufficiency, and concurrent use of ACE inhibitors.

Differential Diagnosis For Hypokalemia And Hyperkalemia

Both hypokalemia and hyperkalemia can present with very vague complaints involving multiple organ systems, leading to very broad differential diagnoses. Common complaints of mild to moderate potassium abnormalities include generalized malaise, lethargy, muscle weakness, and gastrointestinal complaints. These vague complaints can also be seen in diabetes, myocardial infarction, stroke, chronic fatigue, and viral illnesses. In severe hypokalemia

(< 2.5 mEq/L), the weakness and paralysis can resemble myasthenia gravis, botulism, spinal cord diseases, polyneuropathies, and cataplexy. The ECG may be helpful in differentiating between clinically significant hyperkalemia and hypokalemia.

Prehospital Care

Prehospital management of suspected potassium abnormalities is difficult, since serum levels are not generally known in the field. If an ECG is available, it can be very helpful in distinguishing changes concerning for hyperkalemia or hypokalemia from other diagnoses. If the patient has ECG changes that suggest hyperkalemia, such as a widened QRS or peaked T-waves, medical direction and adherence to local protocol are recommended. In the case of hypokalemia, prehospital providers will most likely be treating symptoms of the underlying cause of the hypokalemia such as dehydration and hyperventilation. The same may be true in hyperkalemia, unless the patient has a known history of renal failure and has hyperkalemic-induced dysrhythmias and cardiac arrest. In this case, Advanced Cardiac Life Support® (ACLS®) guidelines are followed, including giving calcium and sodium bicarbonate.

Emergency Department Evaluation

Presenting complaints of potassium disorders are vague, and emergency clinicians must maintain a high index of suspicion in order to prioritize care. For example, a dialysis patient with progressive weakness and vital sign abnormalities must be tri-aged as a high priority and placed in an area in the ED where an ECG can be obtained immediately and care can be expedited.

History

Patients with potassium abnormalities may present with generalized weakness, flaccid paralysis, loss of deep tendon reflexes, respiratory difficulty, generalized malaise, or gastrointestinal complaints.[34] In most cases, there is an underlying illness that may complicate the issue or cause the patient to become symptomatic. The main concern is the rate at which potassium changes, and this is an important factor in determining the urgency versus emergency of the course as well as when treatment should be initiated.[34,35] Because the signs and symptoms of potassium-related abnormalities may be subtle and vague, a specific line of questioning may help to narrow down the etiology. Since there may be more than one potential etiology of the potassium abnormality, a thorough history is important. Areas of questioning include:
- History of kidney disease
- History of endocrine disease

- New medications started in the last year including diuretics, ARBs, ACEIs, diabetes medications, or thyroid medications
- Recent trauma
- Recent gastrointestinal illnesses
- Recent surgery or hospitalizations
- Recent changes in fluid intake or losses
- History of familial periodic paralysis

Physical Examination

As with the history, the physical examination can be vague and varied. The general appearance may range from ill-appearing to completely stable. It is important to assess the skin and mucous membranes for hydration and fluid status. The heart and lung examination is useful for identifying cardiac and renal comorbidities. **See Table 3** for signs and symptoms that may indicate a disorder of potassium homeostasis.

Diagnostic Studies

An ECG is recommended as soon as a potential abnormality is suspected. Other important diagnostic tests include complete blood count (CBC) with platelets, metabolic and renal panel, and urine studies. In patients with severe symptoms, an arterial blood gas, serum and urine osmolality, and urine electrolytes can be considered. These tests help to narrow down the potential cause of any renal insufficiency that may be causing the potassium abnormality. The emergency clinician may not see the results of some of these studies, but they are often helpful for the clinician who may assume either the inpatient or outpatient care. In a case where an elevated serum potassium is found but there is normal renal function, a plasma potassium may be helpful.

Because the typical electrolyte testing used in the ED utilizes serum rather than plasma, some factitious hyperkalemia results may be associated with the clotting agents in the test tubes used for serum testing. When plasma electrolytes are measured, a heparinized test tube is used to prevent clotting, and this may prevent factitious hyperkalemia. Some researchers and clinicians, therefore, recommend using plasma specimens if potassium levels in serum specimens are called into question.[36]

There are some blood dyscrasias that will release potassium during the clotting process in the serum potassium, and this will factitiously elevate the potassium levels. **See Table 4** for causes of hemolysis. **See Table 5** for proper blood draw techniques to avoid hemolysis.

Electrocardiogram In Hypokalemia

Cardiovascular manifestations of hypokalemia include palpitations, postural hypotension, ectopy, and dysrhythmias; however, patients without heart disease rarely demonstrate any significant cardiac abnormalities due to hypokalemia. The ECG may show flattened T-waves, ST-segment depression, and the appearance of U-waves. **(See Figures 2 and 3, page 8.)** An ECG should be obtained in patients when there is concern for severe hypokalemia. Giant U-waves may occur and may be mistaken for peaked T-waves. These large U-waves, however, have a broader base as compared to peaked T-waves. Hypokalemia may also appear as nonspecific ST- and T-wave abnormalities, first- and second-degree heart block, atrial fibrillation, paroxysmal ventricular contractions, ventricular fibrillation, or asystole. Hypokalemia can also cause a prolonged

Table 3. Signs And Symptoms Associated With Disorders Of Potassium

Organ System	Hypokalemia	Hyperkalemia
Cardiac	• Dysrhythmias • Conduction defects • Increased likelihood of dysrhythmias due to digitalis	• Dysrhythmias • Conduction disturbances
Skeletal muscle	• Weakness • Paralysis • Fasciculations and tetany	• Weakness • Paresthesias • Paralysis • Hyperreflexia • Cramping
Gastrointestinal	• Ileus • Nausea • Vomiting • Abdominal distention	• Nausea • Vomiting • Diarrhea
Renal	• Polyuria	

Table 4. Causes Of Hemolysis

- Use of a syringe with excessive force to the plunger
- Forcibly squirting the blood from a syringe into an evacuated tube
- Drawing the blood through a small needle or IV catheter
- Fist-clenching
- Prolonged tourniquet use
- Cleansing with alcohol and not allowing to dry
- Crying and hyperventilation of patient during blood draw
- Vigorous mixing or shaking
- Mechanical trauma (pneumatic tube systems)

Table 5: Proper Blood Draw Techniques That Avoid Hemolysis

- For routine collections, use a 20-22 gauge needle
- Do not remove the needle from the vein with the vacuum tube engaged
- Do not collect a specimen in a hematoma
- Decrease the tourniquet time
- Draw the sample gently and evenly
- Avoid aggressively agitating the sample

QT interval, increasing the risk of malignant arrhythmias or *torsades de pointes*.[37]
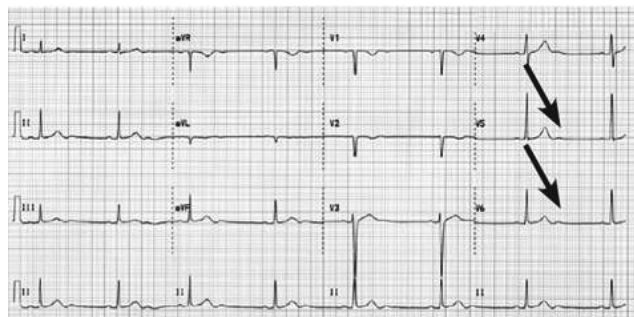
Electrocardiogram In Hyperkalemia

Generally, the first indicator of hyperkalemia is found on the ECG.[38-41] Classic ECG changes—the peaked T-wave, flattened P-wave with prolonged PR interval, or a totally absent P-wave, wide QRS, and sine-wave pattern—have been well-described as appearing sequentially with rising serum potassium levels. **(See Figure 4.)** Peaked T-waves are caused by a change in the resting membrane potential due to the accumulation of potassium in the extracellular fluid. This leads to an early excitatory reaction causing the T-waves to become peaked. The peaked T-wave is one that is taller and more pointed (pronounced) than the normal T-wave **(see arrows in Figure 4).** These T-wave changes are best seen in the precordial leads; they progress to a slowing of the myocardial function as the level of potassium increases, manifested in prolonged P-wave and QRS durations and PR intervals.[2] Further destabilization of the cardiac membrane manifests as changes to the wave form (eg, sine-wave), leading to arrhythmia.

The typical findings of mild hyperkalemia (5.5-6.5 mEq/L) are evolving peaked T-waves and prolonged PR segments.[39,40] Moderate hyperkalemia (> 6.5-7.5 mEq/L) is demonstrated as loss of P-wave and prolongation of the QRS complex and ST-segment elevation as well as ectopic and escape beats. Severe hyperkalemia (> 7.5 mEq/L) leads to progressive widening of the QRS complex to sine-wave formation, bundle branch blocks, and fascicular blocks; without immediate correction, these may lead to ventricular fibrillation.[40]

Caution must be used when reviewing the ECGs of patients with suspected hypokalemia or hyperkalemia. Several studies have questioned the emergency clinician's ability to detect hyperkalemia based solely on the interpretation of the ECG. In one study,

220 patients with a diagnosis of hyperkalemia were identified by chart review. Their ECGs were then given to 2 independent ED physicians for evaluation to determine the physicians' ability to diagnose hyperkalemia solely by ECG. Inter-rater reliability was strong (k = 0.73). The sensitivity was poor for determining hyperkalemia for both physicians (34% and 43%). Specificity was good for both (85%, 86%). Interestingly, when evaluating the ECGs of those patients with severe hyperkalemia, the sensitivity rose to 62% and 55% with a negative predictive value of 69% and 67% for each physician. This study demonstrates that ED physicians can better identify severe hyperkalemia by means of ECG; however, mild and moderate hyperkalemia makes the diagnosis by ECG more difficult.[41] The ECG is instrumental when combined with the clinical scenario in diagnosing the hyperkalemic patient, but it is not absolute. A normal ECG does not exclude the possibility of a potassium-related emergency. In 1999, Martinez-Vea et al published a case series of patient

Figure 3. Electrocardiogram Of Flattened T-Waves In Hypokalemia
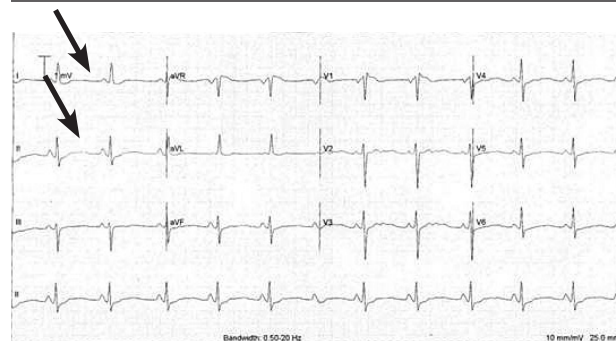
Arrows point out flattened T-waves seen in hypokalemia.
Used with permission of Jeffrey Pepin, MD.

Figure 4. Electrocardiogram Of Peaked T-Waves In Hyperkalemia
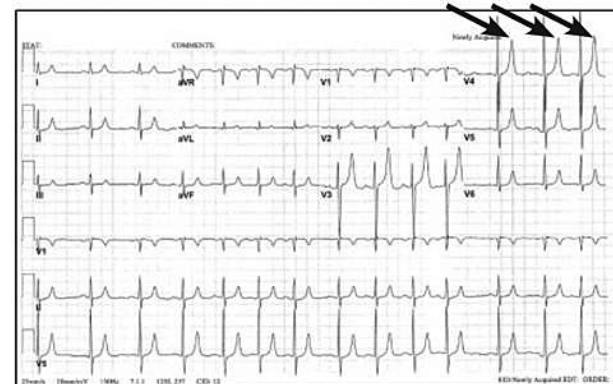
Arrows point out hyperacute T-waves in hyperkalemia.
Used with permission of Jeffrey Pepin, MD.

Figure 2. Electrocardiogram Of U-Waves In Hypokalemia

Arrows point out U-waves seen in hypokalemia.
Used with permission of Jeffrey Pepin, MD.

ECGs that showed no changes with potassium levels > 8 mEq/L.[42] Another study showed that 55% of patients with potassium levels of 6.9 and above had no changes on ECG.[2]

Treatment

Treatment Of Hypokalemia

Treatment of the hypokalemic patient usually starts with identifying the underlying cause, since hypokalemia is rarely an isolated event. Usually, a good history and physical examination suggests the etiology, such as extreme diarrhea or diuretic use without supplementation. Severity of symptoms, rather than the potassium level, is usually a guide in determining the urgency of treatment. When treating hypokalemia, the emergency clinician should remember that each 0.3-mEq potassium drop below normal correlates with an approximately 100-mEq total body deficit.[8]

The majority of patients with mild hypokalemia (3.0-3.5 mEq/L) may be asymptomatic, and the treatment of their underlying disorder will eventually correct their potassium levels. This is especially true in patients who have an acid-base disturbance, such as seen in cases of respiratory alkalosis or in patients who are dehydrated secondary to excessive diarrhea or vomiting. For many patients, it is unnecessary to bring potassium levels back to normal during their ED stay, and they can be discharged with instructions to eat foods that are high in potassium. **(See Table 6.)**

In patients with more protracted illnesses or patients with mild hypokalemia placed on diuretics, it may be suitable to treat them with oral potassium supplementation. There are 3 primary oral preparations for repleting potassium, including potassium bicarbonate, potassium phosphate, and potassium chloride. Potassium chloride is the most common form of replacement in the ED. Potassium chloride given 40-60 mEq orally every 4-6 hours is typically well-tolerated. If the patient is unable to tolerate pills, a liquid formulation is also available.[3] These patients require close follow-up to monitor for progress of treatment and make sure they are receiving the appropriate amount of potassium supplementation.

Table 6. Foods Rich In Potassium

- Baked potatoes
- Tomatoes
- Lima beans
- Spinach
- Bananas
- Cantaloupe
- Raisins
- Oranges

If the patient has moderate to severe hypokalemia (< 3.0 mEq/L) and is clinically symptomatic or has life-threatening ECG changes, then it is recommended to supplement with IV potassium. If IV infusion of potassium is necessary, the initial starting dose is 10-20 mEq/hour. If hypokalemic cardiac arrest occurs or is impending (eg, there is malignant ventricular dysrhythmia), 10 mEq of IV potassium may be given over 5 minutes, and this may be repeated once, if necessary.[3] When infused through a peripheral IV, potassium may be uncomfortable and result in a phlebitis. When the IV repletion rate is faster than 20 mEq/hour, continuous cardiac monitoring is required and central access is recommended. The amount of potassium required to resolve symptoms is dependent on the severity of the potassium level and the total body deficit.

In severely hypokalemic patients, it may be necessary to replace magnesium as well, despite the serum magnesium level being normal. This is due to the requirement of magnesium in the activation of the sodium/potassium pump. With depleted total body magnesium, the pump is unable to utilize adenosine triphosphate (ATP) to bring potassium into the cells. This, in turn, would only allow for transient elevations of serum potassium that would be later wasted in the urine. In many cases (such as diuretic use and diarrhea), magnesium is wasted, creating a total body deficit of magnesium but with only small changes in serum magnesium. Emergency clinicians should infuse at least 0.5 g/hour of magnesium sulfate along with potassium replacement to allow potassium to shift intracellularly.

In patients with hypokalemia associated with thyrotoxic periodic paralysis, it is best to treat the underlying disease process before repleting the potassium. In these attacks, the potassium is shifted into the cells due to the high levels of thyroid hormone, and total body potassium is often normal. If the diagnosis is missed and potassium supplementation is provided, there is a chance that there will be a dangerously high rebound hyperkalemia.

Treatment Of Hyperkalemia

Patients with suspected or known hyperkalemia require IV access and continuous cardiac monitoring. The treatment of hyperkalemia is based on the emergency clinician's clinical suspicion combined with the patient's presentation, ECG, and the laboratory potassium value. There is no clear evidence on when to treat the stable dialysis patient with elevated potassium. A Cochrane Review of the literature from 2005 does not make recommendations for specific levels to initiate treatment. The studies cited by the review, however, were all RCTs that were small in number (ie, n = 12, n = 7).[43] Several review articles suggest treating all patients with levels > 6.5 mEq/L because they are at risk for arrhythmias.[2,44]

Clinical Pathway For Hypokalemia

Serum K^+ < 3.0 mEq/L

↓

- Urgent ECG
- Check Mg^+

┌─────────────────────────┬─────────────────────────┬─────────────────────────┐

No symptoms and nondiagnostic ECG (eg, U-waves, T-wave flattening)

Dysrhythmia (VT most common)

Cardiac arrest (VT, VF, PEA, asystole)

↓

- Potassium chloride PO 20-80 mEq/d in divided doses **(Class II)**
- Discharge with recommendation to increase dietary K^+ **(Class II)**

Potassium chloride IV 20 mmol/hr **(Class II)**

(Max rate: 20 mmol over 10 min followed by 10 mmol over 10 min)

Commence ACLS® **(Class II)**

↓

Magnesium sulfate not necessary unless Mg^+ level low **(Class II)**

Magnesium sulfate IV 5 mL 50% (10 mmol [2 g]) over 30 min **(Class II)**

- Potassium chloride IV 20 mmol over 2-3 min **(Class II)**
- Repeat until K^+ > 4.0 mEq/L **(Class II)**

↓

Magnesium sulfate IV 5 mL 50% (10 mmol [2 g]) over 1-2 min **(Class II)**

↓

Recheck K^+ after every 40 mmol if normal renal function or after every 20 mmol (if severe renal impairment)

Abbreviations: ACLS®, Advanced Cardiovascular Life Support®; ECG, electrocardiogram; IV, intravenous; K^+, potassium; Mg^+, magnesium; PEA, pulseless electrical activity; PO, by mouth; VF, ventricular fibrillation; VT, ventricular tachycardia.

Class Of Evidence Definitions

Each action in the clinical pathways section of *Emergency Medicine Practice* receives a score based on the following definitions.

Class I
- Always acceptable, safe
- Definitely useful
- Proven in both efficacy and effectiveness

Level of Evidence:
- One or more large prospective studies are present (with rare exceptions)
- High-quality meta-analyses
- Study results consistently positive and compelling

Class II
- Safe, acceptable
- Probably useful

Level of Evidence:
- Generally higher levels of evidence
- Non-randomized or retrospective studies: historic, cohort, or case control studies
- Less robust RCTs
- Results consistently positive

Class III
- May be acceptable
- Possibly useful
- Considered optional or alternative treatments

Level of Evidence:
- Generally lower or intermediate levels of evidence
- Case series, animal studies, consensus panels
- Occasionally positive results

Indeterminate
- Continuing area of research
- No recommendations until further research

Level of Evidence:
- Evidence not available
- Higher studies in progress
- Results inconsistent, contradictory
- Results not compelling

Significantly modified from: The Emergency Cardiovascular Care Committees of the American Heart Association and representatives from the resuscitation councils of ILCOR: How to Develop Evidence-Based Guidelines for Emergency Cardiac Care: Quality of Evidence and Classes of Recommendations; also: Anonymous. Guidelines for cardiopulmonary resuscitation and emergency cardiac care. Emergency Cardiac Care Committee and Subcommittees, American Heart Association. Part IX. Ensuring effectiveness of community-wide emergency cardiac care. *JAMA.* 1992;268(16):2289-2295.

Clinical Pathway For Hyperkalemia

Serum K$^+$ > 6.0 mEq/L

↓

Emergent ECG

↓

Mild to moderate (left branch):
- Mild to moderate hyperkalemia (6.5-7.5 mEq/L)
- Patient clinically stable

↓

Regular insulin 10 units IV plus 50 mL of D50 **(Class II)**

Life-threatening (center branch):

Life-threatening hyperkalemia
Any of the following:
- Peaked T-waves (amplitude > R in 2 leads
- Absent P-waves
- Broad QRS
- Sine wave
- Bradycardia
- VT

↓

- Calcium chloride IV 10 mL 10% (6.8 mmol) over 5 min

  +
- Regular insulin 10 units IV plus 50 mL of D50 **(Class II)**

  +
- Albuterol 20 mg, nebulized

Cardiac arrest (right branch):

Cardiac arrest (VT, VF, PEA, asystole)

↓

Commence ACLS®

↓

- Calcium chloride IV 10 mL 10% (6.8 mmol) bolus

  +
- Regular insulin 10 units IV plus 50 mL of D50 **(Class II)**

↓

Consider hemodialysis

Abbreviations: ACLS®, Advanced Cardiovascular Life Support®; D50, 50% dextrose in water; ECG, electrocardiogram; IV, intravenous; K$^+$, potassium; PEA, pulseless electrical activity; PO, by mouth; VF, ventricular fibrillation; VT, ventricular tachycardia.

See class of evidence definitions on page 10.

Treatment of hyperkalemia consists of 3 main steps: (1) stabilizing the cardiac membrane, (2) shifting potassium into the cells, and then (3) removing potassium from the body.

Stabilizing The Cardiac Membrane

Intravenous calcium is used to stabilize the myocardial cell membrane by restoring the electrical gradient. Calcium does not lower the potassium level but stabilizes the cardiac membrane by restoring the normal gradient of the resting membrane potential of the cardiac cells.[40] Calcium is recommended for the treatment of moderate to severe hyperkalemia ($\geq$ 6.5 mEq/L) where ECG changes are present and/or the risk of arrhythmia is present.[45] There are no randomized trials that demonstrate this, though calcium is recommended by the Cochrane Group.[43]

Calcium's effect is rapid, but transient. The onset of action of calcium is less than 3 minutes, and it lasts for about 1 hour. It may be repeated if the ECG does not improve with the initial injection. The dose is 10 mL IV over 10 minutes with continuous ECG monitoring of either calcium chloride or calcium gluconate. Calcium gluconate is less toxic to local tissue if extravasation occurs, but it may not be effective in low-flow states, such as shock or hepatic insufficiency, as it needs to be metabolized to its active form.[44] Calcium chloride contains more calcium than the calcium gluconate mixture (6.8 vs. 2.2 mmol in 10 mL), and it has greater bioavailability if the level of potassium is very high. The Cochrane Review recommends calcium chloride.[43]

Shifting Potassium Into The Cells

The next step in the emergent management of hyperkalemia is aimed at shifting the high extracellular potassium into the cells. Potassium can be shifted intracellularly with beta-2 agonists, insulin,

Time- And Cost-Effective Strategies

- Do not treat hypokalemia due to shifting of potassium.
- In a dialysis patient, if hyperkalemia is the only concern, try to arrange dialysis and avoid a hospital admission.
- In asymptomatic patients with hypokalemia, orally replace the potassium and avoid IV replacement.
- In patients with an elevated potassium level, consider the need to pursue repeat testing based on renal function, medications, and whether the blood was reported as hemolyzed.
- When drawing blood, invest in preventing hemolysis to avoid factitious hyperkalemia.

and (potentially) sodium bicarbonate. Insulin and glucose are used to lower the extracellular potassium by driving it into the cell by stimulating the Na^+/K^+-ATPase pump. These treatments also work in patients with end-stage renal diseases and are recommended for all patients with hyperkalemia requiring treatment.[46] The Cochrane Review found that insulin and glucose were effective in decreasing serum potassium levels and in reducing mortality from hyperkalemia.[43] The effect is independent of cellular uptake of glucose.[47] Ten units of regular insulin are recommended IV, and the effect is evident within 20 minutes. The serum potassium level decreases by 0.5-1.2 mEq/L with a maximum effect within 1 hour.[43,48] If the patient is normoglycemic, give dextrose in the form of D50 with the administration of insulin to prevent a paradoxical rise in the serum potassium. Take caution to avoid hypoglycemia, to which uremic patients may have an attenuated response.

Beta-agonist catecholamines also activate the Na^+/K^+-ATPase by stimulation of the beta-2 receptor. Studied medications include inhaled albuterol and levalbuterol, used with a spacer, and a dose response in maximum reduction of potassium has been reported at higher doses (20 mg vs 10 mg). This is synergistic to the effects of insulin and glucose.[44,49] High-dose albuterol (10-20 mg) delivered via high-flow nebulizer has been used to decrease the potassium 0.6-0.98 mEq/L.[22,49] It occurs within 1-2 minutes of administration and lasts 1-2 hours. A subsequent dose may be given at 2 hours.[44] To date, there has not been a comparative study of metered-dose inhaler versus nebulized beta-agonists; however, a systematic review of the literature concluded that both are effective.[44] Paradoxical elevation of potassium may be noted but should return to baseline at 3 minutes.

Caution must be taken in patients with known cardiac disease, as tachycardia may occur due to the side effects of the inhaled beta-agonists. This side effect occurs about 30 minutes into treatment; in one case, a patient had paroxysmal atrial fibrillation that resolved spontaneously. Other side effects reported are tremors and mild anxiety.[47] A 1995 RCT by Allon (n = 7) demonstrated that when used in combination, these agents (glucose, insulin, and nebulized beta-agonists) are superior to single agents in lowering the serum potassium in hemodialysis patients.[47] This was further recommended by a Cochrane review from 2005.[43]

Another therapy that has been used to treat hyperkalemia is sodium bicarbonate. Sodium bicarbonate is only effective in hyperkalemic patients who are acidotic and has no benefit when used for hyperkalemia in nonacidotic patients.[9] One study showed that sodium bicarbonate did not lower serum potassium levels in dialysis patients when used as either a single agent or in combination with

Risk Management Pitfalls For Potassium Emergencies

1. **"The blood sample was obviously hemolyzed, so I didn't think it was worth repeating the blood draw."**
Do not wait for the laboratory to repeat the evaluation if there is any clinical suspicion of hyperkalemia. Begin treatment immediately. In a well-appearing patient, it may not be necessary to repeat the study in the case of a hemolyzed sample that indicates an elevated potassium and all other electrolytes within normal limits. However, if there is any question at all, send a new blood sample for evaluation. In some cases, a hemolyzed specimen may be masking hypokalemia.

2. **"The ECG looked totally normal, so I assumed that the potassium must be normal."**
A perfectly normal ECG does not rule out a potassium abnormality. If clinically suspicious, a potassium level should be obtained.

3. **"This patient just had dialysis yesterday and his potassium is already 7.0 mEq/L."**
The rate of rise in hyperkalemia is just as important as the absolute number.

4. **"The ED is always packed, and there are not enough monitors to go around; plus I didn't think there was a reason the patient getting IV potassium needed to be on a monitor."**
All patients getting IV potassium supplementation, despite the dose, should be on a monitor both during and after treatment to avoid missing the induction of a dysrhythmia.

5. **"His potassium level is always elevated when he comes to the ED because he chronically misses his dialysis appointments, so I thought he had developed tolerance."**
Patients with end-stage renal disease are often considered to be more tolerant of hyperkalemia; However, these patients should be treated with as much caution as a nonrenal patient with hyperkalemia.

6. **"She had just of touch of CHF, so I just sent her out with furosemide and potassium supplement and thought she would follow up at the clinic – I didn't realize they didn't have any appointments for 3 months. I can't believe her potassium could go so high."**
Patients being discharged from the hospital with loop diuretics should have close follow-up to monitor for hypokalemia before starting them on potassium supplementation.

7. **"I did my job and started the treatment for hyperkalemia…the medicine team should have continued her treatment while she was waiting for a bed in the hospital."**
Underlying causes of hyperkalemia should be treated once the initial treatment of hyperkalemia has been initiated. Such treatments might be fluid for hypovolemia or a Foley catheter for urinary obstruction.

8. **"The potassium level was 7.5 mEq/L and she was scheduled for dialysis in the morning; I thought the SPS would keep her out of trouble."**
SPS is not a suitable therapy for the acute management of hyperkalemia and should be avoided due to its potential to cause bowel necrosis.

9. **"The serum potassium level was low – do you really think it was due to the albuterol? And why did she become hypokalemic?"**
In cases of hyperventilation, albuterol-treated patients, or in trauma, the hypokalemia is generally from a shifting of potassium rather than a total body depletion. In these situations, treating the underlying cause should take priority over the hypokalemia.

10. **"He had missed dialysis and the ECG showed a widened QRS complex – I thought the bicarbonate, insulin, and glucose would fix the problem – I wonder why he went into cardiac arrest?"**
Patients with clinically significant ECG changes concerning for hyperkalemia should be treated with calcium for membrane stabilization prior to other treatments for hyperkalemia.

11. **"The patient was in cardiac arrest; I never considered he could be hyperkalemic."**
Always consider hyperkalemia in patients with cardiac arrest, especially if they have a wide-complex dysrhythmia.

other therapies (ie, albuterol or insulin IV).[50] In 1997, Ngugi demonstrated that infusion therapy had some effect, but it was less effective than current therapies of albuterol, insulin, and glucose.[51] Based on the best available evidence, bicarbonate is not recommended as a monotherapy for hyperkalemia, especially in patients with renal failure or decreased urine output, though it may be adjunctive when managing patients with an organic acidemia.

Removing Potassium From The Body

In hyperkalemic patients not responsive to medical therapy, dialysis is recommended for the removal of potassium. In this treatment, high blood flow causes greater removal of potassium. Different dialysates have been studied and compared, with no clear advantage of one over another.[52,53] In the ED, dialysis is generally only possible on end-stage renal patients and is contingent upon whether a dialysis center is available or transfer can be quickly arranged. Hemodialysis via central venous access can be used during ongoing cardiopulmonary resuscitation to acutely lower serum potassium level and may result in return of spontaneous circulation with intact neurological status despite prolonged resuscitative efforts and failure of conventional medications and defibrillation.

Sodium polystyrene sulfonate (SPS) is a cation exchange resin that exchanges sodium for potassium in the colon and has classically been used in the treatment of hyperkalemia for the past 50 years. SPS is typically given at a dose of 30-60 grams by mouth or through a retention enema. Its onset of action is 4 to 6 hours, and theoretically, it decreases the serum potassium level 0.65 -1 mmol. The United States Food and Drug Administration (FDA) originally approved the use of SPS in 1958, and in 1962 the FDA reapproved its use after 2 small studies showed some decrease in serum potassium with its use. Ultimately, cation exchange resins have not been shown to decrease the serum potassium level within the first 4 hours of treatment and should not be used in the acute management of hyperkalemia. In fact, some studies show that SPS may be unhelpful in hyperkalemia and may increase the chance of colonic necrosis, especially when used with sorbitol.[54]

The first study on SPS was done by Scherr et al and published in the *New England Journal of Medicine* in 1961.[55] The study had 30 patients with hyperkalemia secondary to renal failure who were all treated with SPS, low-sodium diets, a cathartic, and insulin and glucose. This was a poorly designed study with many flaws in its methods and conclusions. Twenty-three of the 30 patients had a decrease of serum potassium of at least 0.4 mEq/L in 24 hours.[55] There was no control group, and most of the patients were treated with other therapies for hyperkalemia. A second study by Flinn et al published in the same

issue of the *New England Journal of Medicine* studied 8 patients; 5 were given SPS with sorbitol and 3 were given just sorbitol. (SPS may cause serious constipation and life-threatening concretions that may be resolved with the concomitant use of sorbitol.) In the study, all of the patients were given a diet high in sugar, gingerale, and no other food and had their potassium checked at 5 days. In the 5 patients who were given SPS and sorbitol, the potassium levels went from 6.6 to 5.2, but in the patients who were given just the sorbitol, the potassium levels went from 6.3 to 4.6. The authors concluded, "Sorbitol alone is as effective as a combination of resin and sorbitol in removing potassium, or more so. However, sorbitol alone caused a greater volume of debilitating diarrhea. In either case, the predictability of the fall in serum potassium was impressive."[56]

In the following years, SPS continued to be a mainstay in the treatment of hyperkalemia despite the lack of evidence to show its clinical effectiveness and safety. In 2007, after years of case studies describing serious and sometimes fatal cases of ischemic colitis, the FDA mandated a decrease in the concentration of sorbitol in the SPS formulations from 70% to 33%, thinking it may be the cause of ischemic colitis; however, episodes of ischemic colitis continued to be reported. In 2009, the FDA placed a warning for the use of SPS and the concomitant use of sorbitol. The warning reads, "Cases of colonic necrosis and other serious gastrointestinal adverse events (bleeding, ischemic colitis, perforation) have been reported in association with SPS use. The majority of these cases reported the concomitant use of sorbitol. Concomitant administration of sorbitol is not recommended."[57]

After reviewing the literature, it is the recommendation of the authors to follow the advice of Dr. Richard Sterns, who in 2010 wrote in the *Journal of American Society of Nephrologists:* "It would be wise to exhaust other alternatives for managing hyperkalemia before turning to these largely unproven and potentially harmful therapies."[58]

Controversies And Cutting Edge

Hyperkalemia In Digoxin Toxicity

Calcium is administered with caution in cases of digoxin toxicity with hyperkalemia due to several case reports of life-threatening dysrhythmias in this setting. In a recently published retrospective study looking at 159 patients over a 17.5-year period with digoxin toxicity treated with IV calcium, the authors found no association between the two. Twenty-three of these patients were given calcium, and there were no life-threatening dysrhythmias in the first hour after calcium administration. Also, the mortality rate was no different between the patients who did not receive calcium and those who did. This study

should bring into question the long-held belief that digoxin-toxic patients should have calcium withheld in the setting of hyperkalemia.[59]

At toxic levels, digoxin disrupts the Na^+/K^+-ATPase pump, leading to hyperkalemia. Over the past 50 years, there have been several case reports of life-threatening dysrhythmias when hyperkalemia in digoxin toxicity is treated with calcium.[60] One theory behind the adverse effects of using calcium in digoxin toxicity is known as the "stone heart" theory, which views calcium as the precipitant of an irreversible noncontractile state due to the failure of diastolic relaxation, resulting from the calcium-binding troponin-C. In addition to the stone heart theory, another concern stems from the delay in depolarization resulting in ventricular dysrhythmias as a result of calcium excess.[59] A study performed in an animal model mimicking digoxin toxicity and hyperkalemia found that there was no detriment to giving calcium.[61]

Succinylcholine

Controversy about the risk of hyperkalemia with the use of succinylcholine in patients with burns, renal failure, or crush injuries has existed in the fields of anesthesia and emergency medicine for decades.[62,63] In a recent systematic review, succinylcholine was reported to be safe when used in cases of acute burns occurring within 48 hours of presentation and in renal patients who had normal ECGs. One prospective cohort study looking at the comparison of succinylcholine versus rocuronium in patients for rapid sequence intubation found only 1 patient who had an episode of hyperkalemia that resulted in QRS widening on ECG (n = 382).[64] The administration of succinylcholine may cause a transient rise in serum potassium (0-0.5 mEq/L), which may be of no consequence in otherwise healthy patients. Nonetheless, in patients with renal disease or pre-existing hyperkalemia, this rise may induce arrhythmias. The approach to this issue should be based on ECG changes (ie, peaked T-waves or widened QRS). If such changes are present, the emergency clinician should opt to use other paralytics in order to prevent adverse outcomes.

Disposition

Hypokalemic patients treated in the ED who are tolerant of potassium by mouth and whose symptoms have resolved can be discharged with a short course of potassium as long as they have close follow-up. If the patient remains symptomatic or does not tolerate potassium by mouth, admission is advised.

There are no definite criteria for admission to the hospital for patients with hyperkalemia. However, patients with potassium levels > 8.0 mEq/L, patients with acute worsening of renal function, and those with comorbid medical conditions should be strongly considered for admission. Patients with hyperkalemia who have potassium levels ≥ 6.5 mEq/L should be treated and admitted in a monitored bed for close observation and treatment. For patients with a potassium level of 5.5-6.5 mEq/L, the disposition will vary depending on the underlying cause. In cases of end-stage renal failure, patients may be sent to dialysis after they are determined to be stable for dialysis.

Summary

Diagnosing and managing potassium abnormalities may be challenging in emergency practice. The first step is to consider the diagnosis and then confirm it by obtaining an ECG and serum electrolytes. Management must be tailored to the patient's presentation and comorbidities. Recognition and treatment of life-threatening dysrhythmias are key, and close monitoring after intervention is always indicated. An additional component to comprehensive emergency care is recognizing the etiology of potassium abnormalities and developing a strategy that prevents its occurrence.

Case Conclusions

In the case of the man who missed dialysis, he was found to be hyperkalemic with a potassium level of 7.8 mEq/L. His ECG showed a widened QRS complex, leading to immediate treatment with 10 mL of calcium gluconate. Nephrology was contacted and emergent dialysis was scheduled for the morning, but in the meantime he was given insulin 10 units IV and 50 mL of D50. A D10W infusion was started with 20 units of insulin per liter and he was admitted to the MICU.

The second patient was found to be hypokalemic, with a potassium level of 2.0 mEq/L. His ECG and other laboratory studies were within normal limits. An order for 20 mmol of potassium chloride IV with close observation of his ECG and vital signs was made. Arrangements were made for an ICU admission.

References

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study, will be included in bold type following the reference, where available.

1. Alfonzo AV, Isles C, Geddes C, et al. Potassium disorders--clinical spectrum and emergency management. *Resuscitation.* 2006;70(1):10-25. **(Review article)**
2. Parham WA, Mehdirad AA, Biermann KM, et al. Hyperkalemia revisited. *Tex Heart Inst J.* 2006;33(1)40-47. **(Review article)**
3. Kim HJ, Han SW. Therapeutic approach to hyperkalemia. *Nephron.* 2002;92(Suppl 1):33-40. **(Review article)**
4. Paltiel O, Salakhov E, Ronen I, et al. Management of severe hypokalemia in hospitalized patients: a study of quality of care based on computerized databases. *Arch Intern Med.* 2001;161(8):1089-1095. **(Review article)**
5. Unwin RJ, Luft FC, Shirley DG. Pathophysiology and management of hypokalemia: a clinical perspective. *Nat Rev Nephrol.* 2011;7(2):75-84. **(Review article)**
6. Blanning A, Westfall JM, Shaughnessy AF. Clinical inquiries. How soon should serum potassium levels be monitored for patients started on diuretics? *J Fam Pract.* 2001;50(3):207-208. **(Review article)**
7. Gennari FJ. Disorders of potassium homeostasis: hypokalemia and hyperkalemia. *Crit Care Clin.* 2002;18(2):273-288. **(Review article)**
8. Gennari FJ. Hypokalemia. *N Engl J Med.* 1998;339:451-458. **(Review article)**
9. Mandal AK. Hypokalemia and hyperkalemia. *Med Clin North Am.* 1997;81(3):611-639. **(Review article)**
10. Lin SH, Chiu JS, Hsu CW, et al. A simple and rapid approach to hypokalemic paralysis. *Am J Emerg Med.* 2003;21:487-491. **(Review article)**
11. Gutmann L, Conwit R. Hyperkalemic periodic paralysis. UpToDate.com. http://www.uptodate.com/contents/hyperkalemic-periodic-paralysis?source=search_result&search=Hyperkalemic+periodic+paralysis&selectedTitle=1%7E9 . Accessed May 7, 2011. **(Online resource)**
12. Stevens MS, Dunlay RW. Hyperkalemia in hospitalized patients. *Int Urol Nephrol.* 2000;32:177-180. **(Retrospective cohort; 35 patients)**
13. Ramadan FH, Masoodi N, El-Solh AA. Clinical factors associated with hyperkalemia in patients with congestive heart failure *J Clin Pharm Ther.* 2005;3:233-239. **(Case series; 938 patients)**
14. Einhorn LM, Zhan M, Hsu VD, et al. The frequency of hyperkalemia and its significance in chronic kidney disease. *Arch Intern Med.* 2009;169:1156-1162. **(Retrospective cohort; 66,259 patients)**
15. Knoll GA, Sahgal A, Nair RC, et al. Renin-angiotensin system blockade and the risk of hyperkalemia in chronic hemodialysis patients. *Am J Med.* 2002;112:110-114. **(Prospective; 251 patients)**
16. Weisberg LS. Management of severe hyperkalemia. *Crit Care Med.* 2008; 36:3246-3251. **(Review article)**
17. Bleyer AJ, Hartman J, Brannon PC, et al. Characteristics of sudden death in hemodialysis patients. *Kidney Int.* 2006;69:2268–2273. **(Prospective cohort; 88 patients)**
18. Sadjadi, SA, McMillan JI, Jaipaul N, et al. A comparative study of the prevalence of hyperkalemia with the use of angiotensin-converting enzyme inhibitors versus angiotensin receptor blockers. *Ther Clin Risk Manag.* 2009; 5:547–552. **(Retrospective cohort; 2331 patients)**
19. Favaloro EJ, Lippi G, Adcock DM. Preanalytical and postanalytical variables: the leading causes of diagnostic error in hemostasis? *Semin Thromb Hemost.* 2008;34:612-634.
20. Smellie WS. Spurious hyperkalemia. *BMJ.* 2007;334:693-695. **(Case series; 2 cases)**
21. Allon M, Copkney C. Nebulized albuterol for acute hyperkalemia in patients on hemodialysis. *Ann Int Med.* 1989;110:426-429. **(Randomized controlled trial; 10 patients)**
22. Acker CG, Johnson JP, Greenberg A. Hyperkalemia in hospitalized patients: causes, adequacy of treatment and results of an attempt to improve physician compliance with published therapy guidelines. *Arch Intern Med.* 1998;158:917-924. **(Prospective study; 127 patients)**
23. Oster JR, Singer I, Fishman LM. Heparin-induced aldosterone suppression and hyperkalemia. *Am J Med.*1995;98:575-586. **(Review article)**
24. Poggio R, Grancelli HO, Miriuka SG. Understanding the risk of hyperkalemia in heart failure: role of aldosterone antagonism. *Postgrad Med J.* 2010;86:136-142. **(Review article)**
25. Rimmer JM, Horn JF, Gennari FJ. Hyperkalemia as a complication of drug therapy. *Arch Intern Med.* 1987;147:867-869. **(Retrospective study; 308 patients)**
26. Reardon LC, Macpherson DS. Hyperkalemia in outpatients using angiotensin-converting enzyme inhibitors. *Arch Intern Med.* 1998;158:26-32. **(Case-controlled study)**
27. Sood MM, Sood AR, Richardson R. Emergency management and commonly encountered outpatient scenarios in patient with hyperkalemia. *Mayo Clin Proc.* 2002;12:1553-1561. **(Review article)**
28. Ramsay LE, Hettiarachchi J, Fraser R, et al. Amiloride, spironolactone, and potassium chloride in thiazide-treated hypertensive patients. *Clin Pharmacol Ther.* 1980;27(4):533-543. **(Prospective study; 16 patients)**
29. Pitt BZ, Zannad F, Remme WJ, et al. The effect of spironolactone on morbidity and mortality in patients with severe heart failure. Randomized Aldactone Evaluation Study Investigators. *N Engl J Med.* 1999;341(10)709-717. **(Randomized controlled trial; 1663 patients)**
30. Juurlink DN, Mamdani MM, Lee DS, et al. Rates of hyperkalemia after publication of the Randomized Aldactone Evaluation Study. *N Engl J Med.* 2004;351(6):543-551. **(Time series analysis)**
31. Lundberg P. The effects of adrenergic blockade on potassium concentration in different conditions. *Acta Med Scand.* 1983;672(suppl):121-132. **(Review article)**
32. Rosa RM, Silva P, Young JB. Adrenergic modulation of extra renal potassium disposal. *N Engl J Med.* 1980;302:431-434. **(Prospective study; 9 patients)**
33. Zimran A, Kramer M, Plaskin M, et al. Incidence of hyperkalemia induced by indomethacin in a hospital population. *Br Med J.* (Clin Res Ed).1985;291:107-108. **(Retrospective study; 50 patients)**
34. Rastergar A, Soleimani M. Hypokalemia and hyperkalemia. *Postgrad Med J.* 2001;77(914):759-764. **(Review article)**
35. Ahmed J, Weisberg LS. Hyperkalemia in dialysis patients. *Semin Dial.* 2001;14(5):348-356. **(Review article)**
36. Hartland AJ. Serum potassium is unreliable as an estimate of in vivo plasma potassium. *Clin Chem.* 1999;45(7):1091-1092.
37. Coca SG, Perazella MA, Buller GK. The cardiovascular implications of hypokalemia. *Am J Kidney Dis.* 2005;45(2):233-247.
38. Mattu A, Brady WJ, Robinson DA. Electrocardiographic manifestations of hyperkalemia. *Am J Emerg Med.* 2000;18:721- 729. **(Case series; 5 cases)**
39. Webster A, Brady W, Morris F. Recognising signs of danger: ECG changes resulting from abnormal serum potassium concentration. *Emerg Med J*. 2002;19(1):74-77. **(Case series; 3 cases)**
40. Dittrich, KL, Walls RM. Hyperkalemia: ECG manifestations and clinical considerations. *J Emerg Med.* 1986;44:49-55. **(Review article)**
41. Wrenn KD, Slovis CM, Slovis BS. The ability of physicians to predict hyperkalemia from the ECG. *Ann Emerg Med.* 1991;20:1229-1232. **(Prospective observational study)**
42. Martinez-Vea A, Bardaji A, Garcia C, et al. Severe hyperkalemia with minimal electrocardiographic manifestations: a report of seven cases. *J Electrocardiol.* 1999;32:45-49 **(Case series; 7 cases)**
43. Mahoney BA, Smith WA, Lo DS, et al. Emergency interventions for hyperkalemia. *Cochrane Database Syst Rev.* 2005. Art no CD003235. **(Cochrane meta-analysis; 12 randomized trials)**

44. Emmet M. Non-dialytic treatment of hyperkalemia in the dialysis patient. *Semin Dial.* 2000;13(5):279-280. **(Review article)**

45. Special resuscitation situations. An advisory statement on conditions which may require modifications in resuscitation procedures or techniques. Prepared by Members of the International Liaison Committee on Resuscitation. Special resuscitation situations. *Resuscitation.* 1997;34:129-149. **(Expert consensus practice guideline)**

46. Allon M, Copkney C. Albuterol and insulin for the treatment of hyperkalemia in hemodialysis patients. *Kidney Int.* 1990;38:869-872. **(Randomized crossover; 12 patients)**

47. Allon M, Shanklin N. Effects of albuterol treatment on subsequent dialytic potassium removal. *Am J Kidney Dis.* 1995;26(4):607-613. **(Randomized controlled trial; 7 patients)**

48. Blumberg A, Weidmann P, Shaw S, et al. Effects of various therapeutic approaches on plasma potassium and major regulating factors in terminal renal failure. *Am J Med.* 1988;85:507-512. **(Prospective cohort; 10 patients)**

49. Greenberg A. Hyperkalemia: treatment options. *Semin Nephrol.* 1998;18(1):46-57. **(Review article)**

50. Allon M, Shanklin N. Effects of bicarbonate administration on plasma potassium in dialysis patients: interactions with insulin and albuterol. *Am J Kidney Dis.* 1996;28(4):508-514. **(Randomized crossover; 8 patients)**

51. Ngugi NN, McLigeyo SO, Kayima JK. Treatment of hyperkalemia by altering the transcellular gradient in patients with renal failure: effect of various therapeutic approaches *East Afr Med J.* 1997;74(8):503-509. **(Randomized controlled trial; 70 patients)**

52. Gutzwiller JP, Schneditz D, Huber AR et al. Increasing blood flow increases kt/V(urea) and potassium removal but fails to improve phosphate removal. *Clin Nephrol.* 2003;59(2):130-136. **(Randomized crossover; 13 patients)**

53. Zehnder C, Gutzwiller JP, Huber A, et al. Low-potassium and glucose-free dialysis maintains urea but enhances potassium removal. *Nephrol Dial Transplant.* 2001;16:276-271. **(Randomized controlled trial; 12 patients)**

54. Gruy-Kapral C, Emmett M, Santa Ana CA, et al. Effect of single dose resin-cathartic therapy on serum potassium concentration in patients with end-stage renal disease. *J Am Soc Nephrol.* 1998;9(10):1924-1930.

55. Scherr L, Ogden DA, Mead AW, et al. Management of hyperkalemia with a cation-exchange resin. *N Engl J Med.* 1961:264;115-119. **(Nonrandomized controlled trial; 30 patients)**

56. Flinn RB, Merrill JP, Welzant WR. Treatment of the oliguric patient with a new sodium-exchange resin and sorbitol: a preliminary report. *N Engl J Med.* 1961;264:111-115.

57. US Food and Drug Administration: Kayexalate (sodium polystyrene sulfonate) powder. Available at: http://www.fda.gov/Safety/MedWatch/SafetyInformation/ucm186845.htm. Accessed January 27, 2010. **(Nonrandomized controlled trial; 8 patients)**

58. Sterns RH, Rojas M, Bernstein P, et al. Ion-exchange resins for the treatment of hyperkalemia: are they safe and effective? *J Am Soc Nephrol.* 2010;21(5):733-735. **(Review article)**

59. Levine M, Nikkanen H, Pallin DJ. The effects of intravenous calcium in patients with digoxin toxicity. *J Emerg Med.* 2011;40(1):41-46.

60. Lown, Black H, Moore FD. Digitalis, electrolytes and the surgical patient. *Am J Cardiol.* 1960;6:309-337. **(Review article)**

61. Hack JB, Woody JH, Lewis DE, et al. The effect of calcium chloride in treating hyperkalemia due to acute digoxin toxicity in a porcine model. *J Toxicol Clin Toxicol.* 2004;42(4):337-342. **(Animal model)**

62. Yentis SM. Suxamethonium and hyperkalaemia. *Anaesth Intensive Care.* 1990;18:92-101. **(Review article)**

63. Martyn JA, Richtsfeld M. Succinylcholine-induced hyperkalemia in acquired pathologic states: etiologic factors and molecular mechanisms. *Anesthesiology.* 2006;104:158-169. **(Review article)**

64. Laurin EG, Sakles JC, Panacek EA, et al. A comparison of succinylcholine and rocuronium for rapid-sequence intubation of emergency department patients. *Acad Emerg Med.* 2000;7(12):1362-1369. **(Prospective cohort, 328 patients)**

CME Questions

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1. **Seventy-five percent of intracellular potassium is found in which type of cells?**
   a. Endothelial
   b. Muscle
   c. Hepatocyte
   d. Adipocyte

2. **Which systems are the primary sites of excess potassium loss from the body?**
   a. Renal and gastrointestinal
   b. Skin and pulmonary
   c. Renal and skin
   d. Renal and pulmonary

3. **In which of the following cases can clinically significant potassium loss occur from the skin?**
   a. Mild sweating
   b. Severe burns
   c. Hypothermia
   d. Severe dehydration

4. **What is the most common drug-related cause of hypokalemia?**
   a. Glucocorticoids
   b. Penicillin
   c. Diuretics
   d. Calcium

5. **Which endogenous hormone is the primary regulator of renal potassium secretion?**
   a. Estrogen
   b. Epinephrine
   c. Thyroid-stimulating hormone
   d. Aldosterone

6. **All of the following cause transcellular potassium shifts into cells EXCEPT:**
   a. Insulin
   b. Albuterol
   c. Metabolic alkalosis
   d. Respiratory acidosis

7. **All of the following medications can induce hyperkalemia EXCEPT:**
   a. ACEIs
   b. ARBs
   c. Potassium-sparing diuretic
   d. Furosemide (loop diuretic)
   e. Beta-blockers

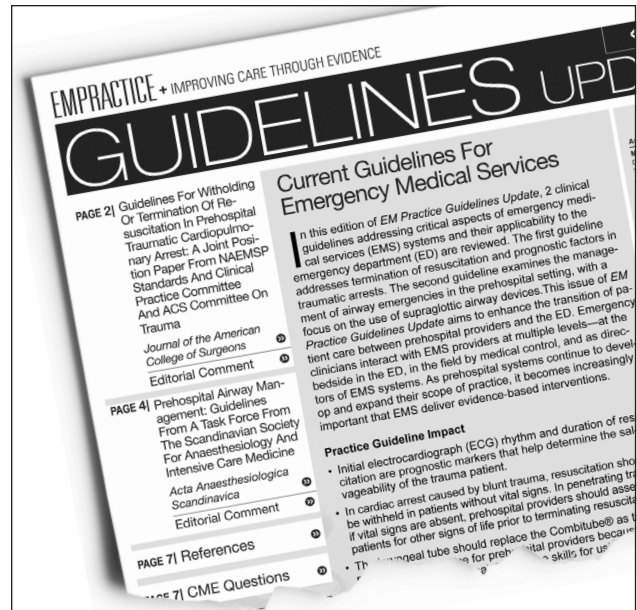8. **The classic ECG changes that appear sequentially as the serum potassium level increases are:**
   a. Sine-wave pattern, wide QRS, prolonged PR interval, peaked T-wave
   b. Wide QRS, prolonged PR interval, peaked T-wave, sine-wave pattern
   c. Peaked T-wave, prolonged PR interval, wide QRS, sine-wave pattern
   d. Prolonged PR interval, wide QRS, peaked T-wave, sine-wave pattern

9. **It may be necessary to replace magnesium as well as potassium in hypokalemic patients because:**
   a. Magnesium is required in the activation of the sodium/potassium pump
   b. Magnesium takes the place of potassium in vital intracellular functions
   c. Magnesium dilates smooth muscle, which decreases the need for potassium
   d. Magnesium causes a transcellular potassium shift, increasing serum potassium

10. **Which of the following does not decrease the serum potassium?**
    a. Calcium
    b. Beta-2 agonists
    c. Insulin
    d. Dialysis

Emergency Ultrasound In Patients With Respiratory Distress

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Emergency ultrasound is a highly valuable and readily learned tool that has expanded rapidly since its introduction more than 20 years ago. In the past decade, emergency ultrasound has progressed from 6 to 11 primary indications. The earliest applications of emergency ultrasound answered questions regarding the presence or absence of life-threatening clinical conditions and enhanced patient safety through procedural guidance. More recently, it has lent itself to the evaluation and management of critically ill patients through the incorporation of multiple ultrasound examinations within a single patient encounter. The information gained can provide crucial, time-dependent information at the bedside, which can enhance diagnostic certainty and guide management. This issue of *EMCC* provides an evidence-based approach to the use of ultrasound in the evaluation of the critically ill patient with respiratory distress and hypotension. Two clinical scenarios are presented: the progressively dyspneic patient with a history of chronic obstructive pulmonary disease (COPD) and decompensated heart failure and the acutely dyspneic patient with hypotension. These scenarios were chosen because they are commonly encountered in clinical practice and require rapid, complex decision making that is augmented with the use of emergency ultrasound. The evidence supporting emergency ultrasound for diagnosis of pulmonary edema, pneumothorax, left ventricular (LV) dysfunction, and right ventricular (RV) dysfunction is presented, and the technique for image acquisition is discussed.

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The Evaluation And Management Of Constipation In The Pediatric Emergency Department

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A 1992 study showed that 7% of patients presenting to a pediatric emergency department with abdominal pain were diagnosed with constipation. Misdiagnosis may lead to multiple unresolved physician visits, utilization of emergency medical services, high doses of ionizing radiation, unnecessary laboratory tests, and even surgical procedures. This issue examines existing literature, though few randomized double-blind controlled clinical trials of good quality existed until recently. The study populations in many articles are obtained from pediatric specialty clinics with subjects who carry a known diagnosis of chronic and often poorly controlled constipation. Analysis of the literature is hampered by lack of a concrete definition of constipation and the variability in outcome measures. The primary evidence-based recommendations from this article are based on published guidelines and include management of constipation in children divided into 3 stages of therapy: disimpaction, maintenance therapy, and behavior modification.

***Pediatric Emergency Medicine Practice* subscribers:** Access this article at no charge at www.ebmedicine.net/PEMP.

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Purchase this article with CME at www.ebmedicine.net/pediatricconstipation or subscribe with a $100 savings at www.ebmedicine.net/PEMPinfo.

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To read a letter from Dr. Andy Jagoda, Editor-in-Chief, about this exciting achievement, please visit www.ebmedicine.net/MEDLINEletter.

All of our readers have played an instrumental role in ensuring the publication's high quality, and we greatly appreciate your support.

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Target Audience: This enduring material is designed for emergency medicine physicians, physician assistants, nurse practitioners, and residents.

Goals: Upon completion of this article, you should be able to: (1) demonstrate medical decision-making based on the strongest clinical evidence; (2) cost-effectively diagnose and treat the most critical ED presentations; and (3) describe the most common medicolegal pitfalls for each topic covered.

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