International Urology and Nephrology (2019) 51:535–542
https://doi.org/10.1007/s11255-019-02076-7

NEPHROLOGY - ORIGINAL PAPER

Peritoneal dialysis can alleviate the clinical course of hungry bone syndrome after parathyroidectomy in dialysis patients with secondary hyperparathyroidism

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Received: 21 September 2018 / Accepted: 3 January 2019 / Published online: 28 January 2019

Abstract

Purpose It is unclear whether clinical courses of hungry bone syndrome (HBS) after parathyroidectomy (PTX) in peritoneal dialysis (PD) and hemodialysis (HD) patients are different. The present study aimed to investigate the possible differences of postoperative hypocalcemia and hyperkalemia between PD and HD patients.

Methods We performed retrospectively 29 PD patients as the PD group and 169 HD patients as the HD group undergoing successful total PTX with autotransplantation. Calcium supplement after surgery was recorded. Higher levels of serum potassium during and immediately after surgery were recorded as K^+_{d0}. K^+_{d3} was recorded as peak pre-dialysis serum potassium level 3 days post-surgery.

Results There were 157 (92.90%) patients in HD group and 22 (75.86%) patients in PD group suffered from HBS after surgery, with significant difference between the groups ($P=0.004$). Patients in PD group had significantly shorter intravenous calcium supplement duration ($P=0.037$) and significantly smaller intravenous calcium supplement dosage ($P=0.042$) and total calcium supplement dosage during hospitalization ($P=0.012$) than patients in HD group. The levels of serum K^+_{d0} ($P<0.001$) and K^+_{d3} ($P<0.001$) were both significantly lower in PD group than those in HD group. Peritoneal dialysis was one of the independent influencing factors with negative correlation for calcium supplement, serum K^+_{d0} and serum K^+_{d3}.

Conclusions Compared with HD patients, the clinical course of HBS after PTX in PD patients was alleviated. Efforts should be devoted to individual perioperative management for PD patients undergoing PTX.

Keywords Peritoneal dialysis · Hemodialysis · Hyperkalemia · Hypocalcemia · Secondary hyperparathyroidism · Parathyroidectomy

Introduction

Secondary hyperparathyroidism (SHPT) is one of the common complications in dialysis patients associated with chronic kidney disease–mineral and bone disorder (CKD–MBD). Parathyroidectomy (PTX) remains a valid treatment option for patients with refractory SHPT, especially when medical or pharmacological therapies fail [1]. Prolonged hypocalcemia, hypophosphatemia and concomitant hyperkalemia after parathyroidectomy is defined as hungry bone syndrome (HBS) [2]. The incidence of hypocalcemia of HBS in patients with SHPT undergoing PTX was reported to be 27.4–86.6% [3–7]. If not treated properly and promptly, postoperative hypocalcemia will lead to skeletal muscle cramp, respiratory muscle weakness, arrhythmia, and other serious consequences. Meanwhile, hyperkalemia during and after PTX, with an incidence of 25–80%, were also reported and may lead to devastating consequences [8–12]. It is the powerful preventive tool for severe perioperative complications to detect early enough and promptly treat hypocalcemia and hyperkalemia. However, the enrolled case series in these studies widely varied in different renal replacement modalities including hemodialysis (HD),

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peritoneal dialysis (PD), and kidney transplantation. It has not yet been clearly defined whether clinical courses of HBS in HD and PD patients are different or not. Thus, the present study aimed to investigate the possible differences of hypocalcemia and hyperkalemia between HD and PD patients after PTX.

Materials and methods

Patient population

This retrospective cohort study was performed on consecutive HD and PD patients undergoing successful total PTX with autotransplantation (tPTX + AT) because of refractory SHPT between March 2014 and March 2018. The inclusion criteria were as follows: age > 18 years, maintenance HD or PD for a minimum of 3 months, refractory SHPT, and underwent tPTX + AT. The exclusive criteria were as follows: (1) administration of cinacalcet hydrochloride during surgery or within 6 months before surgery and (2) unsuccessful tPTX + AT. The finally enrolled patients were divided into two groups, HD group and PD group, according to the dialysis modalities.

The relative definitions were as follows: Refractory SHPT means patients who are drug resistant and met surgical indications for PTX. The drug resistance means ineffectiveness of phosphate binder, calcimimetics and vitamin D analogs in the recommended dose for SHPT [1]. Successful tPTX + AT was defined as the number of resected parathyroid glands ≥ 3 and an iPTH value of < 60 pg/mL 24 h after surgery [13, 14]. If a severe drop in corrected total serum calcium concentration to less than 2.0 mmol/L (8.0 mg/dL) occurs, it is defined as HBS [15]. Hyperkalemia was defined as serum potassium levels ≥ 5.0 mmol/L [16, 17]. The preoperative baseline level of serum potassium (K^+_{base}) was defined as the preoperative pre-hemodialysis serum potassium level for HD and daytime ambulatory peritoneal dialysis (DAPD) patients or morning serum potassium levels for continuous ambulatory peritoneal dialysis (CAPD) patients (averaged three-times measurements would be available). The serum values of corrected calcium (cCa) were calculated using the following formula: serum cCa value (mmol/L) = serum total calcium value (mmol/L) + [40 − serum albumin (g/L)] × 0.025.

Surgery

According to the Kidney Disease: Improving Global Outcomes (KDIGO) guidelines [18] and our previous literatures [19, 20], the surgical indications of tPTX + AT included the following: (1) iPTH > 800 pg/mL, and with hypercalcemia or hyperphosphatemia; (2) clinical manifestations: severe bone ache, itching of skin, and external calcification and deformity of bone; (3) drug resistance; and (4) imageology examination, including neck ultrasonography and parathyroid scintigraphy with technetium-99m methoxyisobutylisonitrile, discovering at least one enlarged parathyroid gland. The surgery was considered if any one of the aforementioned first to third criteria and the fourth criterion were met. The surgery of tPTX + AT was performed in all enrolled patients. The surgical procedures were the same as reported in our previous literature [21].

Perioperative monitoring and treatment

All enrolled HD patients were treated with heparin-free hemodialysis 12–18 h before surgery, while PD patients were treated with PD similar to their previous scheme. The levels of serum potassium were monitored immediately before, during, and immediately after surgery. If the serum potassium levels immediately before surgery were ≥ 5.0 mmol/L, the planned surgery was canceled. The serum calcium and potassium levels were monitored every 4 h after surgery until 72 h postoperatively, and then, every 24 h until complete withdrawal of intravenous calcium supplement and no variation of oral calcium dose.

To control intraoperative hyperkalemia, patients with serum potassium level from 5.0 to 6.5 mmol/L required intravenous insulin/dextrose, while that > 6.5 mmol/L required emergency HD for HD patient or PD same to preoperative scheme for PD patients. On the other hand, patients with immediate postoperative hyperkalemia of serum potassium levels > 5.0 mmol/L required emergency HD for HD patients or PD similar to preoperative scheme for PD patients. In addition, all enrolled HD patients received 3-h heparin-free hemodialysis on days 1 and 3 post-surgery and all enrolled PD patients received PD same to preoperative scheme to avoid or treat hyperkalemia. The dialysate calcium concentration in PD and HD was exactly the same 1.5 mmol/L.

The calcium supplement program aimed to sustain the serum calcium levels at the normal range of 2.10–2.50 (range 8.4–10.0) mg/dL [22]. In the case of patients with postoperative serum calcium levels never < 2.0 mmol/L, when the values of postoperative serum calcium reduction were > 0.25 mmol/L and the levels of postoperative serum calcium were < 2.50 mmol/L, the oral calcium carbonate was administered at an initial daily dose of 18.0 g, divided into three times and in-between meals. In subsequent

postoperative serum calcium monitoring, a daily dose of oral calcium carbonate was adjusted to regulate the postoperative serum calcium levels in the normal range 2.10–2.50 mmol/L. Intravenous calcium supplement was not administrated in these patients. For patients with postoperative serum calcium levels < 2.0 mmol/L, oral calcium and intravenous calcium might be supplemented simultaneously. The program of oral calcium supplement was similar

to those patients, whose postoperative serum calcium levels never fell below 2.0 mmol/L; especially, during the administration of intravenous calcium supplement, the dose of oral calcium carbonate was not decreased. Intravenous 20 mL/h of 5% calcium gluconate solution was initiated when the value of postoperative serum calcium was < 2.0 mmol/L. In subsequent monitoring, the transfusion speed of 5% calcium gluconate solution was adjusted such as to regulate the postoperative serum calcium level in the range of 2.10–2.50 mmol/L, until complete withdrawal of intravenous calcium supplement.

Data collection

Baseline data, including age, gender, body weight, dialysis age, preoperative PD scheme for PD patients, preoperative laboratory parameters including K^{+}_{base} and preoperative serum levels of corrected calcium, phosphorus, albumin (Alb), hemoglobin (Hb), intact parathyroid hormone (iPTH), and alkaline phosphatase (ALP), surgical duration, weight of resected parathyroid glands, duration of hospitalization after surgery and medications within 6 months before surgery were recorded. The higher levels of serum potassium during and immediately after surgery were recorded as K^{+}_{d0}. While K^{+}_{d3} was recorded as peak pre-dialysis serum potassium levels 3 days after surgery. The serum levels of cCa 24 h and 72 h after surgery were in turn recorded as serum Ca^{2+}_{d1} and Ca^{2+}_{d3}. Similarly, the serum magnesium concentration 24 h and 72 h after surgery were in turn recorded as serum Mg^{2+}_{d1} and Mg^{2+}_{d3}. Arterial blood gas analysis (ABG) was tested immediately before (ABG_{base}) and after (ABG_{d0}) surgery, and, for part of patients, was also tested 1 day (ABG_{d1}) and 3 days (ABG_{d3}) after surgery. ABG_{d1} and ABG_{d3} were tested immediately before hemodialysis for HD patients or were tested immediately before the first time of peritoneal dialysis solution infusion that day for PD patients. The postoperative serum iPTH levels were tested at 24 h after surgery. The calcium supplement after surgery was recorded as calcium supplement procedures (intravenous combined with oral, only oral), intravenous calcium supplement holding time, intravenous calcium supplement dosage, and total calcium supplement dosage during hospitalization (equal to intravenous plus oral calcium supplement dosage during hospitalization). The collected data was compared between the HD group and the PD group.

Statistical methods

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 22.0 (SPSS Inc., Chicago, IL, USA). Continuous variables were presented as mean ± SD or median (interquartile range), and categorical variables were presented as number and proportion. The differences between groups were compared using an independent samples *t* test or Wilcoxon rank sum test for continuous variables and a chi-squared or Fisher's exact test for categorical variables. Spearman's correlation analysis was used to examine the associations between the values of calcium supplement or serum potassium after surgery and perioperative baseline variables. The covariates in the Spearman's correlation analysis that reached $P < 0.1$ were further input into a multivariate linear stepwise regression analysis model for identifying the independent influencing factors for the values of calcium supplement or serum potassium after surgery. A P value < 0.05 was considered as statistically significant.

Results

Baseline characteristics

A total of 211 patients came from different local hemodialysis centers in east and south China, including 181 HD patients and 30 PD patients, met the inclusion criteria. All of the patients among the 211 patients, 7 HD patients and 1 PD patients were excluded from analysis for unsuccessful tPTX + AT and 5 HD patients for administration of cinacalcet hydrochloride during surgery or within 6 months before surgery. This study was finally performed on 198 patients, among whom 169 (85.35%) patients was in the HD group and 29 (14.65%) patients in the PD group. In the PD group, 18 patients with CAPD were treated using the dialysate 6–8 L/day, and peritoneal dialysate left abdomen cavity at daytime and night, while 11 patients with DAPD were treated by using the dialysate 6–8 L/day at daytime and evacuated of dialysate from abdomen at night. The medications and baseline characteristics before surgery, operative duration, duration of hospitalization after surgery and weight of resected parathyroid glands during surgery in both groups were recorded and compared (Table 1). Levels of serum K^{+}_{base} and albumin were found to be significantly lower in the PD group. Duration of hospitalization after surgery was significantly different and HD patients were hospitalized longer. Serum Ca^{2+}_{d1} and Ca^{2+}_{d3} in PD group were significantly higher than those in HD group.

Occurrence of hungry bone syndrome and calcium supplement

There were 157 (92.90%) patients in the HD group and 22 (75.86%) patients in the PD group suffered from HBS after surgery, with significant difference between the groups ($P = 0.004$). The HBS patients in both groups were supplemented calcium by intravenous injection and oral administration, while the non-HBS patients in both

Table 1 Comparison of perioperative data between hemodialysis and peritoneal dialysis patients

	PD group [$N=29$ (14.65%)]	HD group [$N=169$ (85.35%)]	P value
Pre-operative data			
Age (year)	44.80 ± 12.71	46.06 ± 10.94	0.633
Female: male	15:14	78:91	0.579
Dialysis age (month) (IQR)	66.00 (54.00, 96.00)	72.00 (60.00, 96.00)	0.122
Body weight (Kg) (IQR)	61.00 (50.25, 71.25)	60.00 (53.00, 70.00)	0.950
Hemoglobin (g/L)	94.70 ± 13.88	102.45 ± 17.78	0.062
Serum K^+_{base} (mmol/L)	3.76 ± 0.74	4.76 ± 0.65	**< 0.001**
Corrected serum calcium (mmol/L)	2.51 ± 0.19	2.53 ± 0.17	0.873
Serum phosphorus (mmol/L) (IQR)	2.17 (1.90, 2.66)	2.13 (1.93, 2.62)	0.907
Serum magnesium (mmol/L)	0.93 ± 0.12	0.97 ± 0.19	0.877
Serum albumin (g/L)	32.59 ± 3.95	38.51 ± 4.23	**< 0.001**
Serum ALP (IU/L) (IQR)	318.05 (180.00, 599.58)	322.75 (180.60, 616.93)	0.724
Serum iPTH (pg/ml) (IQR)	1578.37 (1175.75, 2308.43)	1622.95 (1201.68, 2159.58)	0.897
Medications before surgery			
Phosphate binders			
Calcium containing phosphate binders (%)	15 (51.72)	103 (60.95)	0.350
Non-calcium containing phosphate binders (%)	11 (37.93)	59 (34.91)	0.753
Vitamin D			
Alfacalcidol (%)	2 (6.90)	16 (9.47)	0.656
Calcitriol (%)	14 (48.28)	62 (36.69)	0.236
Intra-operative data			
Operative duration (minute) (IQR)	75.00 (58.00, 85.00)	72.00 (60.00, 84.00)	0.687
Weight of resected parathyroid glands (g) (IQR)	3.26 (2.23, 4.96)	3.68 (2.45, 5.10)	0.392
Post-operative data			
Serum Ca^{2+}_{d1} (mmol/L) (IQR)	2.28 (2.03, 2.45)	1.92 (1.81, 2.07)	**< 0.001**
Serum Ca^{2+}_{d1} < 1.8 mmol/L (%)	2 (6.90)	19 (11.24)	0.483
Serum Ca^{2+}_{d1} ranged from 1.8 to 2.1 mmol/L (%)	8 (27.58)	135 (79.88)	**< 0.001**
Serum Ca^{2+}_{d1} > 2.1 mmol/L (%)	19 (65.52)	15 (8.88)	**< 0.001**
Serum Mg^{2+}_{d1} (mmol/L)	0.97 ± 0.21	0.93 ± 0.18	0.892
Serum Ca^{2+}_{d3} (mmol/L) (IQR)	2.37 (2.19, 2.54)	2.19 (2.11, 2.31)	**0.029**
Serum Ca^{2+}_{d3} < 1.8 mmol/L (%)	0 (0.00)	0 (0.00)	/
Serum Ca^{2+}_{d3} ranged from 1.8 to 2.1 mmol/L (%)	0 (0.00)	21 (12.43)	**0.045**
Serum Ca^{2+}_{d3} > 2.1 mmol/L (%)	29 (100.00)	148 (87.57)	**0.045**
Serum Mg^{2+}_{d3} (mmol/L)	0.91 ± 0.17	0.89 ± 0.20	0.835
Serum iPTH 24 h after surgery (pg/ml) (IQR)	21.40 (4.05, 44.76)	19.83 (3.87, 45.30)	0.872
Duration of hospitalization after surgery (hour) (IQR)	94.00 (79.00, 126.00)	122.00 (94.00, 160.00)	**0.032**

Significant differences are in bold ($P < 0.05$)

IQR Interquartile range, *HD* hemodialysis, *PD* peritoneal dialysis, K^+_{base} pre-operative baseline level of serum potassium, *ALP* alkaline phosphatase, *iPTH* intact parathyroid hormone, Ca^{2+}_{d1} serum level of corrected calcium 24 h after surgery, Ca^{2+}_{d3} serum level of corrected calcium 72 h after surgery, Mg^{2+}_{d1} serum magnesium level 24 h after surgery, Mg^{2+}_{d3} serum magnesium level 72 h after surgery

groups were treated with calcium supplement by only oral administration. For all enrolled patients, levels of corrected serum calcium were raised to the normal range (2.10–2.50 mmol/L) within 48 h after surgery. However, patients in the PD group had significantly shorter intravenous calcium supplement duration and significantly smaller intravenous calcium supplement dosage and total calcium supplement dosage during hospitalization than patients in the HD group (Table 2). Furthermore, multivariate regression analysis found that dialysis modality as peritoneal dialysis was one of the independent influencing factors with negative correlation for intravenous calcium supplement duration, intravenous calcium supplement dosage and total calcium supplement dosage during hospitalization (Table 3).

Table 2 Comparison of post-operative calcium supplement and serum potassium between hemodialysis and peritoneal dialysis patients

	PD group ($N=29$)	HD group ($N=169$)	P value
Intravenous calcium supplement duration (h) (IQR)	54.00 (36.00, 84.00) ($N=22$)	72.00 (44.00, 110.00) ($N=157$)	0.037
Intravenous calcium supplement dosage (mmol) (IQR)	73.75 (47.63, 105.76) ($N=22$)	120.93 (60.47, 212.00) ($N=157$)	0.042
Total calcium supplement dosage during hospitalization (mmol) (IQR)	503.43 (270.00, 882.07)	810.70 (450.70, 1598.66)	0.012
Number of patients with hyperkalemia during and immediately after surgery (%)	2 (6.90)	107 (63.31)	< 0.001
Serum K^+_{d0} (mmol/L) (IQR)	3.91 (3.69, 4.51)	5.16 (4.48, 5.59)	< 0.001
Number of patients with hyperkalemia 3 days after surgery (%)	0 (0.00)	55 (32.54)	< 0.001
Serum K^+_{d3} (mmol/L)	4.11 ± 0.45	4.74 ± 0.53	< 0.001

IQR Interquartile range, *HD* hemodialysis, *PD* peritoneal dialysis, K^+_{d0} the higher levels between serum potassium during and immediately after surgery, K^+_{d3} peak pre-dialysis serum potassium level 3 days post-surgery

Table 3 Multivariate linear stepwise regression analysis for influencing factors of calcium supplement and serum potassium after surgery

Parameters	Variables	Unstandardized β coefficients (95% CI)	Standardized β coefficients	P value
Intravenous calcium supplement duration (hour) ($R=0.675$, $R^2=0.456$, $P=0.013$)	Preoperative serum ALP (U/L)	0.020 (0.004 to 0.037)	0.209	0.013
	Preoperative serum iPTH (pg/ml)	0.029 (0.019 to 0.039)	0.482	< 0.001
	Peritoneal dialysis	− 24.014 (− 41.166 to − 6.862)	− 0.151	0.006
	Constant	11.926 (− 1.777 to 25.630)	–	0.088
Intravenous calcium supplement dosage (mmol) ($R=0.774$, $R^2=0.599$, $P=0.010$)	Preoperative serum ALP (U/L)	0.029 (0.016 to 0.042)	0.315	< 0.001
	Preoperative serum iPTH (pg/ml)	0.026 (0.018 to 0.034)	0.449	< 0.001
	Hemoglobin (g/L)	− 0.335 (− 0.589 to − 0.081)	− 0.127	0.010
	Peritoneal dialysis	− 22.647 (− 36.773 to − 8.520)	− 0.151	0.002
	Constant	33.081 (3.566 to 62.595)	–	0.028
Total calcium supplement dosage during hospitalization (mmol) ($R=0.774$, $R^2=0.599$, $P=0.010$)	Preoperative serum ALP (U/L)	0.068 (0.037 to 0.099)	0.315	< 0.001
	Preoperative serum iPTH (pg/ml)	0.060 (0.041 to 0.079)	0.449	< 0.001
	Hemoglobin (g/L)	− 0.779 (− 1.370 to − 0.188)	− 0.127	0.010
	Peritoneal dialysis	− 52.641 (− 85.495 to − 19.786)	− 0.151	0.002
	Constant	76.869 (8.226 to 145.512)	–	0.028
Serum K^+_{d0} (mmol/L)	Serum K^+_{base} (mmol/L)	0.854 (0.726 to 0.981)	0.636	< 0.001
	Peritoneal dialysis	− 1.016 (− 1.463 to − 0.569)	− 0.346	0.023
($R=0.736$, $R^2=0.541$, $P<0.001$)	Constant	1.056 (0.455 to 1.657)	–	0.001
Serum K^+_{d3} (mmol/L)	Serum K^+_{base} (mmol/L)	0.318 (0.205 to 0.431)	0.413	< 0.001
	Preoperative serum iPTH (pg/ml)	0.00037 (0.00013 to 0.00056)	0.286	< 0.001
	Peritoneal dialysis	− 0.311 (− 0.59 7 to − 0.025)	− 0.159	0.033
	Constant	2.873 (2.293 to 3.453)	–	< 0.001

K^+_{d0} The higher levels between serum potassium during and immediately after surgery, K^+_{d3} peak pre-dialysis serum potassium level 3 days post-surgery

Post-operative serum potassium

The number of patients with hyperkalemia during and immediately after surgery and the number of patients with hyperkalemia 3 days after surgery were both significantly smaller in the PD group than those in the HD group. Similarly, the levels of serum K^+_{d0} and K^+_{d3} were both significantly lower in the PD group than those in the HD group (Table 2). Furthermore, multivariate regression analysis found that dialysis modality as peritoneal dialysis was one of the independent influencing factors with negative correlation for the levels of serum K^+_{d0} and K^+_{d3} (Table 3).

Perioperative arterial blood gas analysis

There was no significant difference in ABG_{base}, ABG_{d0}, ABG_{d1} and ABG_{d3} between the PD and HD groups (Table 4).

Table 4 Comparison of arterial blood gas analysis between hemodialysis and peritoneal dialysis patients

	PD group ($N=29$)	HD group ($N=169$)	P value
ABG_{base}			
PH (IQR)	7.41 (7.36, 7.47)	7.40 (7.36, 7.45)	0.895
PO_2 (mmHg) (IQR)	107 (93, 125)	112 (95, 137)	0.687
PCO_2 (mmHg) (IQR)	38.2 (36.7, 41.4)	38.8 (35.6, 40.1)	0.879
Bicarbonate (mmol/L) (IQR)	25.8 (24.2, 26.9)	25.1 (23.2, 27.8)	0.785
Base excess (IQR)	1 (−1, 3)	1 (−2, 3)	0.823
ABG_{d0}			
PH (IQR)	7.40 (7.36, 7.45)	7.39 (7.36, 7.42)	0.911
PO_2 (mmHg) (IQR)	283 (273, 298)	280 (263, 295)	0.762
PCO_2 (mmHg) (IQR)	37.3 (35.5, 40.2)	38.5 (35.2, 40.5)	0.802
Bicarbonate (mmol/L) (IQR)	24.3 (23.4, 25.7)	23.2 (22.1, 25.8)	0.462
Base excess (IQR)	−1 (−2, 2)	−2 (−3, 1)	0.582
ABG_{d1}			
PH (IQR)	7.41 (7.37, 7.46) ($N=17$)	7.36 (7.33, 7.40) ($N=122$)	0.152
PO_2 (mmHg) (IQR)	109 (95, 119) ($N=17$)	104 (92, 113) ($N=122$)	0.898
PCO_2 (mmHg) (IQR)	38.7 (36.4, 42.1) ($N=17$)	36.6 (33.4, 40.8) ($N=122$)	0.134
Bicarbonate (mmol/L) (IQR)	25.1 (24.4, 26.7) ($N=17$)	22.4 (22.1, 24.9) ($N=122$)	0.168
Base excess (IQR)	1 (−1, 3) ($N=17$)	−3 (−4, −1) ($N=122$)	0.098
ABG_{d3}			
PH (IQR)	7.39 (7.36, 7.43) ($N=15$)	7.35 (7.33, 7.38) ($N=108$)	0.183
PO_2 (mmHg) (IQR)	101 (91, 113) ($N=15$)	109 (95, 116) ($N=108$)	0.754
PCO_2 (mmHg) (IQR)	40.4 (38.2, 41.5) ($N=15$)	36.3 (34.4, 39.8) ($N=108$)	0.569
Bicarbonate (mmol/L) (IQR)	25.4 (23.3, 26.4) ($N=15$)	22.6 (21.7, 23.8) ($N=108$)	0.185
Base excess (IQR)	1 (−2, 2) ($N=15$)	−3 (−4, −2) ($N=108$)	0.079

IQR Interquartile range, *HD* hemodialysis, *PD* peritoneal dialysis, ABG_{base} arterial blood gas analysis immediately before surgery, ABG_{d0} arterial blood gas analysis immediately after surgery, ABG_{d1} arterial blood gas analysis one day after surgery, ABG_{d3} arterial blood gas analysis three days after surgery, *PH* pondus hydrogenii value, PO_2 oxygen partial pressure, PCO_2 partial pressure of carbon dioxide

Discussion

In the current study, a greater decrease in serum calcium after parathyroidectomy was observed in the HD group. Compared with the HD group, post-operative calcium supplement was diminished and in consequence the duration of hospitalization after surgery was shortened in the PD group, which meant alleviated clinical course of hypocalcemia in PD patients. Some rational explanations were made for the influencing factors of hypocalcemia after PTX in the previous study. Withdrawal of prolonged elevation in the serum PTH level turns off the osteoclast activity and bone resorption. However, the osteoblast activity and new bone formation continues. This leads to the influx of calcium into bone, resulting in hypocalcemia after PTX [9, 23]. Therefore, to some extent, hypocalcemia in HBS reflects the severity of bone turnover in renal osteodystrophy (ROD). The other study showed a positive correlation of PTH level with high bone turnover in ROD [24]. Meanwhile, the levels of bone-specific ALP secreted by osteoblasts can reflect the activity of osteoblasts. In SHPT, osteoblasts activated by elevated iPTH further activate osteoclasts, leading to bone resorption [25]. Hence, osteoblasts and osteoclasts are upregulated in coupling [26], resulting in renal osteodystrophy with high turnover and bone calcium loss. Serum ALP levels can reflect bone-specific ALP levels in patients with normal liver function [27]. Therefore, serum levels of iPTH and ALP are associated with the severity of postoperative calcium supplements [28, 29]. In the present study, there was no remarkable difference of serum iPTH and ALP levels between two groups. However, our study showed that, to sustain serum cCa levels in the normal range, patients undergoing PTX in the PD group had shorter intravenous calcium supplement duration, smaller intravenous calcium supplement dosage and lower total calcium supplement dosage during hospitalization. Because a correction on albumin distraction has been made by cCa formula, different levels of serum albumin will not influence serum cCa levels in the PD and HD groups. Thus, in comparison with the HD group, we have reasons to ascribe the alleviated clinical course of hypocalcemia in the PD group to a stronger calcium replenishment because of longer average daily dialysis time. To our knowledge, there is no literature about the difference of hypocalcemia after PTX in PD and HD patients.

The present study also reported that patients in the PD group had lower serum K^+_{base} before surgery. We probed further and found that the number of patients with hyperkalemia during and immediately after surgery in the PD group was significantly less than that in the HD group, and serum levels of K^+_{d0} in PD patients were also significantly lower than HD patients. With the incidence of hyperkalemia 3 days after surgery and levels of K^+_{d3} in the PD group, the situation was similar. A small sample research including 27 HD patients and 5 PD patients found that 8 HD patients but no PD patients suffered from serum potassium level > 5.3 mmol/L during or immediately after PTX [11]. This trend is similar to our current study. Some previous studies have reported that when dialysis patients undergoing PTX have a high normal or elevated level of baseline serum potassium, intraoperative hyperkalemia is rather a common phenomenon [8, 10]. Another recent study reported that the preoperative serum potassium level could preferably predict postoperative hyperkalemia immediately after PTX in hemodialysis patients [12]. It has been widely reported that high incidence of hypokalemia is common in PD patients due to inadequate potassium intake and zero potassium concentration of peritoneal dialysate [30–32]. This is an explanation why occurrence of hyperkalemia during and immediately after PTX is low in PD patients. Lower incidence rate of hyperkalemia 3 days after surgery in PD patients was probably attributed to the similar reason and longer average daily dialysis time with potassium-free dialysate. In addition, heparin-free hemodialysis procedure was only 3 h and was really shorter than usual as four hours. This could have a significant impact on the observed higher potassium levels after parathyroidectomy in HD patients. However, the literature to explain the exact reason is still missing.

The present study has several limitations. The number of enrolled patients within a single center was small, thereby constraining the conclusions. Due to the retrospective nature of the analysis, stringent perioperative diet for calcium and potassium intake was not standardized, which might result in different defects in the study. In addition, monitoring of ion concentration in the extracellular fluid, endocrine measures, and creatine kinase might provide in-depth insights into the underlying mechanisms.

In conclusion, compared with HD patients, we report for the first time a significantly alleviated clinical course of hungry bone syndrome after PTX in PD Patients with SHPT. To sustain serum cCa levels in the normal range, PD patients undergoing PTX had lower calcium supplement dosage and shorter duration of hospitalization after surgery than HD patients, without remarkable difference of serum iPTH and ALP levels between two groups. Occurrence of hyperkalemia during and after PTX is also lower in PD patients. Thus, anesthetists, endocrine surgeons, and nephrologists should be alert to this phenomenon and devoted to reasonable individual perioperative management for PD patients undergoing PTX. More research is needed into the mechanism of alleviated clinical course of hungry bone syndrome in PD Patients.

Acknowledgements This work was supported by the Clinical Medical Technology Special Incentive Fund of Jiangsu Province (BL2014080).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study was approved by the First Affiliated Hospital of Nanjing Medical University Ethics Committee. All procedures performed in the study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

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