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Potassium metabolism in patients with chronic kidney disease. Part II: Patients on dialysis (stage 5)

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Abstract. Potassium is removed mainly by diffusion during dialysis. In hemodialysis, potassium removal averages 70–150 mmol per session, and the presence of glucose-free dialysate, sodium profiling, and hyperkalemia, may increase its removal. The most frequent potassium derangement in hemodialysis patients is hyperkalemia. Hemofiltration removes approximately 60 mmol of potassium per treatment. In peritoneal dialysis patients, despite lower potassium removal (about 30–40 mmol/day), hypokalemia is the most frequent electrolyte alteration, probably due to movement of potassium into the cells mediated by insulin, secondary to glucose absorption from the dialysis solution.

Hemodialysis

Potassium is removed mainly by diffusion (85%) and by convection (15%). Usually, its removal is considered satisfactory if the pre and postdialysis plasma potassium levels are lower than 6 mmol/l and higher than 3.3 mmol/l, respectively [1]. Potassium clearance is similar to that of creatinine, but its rate of removal varies with the potassium gradient between plasma and dialysate. The reduction is greater for patients with hyperkalemia than in those with normal predialysis potassium levels. On the other hand, it appears that potassium removal is increased when sodium 'profiling' is used to make sequential changes in the dialysate sodium concentration from hypertonic to normal levels during dialysis. Treatment with insulin and albuterol, before hemodialysis, results in reduced potassium removal and may cause an exaggerated rebound [2]. Furthermore, dialysate containing glucose in a concentration of 200 mg/dl leads to glucose loading and thus an additional intracellular shift of potassium into cells [3]. This conclusion is supported by the observation that potassium removal was significantly greater with glucose-free dialysate than with dialysate containing 200 mg/dl glucose [4].

The removal of potassium during hemodialysis averages 70–150 mmol per session, depending on dialyzer clearance and potassium concentration gradient [5].

For most stable dialysis patients, a dialysis fluid potassium concentration of about 2 mmol/l (at least in a range of 1–3 mmol/l) is optimal, i.e. a concentration which removes excess potassium, avoids dangerous postdialysis hypokalemia (<3.3 mmol/l) at the end of the interdialytic period and prevents severe predialysis hyperkalemia (>6 mmol/l). In patients with dangerously high (>6 mmol/l) or very low predialysis potassium concentrations (<3.3 mmol/l), dialysate potassium concentrations of 0 or 4 mmol/l, respectively, can be used during the whole or part of the dialysis session [6].

Approximately 60% of the potassium removed during hemodialysis is lost from the intracellular compartment (ICC). Potassium is removed from the intravascular compartment (IVC) to the dialysate, while intravascular potassium is replenished from the ICC. Since the former passage is faster than the latter, movement of potassium from ICC to IVC continues even after the end of dialysis, until a steady state is reestablished between these two compartments [1]. Therefore, after the end of

a highly efficient hemodialysis, one should expect an increase in plasma potassium of 0.5–1 mmol, within 1–3 hours, if there was a marked change in plasma potassium during dialysis. Measurements of plasma potassium after this rebound period (2 or 3 hours after dialysis) will give a more realistic assessment of plasma potassium level [3].

Causes of hyperkalemia in patients on hemodialysis are: high dietary potassium intake, use of salt substitutes, hypoaldosteronism, reduction in residual glomerular filtration, hypercatabolic state, blood transfusions, metabolic acidosis, reduction in the dialysis clearance, and certain drugs e.g. cox1 and cox2 inhibitors, β-blocking agents, angiotensin-converting enzyme inhibitors, spironolactone, succinylcholine, AT1-receptor blockers, digoxin, cyclosporin, tacrolimus, ketoconazole, and those containing potassium [1, 2, 7–9].

Reduction in the dialytic clearance of potassium can be mediated by loss of effective dialyzer area such as with surface area clotting, cold dialysate, reduced effective dialysate or blood flow rates – low pump settings, recirculation, etc [1].

Hypokalemia is a rare event in hemodialysis patients. In one large series, 10% of chronic hemodialysis patients exhibited hyperkalemia, whereas the incidence of hypokalemia was only 0.4%. Dialysis can aggravate hypokalemia in potassium-depleted patients, resulting in life-threatening arrhythmias [3].

Patients who present with predialytic normokalemia and metabolic acidosis are at risk of developing marked hypokalemia during dialysis, even when one chooses a relatively high dialysate potassium of 3–5 mmol/l, because the correction of predialysis acidosis may unmask an underlying total body potassium depletion. Thus it is essential to assess both predialysis plasma–potassium concentration and acid–base status in order to evaluate total body potassium depletion. In the acidotic patient potassium repletion is best done by the intravenous or oral routes and not via increasing dialysate potassium, because the gradient between the dialysate and plasma potassium may not be adequate enough to achieve sufficient transfer of potassium [3]. Some authors have hypothesized that the rapid removal of potassium during dialysis might limit the correction of metabolic acidosis, because the cellular hyperpolarization caused by a rapid fall in serum potassium, might interfere with the extraction of H^+ from the cells and the cellular uptake of bicarbonate [10, 11].

Hypokalemia in hemodialysis patients is less frequent and can be caused by a low potassium intake, recovery of glomerular filtration, chronic diarrhea and and/or prescription of drugs that can increase intestinal potassium excretion such as mineralocorticoids and ion-exchange resins [12].

Peritoneal dialysis

Although the same general principles apply in chronic intermitent peritoneal dialysis (IPD) as in hemodialysis, the rate of potassium removal is markedly slower [3]. Peritoneal clearance for potassium averages about 17 ml/minute for IPD and approximately 7 ml/minute for continuous ambulatory peritoneal dialysis (CAPD). These values are between those for urea and creatinine clearances. Interestingly, during the first hour of a dwell, potassium clearance is higher (24 ml/minute) than that of the remaining period and the most probable explanation for these high values is the release of potassium from the cells that line the peritoneal cavity. This release may be promoted by the initial low pH and/or by the hyperosmolality of the instilled dialysate [13]. Standard peritoneal dialysis solutions contain no potassium [12, 14].

In patients with severe hyperkalemia and total body potassium excess, peritoneal dialysis is inefficient to remove adequate amounts of potassium and, therefore, hemodialysis is recomended to treat such emergency [3].

In IPD, as in hemodialysis, during the first 1 to 2 hours, there is a more rapid fall in plasma potassium concentration which is due chiefly to a shift of potassium into the cells [3]. Subsequently potassium concentration decreases primarily as the result of potassium removal. During intermittent peritoneal dialysis, 60-minute cycles achieve approximately a 70% equilibration between dialysate and plasma and 30-minute cycles achieve about 55% equilibration. In CAPD with cycles of more than 4 hours, one can assume an equilibration of almost 83–88% [3]. Thus, using a 2-l CAPD exchange four times per day with potassium-free dialysate and a steady-state plasma potassium of 5 mmol/l, one can estimate the potassium removal close to 33–35 mmol/day [13]. Some additional potassium also is removed with ultrafiltration.

Assuming fluid removal of 2 l/day by ultrafiltration, the total potassium removal would be increased by 8–9 mmol/day [3]. Contrary to patients on hemodialysis, peritoneal dialysis patients have a normal or even high intracellular potassium content, especially those on CAPD. This phenomenon is probably related to the continuous glucose absorption from the dialysis solutions and the subsequent stimulation of intracellular uptake of potassium, mediated by insulin release [3, 15, 16].

Hyperkalemia is considerably less common in stable CAPD patients contrary to those on chronic hemodialysis [17]; its prevalence among CAPD patients is 0.8% as contrasted to 10% in chronic hemodialyisis patients.

Oreopoulos et al. in 1982 reported that 10–15% of CAPD patients required potassium supplementation for hypokalemia [18, 19], while Spital and Sterns noted that 36% of their CAPD patients had a serum potassium less than 3.5 mmol/l at some time during their course [20]. Gao et al. reported that patients on CCPD had significantly lower serum potassium levels compared to CAPD patients. Since CCPD uses a greater number of exchanges with shorter dwell times and does not allow for equilibration to occur, there is always a concentration gradient difference between the dialysate and the plasma allowing more potassium to be transported into the dialysate fluid. It has also been shown that patients treated with CCPD tend to have more gastrointestinal symptoms, which may result in a decreased potassium intake [21].

In a recent study, Oreopoulos et al. have found that hypokalemic patients on peritoneal dialysis were younger, had been on CAPD for longer periods, had a high K_t/V, had a lower urine creatinine clearance and urine volume, and they had a lower weight respect to the normokalemic ones [22].

Hemofiltration

The filtrate replacement fluid contains potassium in a concentration of 0.0–2.0 mmol/l. The potassium loss depends on the potassium gradient between plasma and dialysate, and the fluid removal during hemofiltration. Using an infusate containing 2 mmol potassium per liter, Streicher and coworkers found an average net potassium removal of 63 mmol per intermittent hemofiltration treatment [3].

Summary

Potassium retention is one of the dangers that accompanies endstage renal disease, while its removal is one of the advantages of the kidney replacement therapies. Potassium handling characteristics differ among hemodialysis, peritoneal dialysis and hemofiltration procedures.

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