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HYPERKALEMIA: A POTENTIALLY LETHAL CLINICAL CONDITION

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SUMMARY – Hyperkalemia develops when the regulation between potassium intake and potassium excretion, or the distribution between intra- and extracellular potassium is disturbed. It is a common, silent, and potentially lethal clinical condition, which seldom occurs in patients with normal renal function. Clinically, the most important effect of hyperkalemia is that which the condition has on the myocardium, but it also affects neuromuscular, gastrointestinal, and hormonal functioning. The management of hyperkalemia requires exclusion of pseudohyperkalemia, assessment of the urgency for treatment, and institution of appropriate therapy. The initial treatment for life-threatening hyperkalemia should always include insulin plus glucose, as the hypokalemic response to insulin is both prompt and predictable. Combined treatment with β_2-agonists and insulin is also effective, but the most rapid method of potassium removal is hemodialysis.

Key words: *Hyperkalemia, physiopathology; Hyperkalemia, therapy; Kidney, physiopathology*

Introduction

Hyperkalemia is rarely encountered in healthy subjects because of the effective cellular buffering of acute potassium loads and renal excretion of excess potassium that occurs within 6 hours. Thus, an average daily potassium load (100 mmol/day) if given acutely, would result in frank hyperkalemia were it not for extrarenal potassium homeostatic mechanisms that rapidly translocate the administered potassium into the intracellular compartment. The extrarenal mechanisms that govern internal potassium distribution include hormones such as insulin, epinephrine, and aldosterone. In addition, acid-base status and plasma osmolality influence internal potassium balance[1]. The gastrointestinal tract, which normally contributes little to potassium excretion, assumes a greater role in the maintenance of potassium homeostasis in patients with chronic renal failure (CRF).

Potassium Adaptation

The mechanism of potassium adaptation in renal failure appears to be similar to the process which occurs in subjects with intact renal function given a high potassium diet. Renal adaptation was demonstrated as early as 24 hours following partial renal ablation in experimental animals, and micropuncture studies suggest that net potassium excretion occurs between the end of distal tubule and the end of collecting tubule. There is an increase in both the number and activity of the sodium – potassium pump in the collecting tubule cells. The increased activity is not a nonspecific event secondary to the hypertrophic changes taking place, since the sodium – potassium – ATPase site density is increased out of the proportion to the increase in basolateral membrane surface area. The renal medullary structures may also contribute to renal potassium adaptation. The intrinsic capacity for potassium secretion is increased in deeper nephrons. Increased delivery of potassium to the juxtamedullary nephrons may

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also contribute to the increased excretion of potassium by these nephrons. Additionally, potassium recycling allows for the secretion of any potassium that might have diffused back from the cortical collecting duct into the interstitial medulla, thus increasing the efficiency of the kidney to excrete potassium[2]. The renal adaptive changes in potassium excretion in response to a reduction in nephron mass are largely dependent on intact aldosterone secretion and adequate sodium delivery. Aldosterone concentrations are often elevated in patients with renal failure, probably as an adaptive response to reduced renal mass, which helps prevent hyperkalemia. With a normal potassium intake, potassium retention does no occur until a glomerular filtration rate (GFR) of 5 to 10 ml/min is reached. However, if potassium intake is acutely increased, hyperkalemia may ensue despite a relatively preserved glomerular filtration (e.g., 10 to 40 ml/min)[2,3].

In the presence of renal failure, adaptive changes in the colonic mucosa permit an increase in the amount of potassium excreted by the colon. Rectal excretion of potassium in end-stage renal disease (ESRD) patients may be by up to 200% greater than in the normal subjects[4], and increased activity of sodium – potassium – ATPase in the colonic mucosa of such patients has been reported[5]. Aldosterone receptors are present in colonic mucosa, and a role for mineralocorticoids in this adaptive response has also been suggested.

Definition

Hyperkalemia is defined as a serum potassium concentration greater than 5.5 mmol/l. It seldom occurs in patients with normal renal function. Like hypokalemia, it is often due to iatrogenic (treatment-induced) causes. While less common than hypokalemia, it is often more dangerous since cardiac arrest is more often associated with high serum potassium levels (>7.0 mmol/l)[6].

Etiology

Hyperkalemia develops when the regulation between potassium intake and excretion, or the distribution between intra- and extracellular potassium is disturbed. The etiology of hyperkalemia is summarized in Table 1.

Pseudohyperkalemia

Spurious hyperkalemia is an artifically elevated potassium concentration resulting from potassium leakage from the cells during blood drawing or after blood collection. Hemolysis that occurs during a traumatic blood draw is the most common cause of pseudohyperkalemia. A prolonged, tight tourniquet and repeated fist clenching may also result in artificially elevated potassium concentration. If the leukocyte count is greater than $2x10^5/mm^3$, or the platelet count is greater than $1x10^6/mm^3$, an abnormally high amount of potassium will leak out of these cells during coagulation, thus artificially raising the serum potassium.

Table 1. Etiology of hyperkalemia

Spurious	Redistribution	Renal
Ischemic blood drawing	Acidosis	Renal failure (severe)
Hemolysis	Insulin deficiency	Aldosterone deficiency
Abnormal erythrocytes	Hyperosmolality	Addison's disease
Thrombocytosis	β-Adrenergic blockade	Enzymatic defects
Leukocytosis	Drugs	Adrenogenital syndrome
	Arginine HCl	Corticosterone methyloxidase
	Succinylcholine	Isolated aldosterone deficiency
	Digitalis	Hyporeninemic hypoaldosteronism
	Fluoride	Drugs
	Hyperkalemic periodic paralysis	Prostaglandin synthetase inhibitors
	Exercise	Angiotensin-converting enzyme inhibitors
	Malignant hyperthermia	Heparin
		Cyclosporin
		Tubular dysfunction
		Acquired disorders
		Pseudohypoaldosteronism
		K+ sparing diuretics

With a good blood drawing technique and analysis of blood before clotting, a true measure of extracellular potassium can be obtained. A normal serum plasma level and an elevated serum potassium level along with the absence of electrocardiogram (ECG) changes confirm the diagnosis of pseudohyperkalemia.

Transcellular shifts

A potassium shift out of cells commonly contributes to hyperkalemia, but it alone will not result in persistent hyperkalemia.

In the presence of acidosis, especially metabolic, potassium leaks out of cells into the extracellular fluid. This occurs as hydrogen ions enter the cells, a process which buffers the extracellular fluid pH. Organic acids such as that seen in lactic acidosis or diabetic ketoacidosis are less likely to cause shifts of potassium on the basis of acidosis alone. The lack of insulin in diabetic ketoacidosis and the release of potassium from ischemic cells in lactic acidosis contribute to hyperkalemia more than the acidosis *per se*.

Hyperglycemia produces hyperkalemia in diabetic patients by the combined effects of insulin deficiency and hyperosmolarity on transcellular potassium distribution. An absolute decrease in insulin as the one that occurs in type I diabetics or in a fasting patient with ESRD may provoke hyperkalemia[7], involving not only a fasting-induced decrease in baseline insulin levels but also an insensitivity to catecholamine-driven potassium uptake by cells.

Tissue ischemia which results in cell death will release intracellular potassium (140 mmol/l) and, combined with renal underexcretion, can result in marked hyperkalemia. The more common clinical conditions include crushing injuries, severe infections, and lysis of malignant cells after administration of chemotherapy, particularly in lymphoma, plasmacytoma, and leukemia.

Several drugs can produce hyperkalemia by altering the transcellular distribution of potassium. Depolarizing muscle relaxants such as succinylcholine can result in hyperkalemia by promoting the shift of potassium out of cells. Patients with neuromuscular disease are especially sensitive to the hyperkalemic effects of succinylcholine. Infusion of 30 g of the cationic amino acid, arginine HCl, increases plasma potassium by 0.5 to 1.0 mmol/l and can produce life-threatening hyperkalemia in individuals with deranged potassium metabolism. Digitalis preparations diminish cellular potassium uptake by inhibiting the sodium – potassium pump. Substantial hyperkalemia can accompany digitalis intoxication[8]. Fluoride intoxication appears to increase the plasma potassium concentration by provoking leakage from the intracellular compartment. The associated hypocalcemia enhances the cardiac risks of fluoride-induced hyperkalemia. ACE-inhibitors can also result in hyperkalemia in patients with renal failure, and the mechanism involves a decrease in aldosterone production as the result of decreased angiotensin II levels. Prolonged heparin therapy has been reported to interfere with aldosterone release, resulting in hyperkalemia.

Hereditary hyperkalemic periodic paralysis is a rare cause of hyperkalemia as the result of potassium shift out of cells. It is inherited in an autosomal-dominant pattern.

Excessive potassium retention

In most circumstances, potassium retention occurs because of a deficit in renal elimination. Defective urinary excretion of potassium has three major causes: 1) renal failure; 2) a defective mechanism of tubular potassium excretion; and 3) hypoaldosteronism.

A normal kidney has the capacity to excrete in excess of 400 mmol of potassium *per day*, and it is unlikely that an individual will become chronically hyperkalemic without some degree of chronic renal impairment. The kidney's ability to maintain homeostasis on a normal potassium diet is preserved until GFR is markedly diminished (GFR <10 ml/min), but once a critical number of nephrons have been lost, the remaining nephrons cannot excrete a normal potassium load. To prevent hyperkalemia at this point, dietary potassium must be restricted (<60 mmol/day). The risk of hyperkalemia is magnified in catabolic patients with acute renal failure (ARF), in whom the daily increment in plasma potassium averages 0.7 mmol/l or more, in contrast to the increment of 0.3 to 0.5 mmol/l in noncatabolic patients with oliguric ARF.

Hypoaldosteronism, especially when combined with a decrease in renal function, can substantially impair urinary potassium excretion. Diminished levels of aldosterone result from either a primary defect in the adrenal gland or from an abnormality in the renin – angiotensin II mechanism for stimulating aldosterone secretion. Hyperkalemia is detected in approximately half of the patients with acquired primary adrenal insufficiency as well as in those with two forms of adrenogenital syndrome resulting in mineralocorticoid deficiency (C-21 hyroxylase deficiency and deficiency in corticosterone methyloxidase I or II)[9]. Decreased renin secretion may result from pathologic involvement of the juxtaglomerular apparatus, defective prostacyclin production, disordered conversion of inactive (prorenin) to active renin (e.g., a complication of diabetes mellitus), chronic expansion of extracellular fluid vol-

ume, and acute salt restriction. Drug-induced hypoaldosteronism results from interference with the renin – angiotensin – aldosterone axis (ACE-inhibitors, prostaglandin synthetase inhibitors, cyclosporin), or from direct effects on the adrenal gland (heparin).

A minority of hyperkalemic patients with CRF and an adequate GFR have normal values of aldosterone and plasma renin activity, and apparently a primary defect in the potassium secretory function of the distal nephron. This abnormality has been well documented in patients with tubulointerstitial renal diseases (e.g., medullary sponge kidney, amyloidosis, sickle-cell disease, lupus erythematosus, obstructive uropathy, and renal transplants), all of which can also produce hyporeninemic hypoaldosteronism.

Increased potassium intake

Hyperkalemia tends to develop in response to an increase in potassium intake only when renal potassium handling is compromised. This may occur in patients with impaired renal function who are given large amounts of potassium-rich fruits and vegetables, hyperalimentation fluids, multiple transfusions of blood aged in storage, large doses of penicillin G (1.7 mmol potassium *per* million units), or potassium salts (up to 13 mmol potassium *per* gram)[10,11]. Geophagia of red clay with a high potassium content may result in hyperkalemia in patients with impaired renal function.

Signs and Symptoms

Hyperkalemia can cause adverse effects that range from subtle and difficult to recognize to those that are life-threatening. A majority of these effects are related to the effects of potassium on cellular membrane potential or voltage. The primary determinant of cell membrane potential in most cells is the ratio of intracellular to extracellular potassium concentration. Small changes in extracellular potassium can result in great changes in the intracellular to extracellular potassium ratio, and hence great changes in resting membrane potential. Resting membrane potential is important in all electrically active cells, including voluntary and involuntary muscles, and neurons.

Cardiac

The most prominent effect of hyperkalemia is that on the myocardium. Decreases in resting membrane potential decrease myocardial cell conduction velocity and increase the rate of epithelization. Changes in cardiac conduction induced by high potassium are reflected by ECG and generally parallel the degree of hyperkalemia (Fig. 1). The earliest changes are tenting of T wave, which can progress to P wave fluttering, prolongation of PR interval and widening of QRS complex, with development of a deep S-wave. A slowed conduction velocity, especially

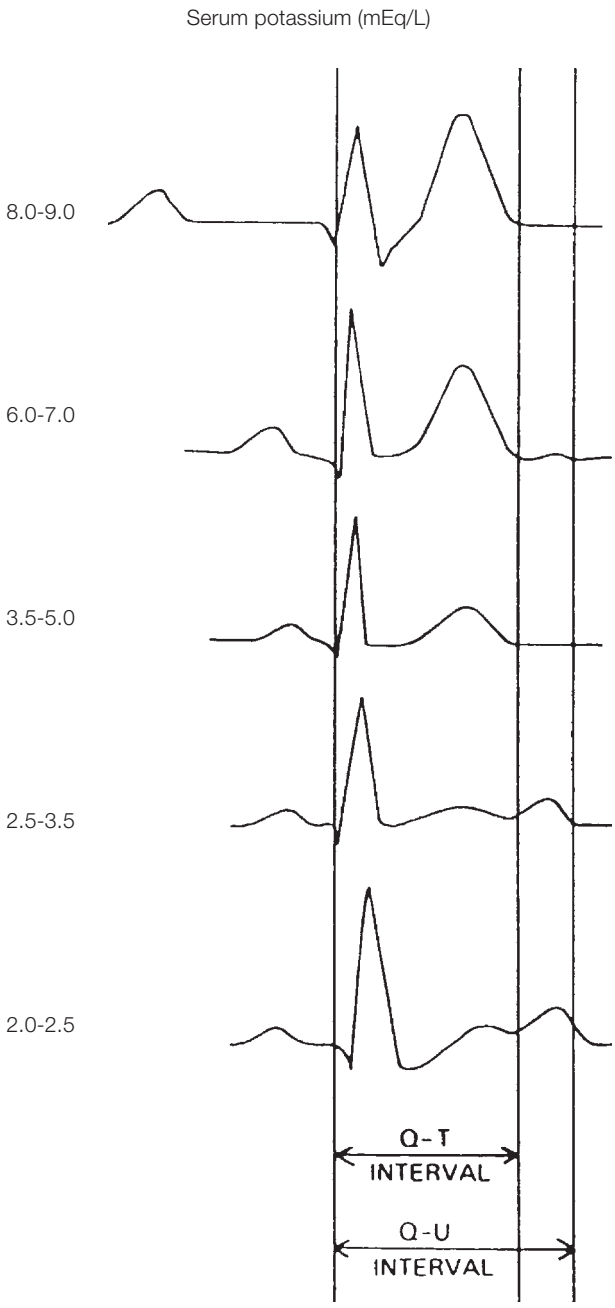


Fig. 1. Effect of serum potassium levels on ECG

in the presence of peaked T waves, increases the chance that ventricular fibrillation may develop, leading to sudden death[12]. The progression from benign to lethal arrhythmias in hyperkalemia is unpredictable, and the presence of any ECG findings of hyperkalemia should be considered a medical emergency.

Factors exaggerating ECG changes of hyperkalemia are low serum sodium and calcium levels as well as acidosis and a high serum magnesium concentration. These changes are counteracted by an increased calcium level, explaining why calcium infusion is an emergency treatment for serious hyperkalemia. Medications that may aggravate hyperkalemia include heparin, procainamide, and propranolol.

Hyperkalemia also produces conduction abnormalities of implanted pacemakers[13]. In profound hyperkalemia, the heart becomes dilated and flaccid due to decreased strength of contraction (related to decreased number of active muscle units).

Hemodynamic

A high potassium diet decreases blood pressure in hypertensive humans[14]. The mechanism is not clear but it could be related to its natriuretic properties, vasodilatatory effect, renin suppression, baroreceptor or central neurogenic mechanisms, and in part to stimulation of the release of endothelial cell-derived relaxing factor[15]. There also are some studies suggesting that a high potassium diet may protect against the development of stroke by a mechanism distinct from its antihypertensive properties[15].

Neurologic

Skeletal muscles are particularly sensitive to hyperkalemia, resulting in increased weakness, fatigue, and even paralysis related to depolarization block in the muscle. While hyperkalemia has marked effects on the peripheral neuromuscular system, it has little effect on the central nervous system. Paralysis of respiratory muscles and those required for phonation may also occur (Table 2).

Gastrointestinal

Gastrointestinal symptoms such as nausea, intermittent intestinal colic, diarrhea, or even enteritis may occur in hyperkalemic patients. These changes have been attributed to smooth muscle hyperreactivity.

Table 2. Defining characteristics of hyperkalemia

Cardiac effects:
• tall, peaked T wave in precordial leads
• widened QRS complex
• prolonged P-R interval
• decreased amplitude and disappearance of P wave
• sine wave (blending of QRS into T wave)
• ventricular arrhythmias
• cardiac arrest
Neuromuscular effects:
• vague muscular weakness (usually first sign)
• flaccid muscle paralysis (first noticed in the legs, later in the trunk and arms, facial and respiration muscles affected last; muscles supplied by cranial nerves are usually spared)
• paresthesias of the face, tongue, feet and hands are common and are the result of stimulation of pain receptors
• central nervous system is not affected, patient often remains alert and apprehensive in spite of other changes until cardiac arrest occurs
Gastrointestinal effects:
• nausea
• intermittent intestinal colic or diarrhea
Laboratory data:
• serum potassium >5.5 mmol/L
• often associated with acidosis

Endocrine

Hyperkalemia directly stimulates adrenal aldosterone secretion as well as insulin and glucagon secretion, and decreases renin secretion by an effect on the macula densa. Sometimes, the natriuretic effects of a high potassium level override the direct, potassium-mediated effects on renin, so that the levels of plasma renin activity are elevated rather than depressed[16].

Fluid and electrolytes

Hyperkalemia has a natriuretic effect. A high potassium level also decreases the renal production of ammonia and may directly impede ammonia secretion, leading to the development of metabolic acidosis.

Diagnosis

On assessing true hyperkalemia, it is useful to determine whether the potassium level is elevated as the result of a potassium shift or due to renal underexcretion. This determination can often be made by completing history and routine laboratory data (Fig. 2). A 24-hour urine potassium may be helpful if some question remains unsolved.

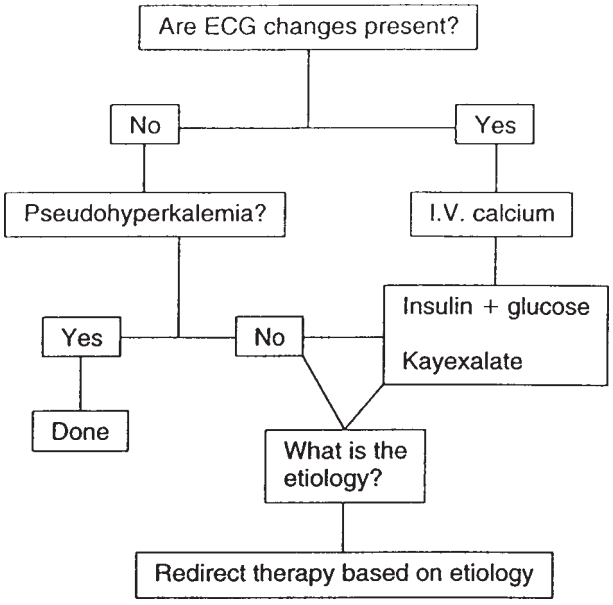


Fig. 2. General scheme for approaching a patient with hyperkalemia

Treatment

There are two aims of therapy for hyperkalemia: 1) to reverse acute effects of hyperkalemia by increasing the transport of potassium from extracellular fluid into cells; and 2) to correct the underlying cause of hyperkalemia. Since severe hyperkalemia most often occurs in a setting of CRF, it is important to know whether or not the mechanisms of internal potassium disposal are intact in this setting.

Blocking cardiac effects

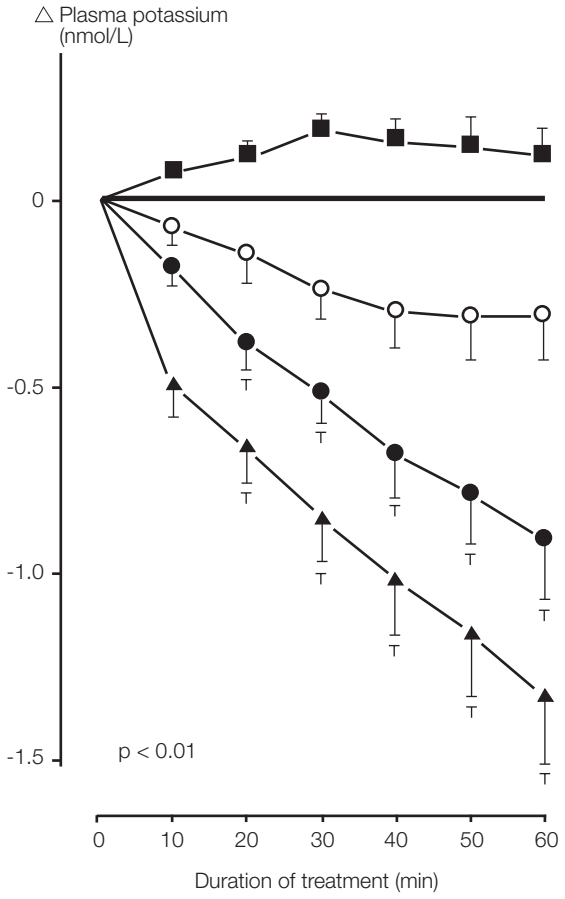
In the presence of ECG changes, the intravenous administration of calcium can be life-saving, as it rapidly counteracts the toxic effect of hyperkalemia on the myocardium. This approach is universally accepted. Calcium can be administered as either calcium gluconate or calcium chloride. Calcium gluconate is preferred if a peripheral vein is used for administration, because extravasation of calcium chloride is toxic to dermal tissue. For a patient in cardiac arrest, treatment with calcium chloride is preferred because of a slight delay in the action of calcium gluconate. These effects can be documented on ECG within 1 to 3 min, and last for 30 to 60 min. A second dose may be given if no effect is seen within 5 to 10 min. Because of the rapid onset of its effect, intravenous calcium administration should be the initial treatment for patients with ECG abnormalities related to hyperkalemia.

Several precautions should be observed with intravenous calcium: 1) it should not be administered in solutions containing bicarbonate because $CaCO_3$ precipitation may occur; and 2) hypercalcemia that occurs during rapid calcium infusion may potentiate the myocardial toxicity of digitalis. Hyperkalemic patients taking digoxin should be given calcium as a slow infusion over 20 to 30 min to avoid hypercalcemia[17].

Cellular potassium uptake

Plasma potassium level is not lowered by calcium administration, and it must be achieved by other measures. The second fastest way to treat hyperkalemia is to alter potassium distribution by increasing cellular uptake with either insulin or β_2-adrenergic agonist administration.

Insulin rapidly stimulates cellular potassium uptake by extrarenal cells, primarily hepatocytes and myocytes. Ten units of insulin should be administered intravenously to ensure rapid and consistent bioavailability, and will begin to affect serum potassium levels within 10 to 20 min, with the effect lasting for 4 to 6 hours[17]. The higher the initial potassium, the greater was the decline after insulin administration. Also, the higher the insulin dose, the more remarkable was the effect and the decrement of plasma potassium was often accompanied by reversal of the ECG changes of hyperkalemia[18]. When insulin was compared with other treatments for hyperkalemia, Blumberg *et al.*[19] found that insulin was the most rapidly acting agent short of hemodialysis (Fig. 3). These observations further support the use of insulin, together with glucose to prevent hypoglycemia, as the most efficacious way of treating hyperkalemia in CRF patients until dialysis is available. Glucose should not be given to hyperglycemic patients because glucose-induced hyperglycemia can lead to further increases in the potassium concentration due to hypertonicity-induced potassium redistribution[17]. Table 3 lists the studies



that evaluated the efficacy of insulin in the treatment of hyperkalemia.

A second effective treatment for hyperkalemia is β_2-agonist administration. Intravenous albuterol, 0.5 mg, rapidly stimulates potassium uptake and can decrease potassium by approximately 1 mmol/l[22]. Albuterol, when administered by a nebulizer at a dose of 10 or 20 mg, decreases serum potassium by 0.62 or 0.98 mmol/l, respectively, with an immediate onset of action and maximal effect at 90 to 120 min[23]. It should be noted that the dose used for nebulization is roughly 10 times higher than that used for the treatment of asthma (20 mg *vs* 2.5 mg). When smaller doses similar to those given to patients with acute asthma were used (180 μg twice by inhalation), only a minimal response was noted. Although no serious side effects have been reported with this relatively large dose, two potential problems may be associated with the use of β_2-agonists. One is the risk of tachyarrhythmias, and the other is the risk of precipitation of angina pectoris in patients with coronary artery disease. Another disadvantage of the use of these agents is that some patients with CRF are resistant to the hypokalemic effect of β_2-agonists[18].

Fig. 3. Changes in plasma potassium during intravenous infusion of 8.5% bicarbonate solution (■), *epinephrine* (❍), *or insulin* (●), *and during hemodialysis* (▲)

Table 3. Studies examining the effect of glucose and insulin on plasma potassium

Study	No. of patients	Dose	K_i (mmol/l)	K_{fin} (mmol/l)	ΔK (mmol/l)	Time	Comments
Blumberg[19]	10 (ESRD)	100 U of insulin in 500 ml of 20% glucose at a dose of 5 mU/kg/min	5.62±0.33	4.7±0.33	-0.92	60 min	The greater the initial Ki, the greater the decline
Allon[20]	12 (ESRD)	10 U insulin as i.v. bolus + 50 ml of D50 over 5 min	5.48±0.21		-0.65±0.09	Significant decrease noted at 15 min	
Lens[21]	10 (CRF)	Insulin (10 U) i.v. bolus + 40 g glucose over 15 min	6.7±0.2	5.7±0.2	-1±0.1	60 min	Reversal of ECG changes

K_i= initial potassium; K_{fin}= final potassium; ΔK= potassium decrement

Table 4. Studies examining the effect of catecholamines on plasma potassium

Study	No. of patients	Preparation	Dose	K_i (mmol/l)	K_{fin} (mmol/l)	ΔK (mmol/l)	Time	Comments
Blumberg[19]	10	Epinephrine	0.05 μg/kg/min	5.57±0.31	5.25±0.29	NS	60 min	
Allon[20]	12	Albuterol (nebulizer)	20 mg in 4 ml of NS over 10 min	5.56±0.22		-0.66±0.12 overall -0.89±0.12 in responders	60 min	No significant potassium change in 4 of 10 patients
Lens[21]	24	Albuterol sulfate	0.5 mg diluted in 100 ml of D5W over 10 to 15 min	7.02±0.2	5.6±0.2	-1.4±0.1	60 min	
Allon[24]	10	Nebulized albuterol	10 mg	5.93±0.27		-0.62±0.09	90 min	Two patients resistant
	10	Same	20 mg	5.81±0.41		-0.98±0.14	120 min	

K_i= initial potassium; K_{fin}= final potassium; ΔK= potassium decrement

Table 4 summarizes the studies that examined β-adrenergic-mediated extrarenal potassium disposal. In severe hyperkalemia, combined therapy with albuterol and insulin plus glucose has been shown to produce a substantially greater decrease in potassium than that following each drug administered separately[20].

Recent studies show that the changes in serum potassium with intravenous bicarbonate are small and incon-

Table 5. Potassium removal options

Mechanism	Therapy	Dose	Onset	Duration
Antagonizes membrane effects	Calcium	Calcium gluconate, 10% solution, 10 ml i.v. over 10 min	1 to 3 min	30 to 60 min
Cellular potassium uptake	Insulin	Regular insulin, 10 U i.v., with dextrose, 50%, 50 ml if plasma glucose is <13.8 mmol/l	30 min	4 to 6 h
	β_2-Adrenergic agonist	Nebulized albuterol, 10 mg	30 min	2 to 4 h
Potassium removal	Sodium polystyrene sulfonate	Kayexalate, 60 g p.o. in 20% sorbitol, or Kayexalate, 60 g *per* retention enema, without sorbitol		
	Hemodialysis		Immediate	Until dialysis is completed

i.v.= intravenously; p.o.= perorally

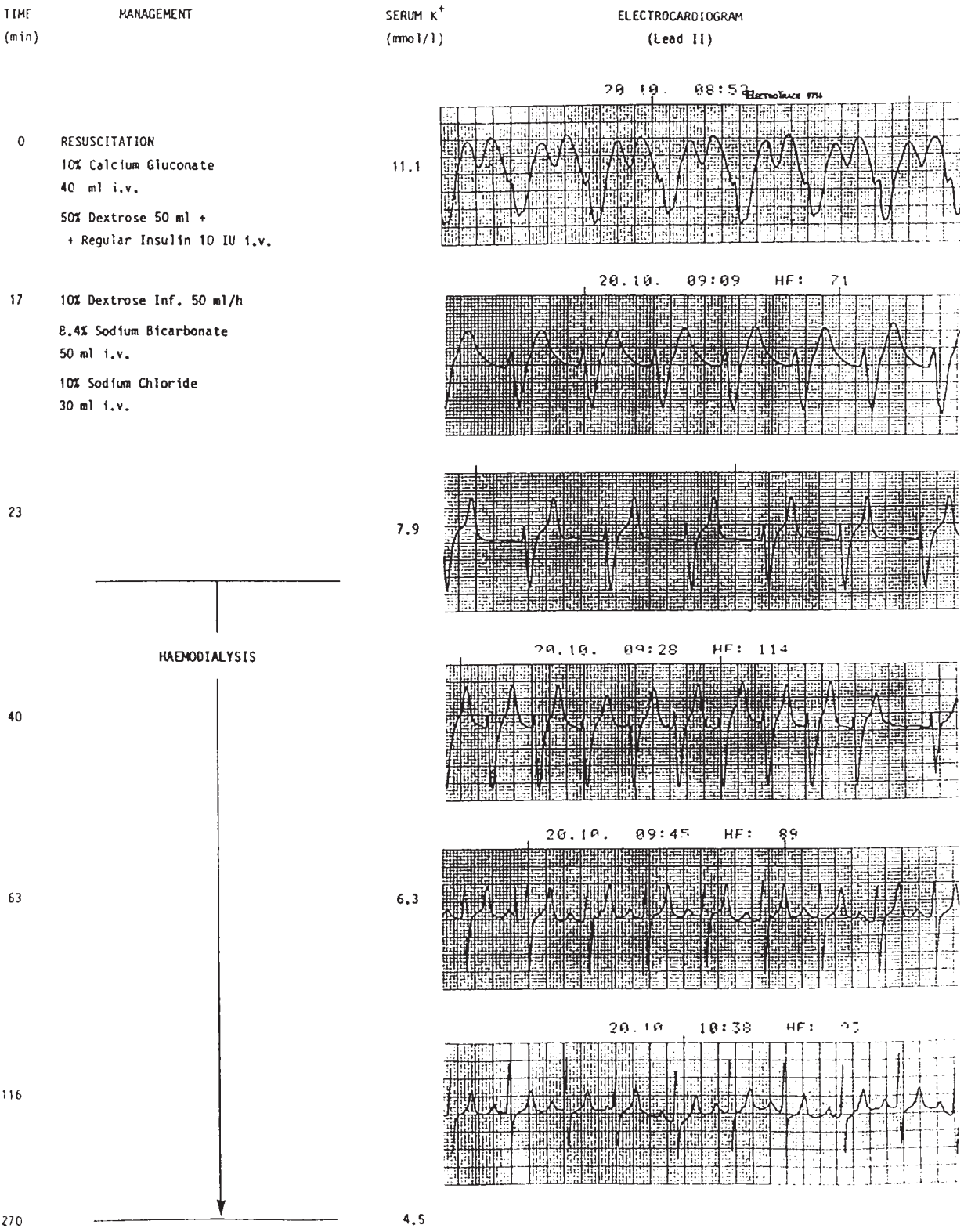


Fig. 4. ECG changes in a patient with extreme hyperkalemia
A patient with extreme hyperkalemia was treated with i.v. bolus of 10% calcium gluconate, 10% sodium chloride, 50% dextrose, and regular insulin followed by rapid infusion of 10% dextrose, and 8.4% sodium bicarbonate. Finally, the patient underwent hemodialysis.

sistent (Fig. 3)[19]. Moreover, the associated sodium load may worsen hypertension and contribute to the development of acute heart failure and pulmonary edema. At present, only in patients with hyperkalemia, metabolic acidosis, and volume depletion, rehydration with 5% dextrose solutions with the addition of 150 mmol/l sodium bicarbonate may be an intravenous solution for rehydration preferable to normal saline solutions[17].

Potassium removal

Removal of potassium from the body can be achieved by either loop or thiazide diuretics, dialysis, and cation-exchange resins (Table 5).

Diuretics such as ethacrynic acid, furosemide, or thiazides inhibit tubular reabsorption of sodium chloride and water, and stimulate potassium excretion. Although diuretics are not used specifically as primary agents for treating hyperkalemia, they are very useful for treatment of chronic, mild hyperkalemia complicated with fluid retention[25]. Acute hyperkalemia is generally not treated optimally with diuretics because the rate of potassium excretion usually will not be adequate[26].

Most of the patients with hyperkalemia have underlying renal failure as a contributing factor, limiting the effectiveness of diuretics. If pharmacologic agents are responsible for hyperkalemia, such medications should be discontinued (Table 1). In case of a rapidly reversible disease (e.g., obstructive uropathy), treatment of the underlying condition with close observation of the potassium level in association with continuous ECG observation may be adequate. If CRF with decreased excretion of potassium is responsible for hyperkalemia, dietary intake of potassium should be restricted to less than 60 mmol/day.

Dialysis or continuous arterio(veno)venous hemofiltration may be used to remove potassium from the body if medical interventions have failed to reverse hyperkalemia, or in case of massive release of cellular potassium associated with intercurrent hypercatabolism. Peritoneal dialysis removes potassium at a slower rate reducing serum potassium by 50% for every 12 hours of dialysis[27]. Continuous arterio(veno)venous hemofiltration is effective in chronic hyperkalemia, but does not remove potassium fast enough to be recommended for use in acute, severe hyperkalemia. Hemodialysis is the most rapid method of potassium removal (Fig. 4)[28]. If a potassium-free dialysate is used, serum potassium may decrease as much as 1.2 to 1.5 mmol/hour[19]. However, care should be taken with the use of up to 2 mmol/l of potassium in dialysate fluids to avoid precipitating hypokalemia[29].

The resin, sodium polystyrene sulfonate (Kayexalate), exchanges sodium for potassium in the gastrointestinal tract, thereby allowing for potassium elimination. It can be administered either orally or per rectum as a retention enema. The rate of potassium removal is relatively slow (one gram of sodium polystyrene sulfonate removes approximately 0.5 to 1.0 mmol of potassium in exchange for 2 to 3 mmol of sodium), requiring 4 hours for full effect[17]. When given orally, sodium polystyrene sulfonate is generally administered with sorbitol (20 g of Kayexalate in 100 ml of 20% sorbitol) to avoid constipation. If given as an enema, avoiding the use of sorbitol may be prudent because several case reports suggest an association between rectal administration of sodium polystyrene sulfonate with 20% sorbitol and subsequent colonic perforation[30].

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Sažetak

HIPERKALEMIJA: POTENCIJALNO POGUBNO KLINIČKO STANJE

P. Kes

Hiperkalemija nastaje kao posljedica poremećaja u unosu i izlučivanju kalija, kao i zbog nerazmjera u razdiobi kalija između izvanstaničnog i staničnog prostora. Radi se o čestom, pritajenom, ali potencijalno smrtonosnom kliničkom stanju koje se rijetko vidi u bolesnika s normalnom bubrežnom funkcijom. Najznačajniji klinički učinak hiperkalemija ima na srce, ali dovodi i do poremećaja u radu živaca i mišića, probavnog sustava i žlijezda s unutarnjim lučenjem. Prije liječenja hiperkalemije potrebno je isključiti lažnu hiperkalemiju, prepoznati potrebu za hitnim liječenjem i započeti s odgovarajućom terapijom. Hiperkalemiju koja ugrožava život bolesnika treba gotovo uvijek početi liječiti inzulinom i glukozom, s obzirom na to da je hipokalemijski učinak inzulina brz i predvidiv. Kombinirana uporaba inzulina i beta$_2$-agonista je učinkovita, ali je hemodijaliza metoda koja najbrže uklanja kalij iz organizma.

Ključne riječi: *Hiperkalemija, fiziopatologija; Hiperkalemija, terapija; Bubreg, fiziopatologija*