Disorders of Acid-Base Metabolism and Electrolytes in CAPD

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Since the pioneering development of a permanent silicone peritoneal catheter by Tenckhoff in 1968[1] followed by the introduction of ambulatory peritoneal dialysis techniques and equipment in the late 1970s, several inconvenient technical problems of previous peritoneal dialysis methods were repaired and the potential for bacterial peritonitis was minimized. Thus, CAPD became an acceptable alternative treatment to hemodialysis for ESRD, and a tremendous growth of CAPD was noted worldwide including our country (Korea).

The goal of CAPD is to not only substitute for impaired renal capacity to excrete metabolic waste products but also to maintain body fluid, electrolyte and acid-base homeostasis. To satisfy the latter, the variation of regimens, and diversity of CAPD patient populations, the composition of CAPD solutions evolved gradually and led to that of currently available commercial dialysate solutions (Table 1)[2]. However, similar or somewhat unique treatment-related manifestations or complications on maintenance CAPD as compared to those on hemodialysis have been still noted. In this paper, disturbances of fluid, electrolytes and acid-base homeostasis among noninfectious complications of CAPD will be discussed.

Acid-Base disorders

Regardless of the prescription of dialysis modes, one of the goals of dialysis is to normalize the acid-base balance. However, the acid-base changes during CAPD may vary, depending on the specific CAPD technique used, the concentration of base in the dialysate, and in some cases the dialysate buffer chosen. Ultimately, acid-base balance in CAPD patients depends on the net effects of dietary H^+ retention and base gains and losses during dialysis[3].

1. Metabolic Acidosis

A study using a CAPD solution with 36 mEq/L lactate, demonstrated that the loss of bicarbonate into the dialysate (192 mEq/day) essentially equalled lactate uptake from the dialysate (212 mEq/day)[4]. When dietary H^+ accumulation and organic acid anions (base precursors) lost into the dialysate also measured, the net base balance amounted to a loss of 26.4 mEq/day. This net loss of base was associated with average blood gas values of pH 7.36, a pCO_2 of 34 mmHg, and a bicarbonate level of 20 mEq/L. However, more severe metabolic acidosis in CAPD patients would occur in various clinical conditions (Table 2). In

Table 1. Composition of Commercially Available Peritoneal Dialysis Solutions

Component	Range of concentration (mEq/L)
Sodium	130 - 135
Potassium	0
Calcium	2.5 - 3.5
Magnesium	0.5 - 1.5
Lactate	35 - 45
Chloride	95 - 106
Glucose (g/dL)	1.5, 2.5, 3.5, 4.25
Osmolality (mOsm/L)	346, 396, 447, 485

Table 2. Causes of Metabolic Acidosis in CAPD

Increased H^+ gain or bicarbonate loss
Hypercatabolism
Increased protein intake
GI losses: laxatives, diarrhea, enterostomy
Diabetic ketoacidosis
Decreased H^+ loss or bicarbonate gain
Decreased dialysis clearance
Inadequate dialysate concentration
Noncompliance to base supplements ($NaHCO_3$)
Deterioration of residual function
Miscellaneous
D-lactic acidosis

Table 3. Causes of Metabolic Alkalosis in CAPD

Increased H^+ loss or bicarbonate gain
Standard dialysate for mildly alkalotic patient
High dialysate base concentration
GI losses: vomiting, nasogastric suction
Base supplements ($NaHCO_3$)
Decreased H^+ gain or bicarbonate loss
Dietary protein restriction
Miscellaneous

hypercatabolic patients leading to increased hydrogen ion generation and those with increased bicarbonate loss, dialysis must achieve a relatively greater delivery of bicarbonate or an equivalent base than is necessary in stable chronic patients who do not have predialysis acidosis. For these variable needs for bicarbonate delivery, commercial dialysate solutions offer only a narrow range of concentrations of bicarbonate and other bases (Table 1). In cases of negative bicarbonate balance, using higher dialysate lactate levels or supplementation of sodium bicarbonate or citrate orally could correct its imbalance, but with a risk of causing metabolic alkalosis.

In patients with severe hepatic failure or those with lactic acidosis, the metabolic conversion of lactate to bicarbonate may be impaired. Inadequate metabolism of lactate, along with loss of bicarbonate into the dialysate, can exacerbate the lactic acidosis. In these instances, use of specially prepared bicarbonate dialysate is recommended[5]. Commercially available CAPD dialysate contains lactate consisting of the racemic mixture of the D- and L-isomers. Both L-and D-lactate are metabolized predominently in the liver to pyruvate, which can then enter metabolic pathways. Therefore, the metabolic overload of infused D-lactate leading to toxicity from L-or D-lactate absorption in CAPD would have to involve a defect in the normal utilization of this isomer. Those clinical conditions include heatic disfunction and glucose loading, which could limit the metabolic reserve for lactate and lead to rising serum levels with inefficient bicarbonate generation[6, 7]. A report of D-lactate acidosis was noted in a diabetic patient receiving peritoneal dialysis, who was characterized with marked encephalopathy in the setting of severe respiratory alkalosis.

2. Metabolic Alkalosis

Generally, metabolic alkalosis as compared to metabolic acidosis is a rare occurrence in CAPD patients. Causes of metabolic alkalosis are often not dialysis-related (Table 3). The metabolic alkalosis can result from contraction of the extracellular fluid volume, as reported in the treatment phase of hyperglycemia in diabetic patients on CAPD[8] or with the frequent use of hypertonic dialysis solutions[9]. However, the dialytic process, including CAPD, is by nature autoregulatory in terms of metabolic acid-base balance: the higher the prevailing serum bicarbonate concentration, the greater the bicarbonate efflux using nonbicarbonate dialysis or the smaller the influx during bicarbonate-based dialysis, thus limiting the alkalinization. Uremic acidosis is characterized by a low bicarbonate and a low pCO_2 due to compensatory hyperventilation. Normally, there is a lag in the correction of the hypocapnia after the bicarbonate has been normalized. Because hemodialysis corrects rapidly hypobicarbonatemia, the

sustained hypocapnia causes a transient alkalemia. However, the slower correction of bicarbonate by CAPD keeps pace with the slow correction of hypocapnia in CAPD, thereby minimizing the degree of alkalemia that often complicates repair of metabolic acidosis[10].

3. Respiratory Alkalosis

In patients with respiratory alkalosis, the normally functioning kidneys defend against alkalemia by excreting bicarbonate. The CAPD patients has no such mechanism. Furthermore, the constant infusion of buffer in CAPD patients with respiratory alkalosis can lead to serious alkalemia[11].

4. Respiratory Acidosis

Though increased ventilation is the usual response to CAPD with mild reduction in lung volumes, existing borderline respiratory reserve or with exaggerated carbohydrate loading with high-flow hypertonic CAPD may induce carbon dioxide retention and hence respiratory acidosis[12].

Electrolyte Disorders

CAPD patients are subject to a variety of electrolyte disturbances like hemodialysis patients. However, the incidence and degree of each electrolyte disturbances is somewhat different between both dialysis modes. For example, hypokalemia requiring potassium supplementation has been noted in about 10 to 20 percent of CAPD patients[13]. Nevertheless, hyperkalemia is considerably less common in stable CAPD than in chronic hemodialysis patients[14].

1. Hypernatremia and Hyponatremia

Because the fluid entering the peritoneal cavity by osmotically-driven flow is hyponatremia, that is, more water than salt flows from plasma to peritoneal compartment leading to a relative water deficit; the patient should become hypernatremia. However, hypertonicity is a powerful stimulant of ADH secretion which in turn stimulates thirst. The patients drinks water or other hypotonic fluid until tonicity restored to normal. In fact, patients on CAPD may actually demonstrate plasma sodium concentrations slightly lower than normal.

Hypernatremia (>150 mEq/L) has been frequently reported as a complication of intermittent peritoneal dialysis (IPD) whereas that is rarely seen in CAPD patients because of both the longer dwell times and the tendency of these patients to ingest adequate amounts of hypotonic fluids[15].

Hyponatremia in CAPD patients usually results from excessive ingestion of water more than sodium, which may cause pulmonary edema if a favorable diffusion gradient for sodium from dialysate to blood results in a large net positive sodium balance, specially in patients with little volume removed by ultrafiltration[16]. Hyponatremia may occur in both CAPD and hemodialysis patients with hyperglycemia as a result of osmotic flux of water from the intracellular to the extracellular compartment. However, patients on hemodialysis demonstrate a greater fall in serum sodium concentration than do hyperglycemic patients on CAPD. In CAPD patients, the degree of hyponatremia more closely parallels that seen in normal individuals. In these patients, water intake appears to be counterbalanced by ongoing removal of hypotonic fluid from the extracellular compartment by CAPD[17].

2. Hyperkalemia and Hypokalemia

As above described, hyperkalemia in CAPD (0.8 percent) is uncommon but may develop with noncompliance with dietary prescription or in catabolic states or gradually reduced clearance. Hyperkalemia can result from the CAPD treatment per se if excessive potassium chloride has

Table 4. Causes of Hypocalcemia in CAPD

Increased calcium loss
Low dialysate calcium
Malabsorption (steatorrhea)
Decreased calcium intake
Low dietary intake or decreased GI absorption
Noncompliance to Ca or Vitamin D
Deficiency of active vitamin D
Shifts of calcium
PTH resistance - due to uremia or Mg deficiency
Parathyroidectomy (hungry bone syndrome)
Hyperphosphatemia
Alkalosis (low ionized Ca)
Hypoalbuminemia (normal ionized Ca)

Table 5. Causes of Hypermagnesemia in CAPD

Increased intake or absorption
High dialysate Mg
Antacids
Laxatives
Hard water, failure of water treatment
Decreased loss
Deterioration of residual renal function
Increased release from cells
Rhabdomyolysis

been added to dialysate. Also, when hyperkalemia is noted in CAPD patients, other factors affecting extrarenal potassium disposal, such as insulin deficiency, drugs including ACE inhibitors and beta blockers should be considered.

Hypokalemia (< 3.0 - 3.5 mEq/L) in CAPD patients is relatively common, which is dangerous in the patients on digoxin or with a history of cardiac arrhythmias. Severe hypokalemia has also been reported in a CAPD patient during a period of diminished dietary intake and increased gastrointestinal losses of potassium. In this acute setting, up to 20 mEq/L of KCl can be added to the dialysate with a low incidence of side effects. This dose has been reported to increase the plasma potassium concentration by an average 0.44 mEq/L over 2-3 hours. Sixty-six to 79 percent of the intraperitoneal potassium dose was absorbed via this route[13]. Potassium supplementation should be monitored in dialysis patients because of the absence of renal reserve to excrete excess potassium.

3. Hypercalcemia and Hypocalcemia

Recently, the incidence of hypercalcemia (> 11.5 mg/dL of total calcium) became more frequent in CAPD patient as the use of more vitamin D and calcium carbonate-containing phosphorus binders became commonplace. These hypercalcemias typically normalized over one to three weeks following adjustment of oral calcium and vitamin D doses. The resistant hypercalcemia to these general management could be tried with the use of other phosphate binders or CAPD dialysate with low or even free calcium content. However, other various causes of hypercalcemia including severe hyperparathyroidism, malignancy, granulomatous diseases, or hypervitaminosis, etc should be considered.

In ESRD patients, serum calcium concentration is typically decreased but more severe hypocalcemia on CAPD may develop with dialysis unrelated causes (Table 4). Predialysis hypocalcemia is likely to persist even when high dialysate calcium is utilized unless efforts are made to achieve a positive calcium balance by supplementation with oral calcium or vitamin D analogues or both on a daily basis. However, recent introduction of intravenous administration on regular basis improved much calcium homeostasis[18].

4. Hypermagnesemia and Hypomagnesemia

A well known hypermagnesemia in ESRD patients tends to be corrected with CAPD. However, the combination of nonfunctioning kidneys and the use of dialysate containing 1.5 mEq/L magnesium occasionally produces mild hypermagnesemia[18]. Clinical manifestations are generally not present unless plasma concentrations are

above 4 mEq/L. The severe hypermagnesemia have several other causes (Table 5). Chronic asymptomatic hypermagnesemia has been implicated in the development of soft-tissue calcification and in the development of renal osteodystrophy. Therefore, it appears desirable to avoid hypermagnesemia, even when it is asymptomatic. The use of a lower magnesium dialysate of 0.5 mEq/L has been recommended for CAPD. Moreover, magnesium-free dialysate can be employed successfully while using magnesium-containing antacids.

As compared to hypermagnesemia, hypomagnesemia is a rare complication because magnesium-free dialysate leads to magnesium depletion only in few patients. Therefore, the presence of persistent hypomagnesemia in CAPD patients should look for other factors such as gastrointestinal loss with malabsorption.

REFEREMCES

1) Tenckhoff H, Schechter H: *A bacteriologically safe peritoneal access device. Trans Am Soc Artif Intern Organs 14:181, 1968*
2) Vidit DG: *Editorial note: Recommendation of choice of peritoneal dialysis in a patient with renal failure. Artif Organs 2:421, 1978*
3) LaGreca A, et al.: *Acid-base homeostasis in clinical dialysis, in Mahler JF(ed): Replacement of renal function by dialysis, 3d ed, Boston, Kluwer Academic, 1989, p 808*
4) Teehan BP, et al.: *Acid-base studies in continuous ambulatory peritoneal dialysis, in Moncrief JW, Popovitch RO (eds): CAPD update: Continuopus Ambulatory Peritoneal Dialysis. New York, Masson, 1981, p 95*
5) Vaziri ND, et al.: *Bicarbonate-buffered peritoneal dialysis: An effective adjunct in the treatment of lactic acidosis. Am J Med 67:392, 1979*
6) Lee HA, et al.: *Lacticacidemia in peritoneal dialysis. Proc Eur Dial Transplant Assoc 4:150, 1967*
7) Veech RL, et al.: *Cerebral dysfunction and respiratory alkalosis during peritoneal dialysis with D-lactate-containing dialysis fluids (Letter to editor). Am J Med 82:572, 1987*
8) Tzamaloukas AH: *Contraction alkalosis during treatment of hyperglycemia in CAPD patients. Perit Dial Bull 3:196, 1983*
9) Nolph KD, et al.: *Multicenter evaluation of a new peritoneal dialysis solution with a high lactate and low magnesium concentration. Perit Dial Bull 3:63, 1983*
10) Bargman JM, Oreopoulos DG: *Complications other than peritonitis or those related to the catheter and the fate of uremic organ dysfunction in patients receiving peritoneal dialysis, in Nolph KD (ed): peritoneal dialysis, 3d ed. Boston, Kluwer Academic, 1989, p 289*
11) Kenamond T, et al.: *Severe recurrent alkalemia in a patient undergoing continuous cyclic peritoneal dialysis. Am J Med 81:548, 1986*
12) Bischel MD, Barbour BH: *Peritoneal dialysis with sorbitol versus dextrose dialysate. Nephron 12:449, 1974*
13) Spital AS, Sterns RH: *Potassium supplementation via the dialysate in CAPD. Am J Kid Dis 6:173, 1985*
14) Tzamaloukas AH, Avasthi PS: *Temporal profile of serum potassium concentration in nondiabetic and diabetic outpatients on chronic dialysis. Am J Nephrol 7:101, 1987*
15) Vaamonde CA, et al.: *Complication of acute peritoneal dialysis. J Chron Dis 28:637, 1975*
16) Swales JD: *Sodium uptake in peritoneal dialysis. Br Med J 3:345, 1967*
17) Tzamaloukas AH, Avasthi PS: *Effect of hyperglycemia on serum sodium concentration in outpatients on chronic dialysis. Am J Kidney Dis 7:477, 1986*
18) Parker A, Nolph KD: *Magnesium and calcium net mass transfers during CAPD. Trans Am Soc Artif Intern Organs 26:194, 1980*