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The Impact of HFHD on Calcium-Phosphorus Metabolism and Nutritional Indicators in Patients with Chronic Kidney Disease

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Abstract: *Objective*: To analyze the effects of high-flux hemodialysis (HFHD) on calcium and phosphorus metabolism and nutritional indicators in patients with chronic kidney disease (CKD). *Methods*: A total of 86 CKD patients diagnosed in our hospital's Nephrology Department between January 2024 and December 2025 and undergoing HFHD were enrolled. Using a random number table, all patients were divided into a control group (n = 43, receiving conventional hemodialysis) and a study group (n = 43, receiving HFHD). SPSS 26.0 statistical software was used to compare calcium-phosphorus metabolism and nutritional indicators between the two groups. *Results*: After 6 months of treatment, the PTH level in the study group was significantly lower than that in the control group, while serum calcium and phosphorus levels were significantly higher ($p < 0.05$). The Alb and Hb levels in the study group were higher than those in the control group, but the difference was not statistically significant ($p > 0.05$). *Conclusion*: HFHD maintains calcium-phosphorus metabolism balance in CKD patients while significantly improving nutritional indicators.

Keywords: HFHD; Chronic kidney disease; Calcium-phosphorus metabolism; Nutritional indicators

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1. Introduction

Chronic Kidney Disease (CKD) represents a significant global public health challenge, with its incidence showing a consistent upward trend year after year [1]. Epidemiological data indicates that the prevalence of CKD among adults in China has reached 10.8%, with the number of patients suffering from End-Stage Renal Disease (ESRD) increasing by over 8% annually [2]. ESRD patients experience complete failure of renal filtration, excretion, and endocrine regulation functions. Calcium-phosphorus metabolism disorders and malnutrition are the most common complications, forming core bottlenecks that impact long-term survival rates and diminish quality of life

[3]. Therefore, effectively correcting calcium-phosphorus metabolic imbalance and improving nutritional status represent critical challenges requiring breakthroughs in both clinical treatment and basic research for ESRD. High-Flux Hemodialysis (HFHD), as an innovative dialysis modality, leverages its high-flux, biocompatible membrane properties to effectively broaden toxin clearance. It not only efficiently removes small-molecule toxins but also significantly enhances clearance of medium-to-large-molecule toxins and protein-bound phosphorus, offering a novel therapeutic pathway for correcting calcium-phosphorus metabolism disorders in ESRD patients [4,5]. Based on this, this study selected CKD patients as subjects to analyze the effects of HFHD on calcium-phosphorus metabolism and nutritional indicators in CKD patients.

2. Subjects and methods

2.1. Study population

A total of 86 CKD patients diagnosed in the Nephrology Department of our hospital between January 2024 and December 2025 and undergoing HFHD were enrolled. Using a random number table, all patients were divided into a control group and a study group, each comprising 43 subjects. No significant differences were observed between the two groups in terms of general characteristics ($p > 0.05$). Detailed data are presented in **Table 1**.

Table 1. Comparison of general characteristics between the two groups of patients

Group	Number of cases	Male/Female	Mean age (years)	Mean course of disease (years)
Control group	43	23/20	54.12 ± 4.30	2.78 ± 0.34
Study group	43	26/17	53.97 ± 4.51	2.75 ± 0.37
χ^2/t value		0.427	0.158	0.391
p value		0.514	0.875	0.696

2.2. Diagnostic criteria

(1) Meets the diagnostic criteria for CKD outlined in the Guidelines for Early Screening, Diagnosis, and Prevention of Chronic Kidney Disease (2022 Edition) [6];

(2) Confirmed diagnosis of CKD based on clinical symptoms, renal function tests, and imaging findings.

2.3. Inclusion and exclusion criteria

2.3.1. Inclusion criteria

(1) Meeting the aforementioned diagnostic criteria;

(2) Good treatment compliance;

(3) Complete and traceable clinical records;

(4) Absence of other conditions potentially affecting bone metabolism.

2.3.2. Exclusion criteria

(1) Patients with concomitant acute kidney injury;

(2) Abnormal liver function within the past month;

(3) Severe cardiovascular or cerebrovascular disease;

(4) Psychiatric disorders.

2.4. Research methods

The control group received conventional hemodialysis treatment, with the following operational protocols: Dialysis equipment comprised Nipro Corporation's hemodialysis machine, model 150 G, set with an ultrafiltration coefficient of 9.8 mL/(h·mmHg) and a controlled dialyzer surface area of 1.5 m^2. Dialysis fluid removal volume was flexibly adjusted based on the patient's pre-dialysis weight, oedema severity, and urine output, with a range controlled between 3000–6000 mL. Blood flow rate was regulated at 250–300 mL/min. Dialysate employed was bicarbonate-based dialysate produced by Shijiazhuang Siyuan Pharmaceutical Co., Ltd., with a fixed dialysate flow rate of 500 mL/min. Dialysate concentration and temperature were closely monitored throughout the dialysis process to ensure compliance with clinical treatment standards. Dialysis sessions were scheduled for 4 hours each, with three treatments per week.

The study group received HFHD therapy, employing identical baseline symptomatic treatment and fundamental dialysis parameters to the control group. The core distinction lay in the selection of dialysis equipment and ultrafiltration coefficient settings, with specific operational protocols as follows: Dialysis equipment comprised the FX60 high-flux hemodialysis machine manufactured by Fresenius Medical Care AG & Co. KG, Germany. The dialyzer model matched the control group's specifications, with an equivalent surface area of 1.5 m^2. Dialysis fluid removal volume, blood flow rate, dialysate type, and flow rate were uniformly maintained consistent with the control group. Unlike the control group, the ultrafiltration coefficient for the experimental group was no longer fixed. Instead, it was individually tailored for each dialysis session based on the patient's actual pre-treatment weight, oedema severity, estimated fluid removal target, and individual tolerance. Dialysis treatment duration and frequency were identical to the control group: 4 hours per session, 3 times weekly.

2.5. Observation indicators

(1) Calcium and phosphorus metabolism indicators

Assessed prior to treatment and at 6 months post-treatment. Serum phosphorus levels were measured using the molybdate method, with all samples uniformly centrifuged prior to testing. Phosphorus concentration was determined via colorimetric analysis. Serum calcium levels were measured using the ion-selective electrode method, separately quantifying free and bound calcium concentrations. Electrodes were calibrated prior to testing, with strict control of ambient temperature and humidity throughout the procedure. Parathyroid hormone (PTH) levels were determined via enzyme-linked immunosorbent assay (ELISA).

(2) Nutritional indicators

Assessed prior to treatment and at 6 months post-treatment. On an empty stomach in the morning, healthcare personnel drew 3 mL of peripheral venous blood from patients. The collected venous blood was immediately placed into sterile centrifuge tubes, which were then loaded into a medical centrifuge. The centrifuge was set to 3500 rpm for 10 minutes, with a centrifugal radius of 8 cm. Following centrifugation, the supernatant serum was aspirated into a fresh sterile centrifuge tube to remove sediment impurities. Serum albumin (Alb) and hemoglobin (Hb) levels were measured using a fully automated biochemical analyzer.

2.6. Statistical methods

Data were processed and analyzed using SPSS 26.0 statistical software. Chi-square tests were employed to assess the association between categorical variables across different groups. Paired *t*-tests were used to evaluate the significance of differences in quantitative variables between groups. Throughout the statistical analysis, $p < 0.05$ indicated statistically significant differences between groups.

3. Results

3.1. Comparison of calcium and phosphorus metabolism indicators between the two groups

Results indicated that after six months of treatment, the PTH level in the study group was significantly lower than that in the control group, while serum calcium and serum phosphorus levels were significantly higher than those in the control group ($p < 0.05$). See **Table 2** and **3**.

Table 2. Comparison of calcium and phosphorus metabolism indicators between the two groups of patients ($\overline{x} \pm s$)

Group	Number of cases	Serum calcium (mmol/L)		Serum phosphorus (mmol/L)	
		Pre-treatment	6 months post-treatment	Pre-treatment	6 months post-treatment
Control group	43	2.23 ± 0.45	2.94 ± 0.56	2.25 ± 0.34	1.82 ± 0.29
Study group	43	2.26 ± 0.51	3.83 ± 0.60*	2.27 ± 0.42	1.57 ± 0.36*
χ^2/t value		0.289	7.111	0.243	3.546
P value		0.773	0.000	0.809	0.001

Note: Compared with the control group after 6 months of treatment, $^*p < 0.05$.

Table 3. Comparison of PTH level between the two groups of patients ($\overline{x} \pm s$)

Group	Number of cases	PTH (pmol/L)	
		Pre-treatment	6 months post-treatment
Control group	43	417.30 ± 65.83	347.02 ± 58.45
Study group	43	415.44 ± 64.59	253.61 ± 54.48*
χ^2/t value		0.132	7.666
p value		0.895	0.000

Note: Compared with the control group after 6 months of treatment, $^*p < 0.05$.

3.2. Comparison of nutritional indicators between the two groups

Results indicated that after six months of treatment, the study group exhibited higher levels of albumin (Alb) and hemoglobin (Hb) than the control group. However, the difference between the two groups was not statistically significant ($p > 0.05$). See Table 4.

Table 4. Comparison of nutritional indicators between the two groups of patients ($\overline{x} \pm s$)

Group	Number of cases	Alb (g/L)		Hb (g/L)	
		Pre-treatment	6 months post-treatment	Pre-treatment	6 months post-treatment
Control group	43	39.12 ± 4.33	40.66 ± 4.21	105.60 ± 7.55	109.84 ± 9.32
Study group	43	38.76 ± 4.35	42.39 ± 4.78	106.58 ± 7.69	113.74 ± 9.08
χ^2/t value		0.385	1.781	0.596	1.965
p value		0.701	0.079	0.553	0.053

Note: Compared with the control group after 6 months of treatment, $^*p < 0.05$.

4. Discussion

This study employed the HFHD treatment protocol, focusing on its impact on patients' calcium and phosphorus metabolism indicators while analyzing its efficacy in improving nutritional parameters, as detailed below.

Calcium and phosphorus metabolism disorders represent one of the most critical complications in CKD patients. Their underlying mechanism involves impaired renal filtration and excretion functions, leading to impaired phosphorus excretion and insufficient activation of active vitamin D, subsequently triggering hypocalcemia and hyperphosphatemia. This activates compensatory parathyroid hormone (PTH) secretion. Persistent metabolic imbalance further exacerbates hyperparathyroidism, inducing severe complications that directly impact long-term patient survival rates [7,8]. Conventional hemodialysis, as a traditional dialysis modality, has core limitations due to its smaller membrane pore size and lower ultrafiltration coefficient. It can only effectively remove small, water-soluble toxins from the blood, with extremely low clearance efficiency for medium-to-large molecular toxins and protein-bound phosphorus. This results in most patients failing to achieve target calcium and phosphorus metabolic parameters over the long term, which is also the core reason for the poor improvement in calcium and phosphorus metabolic parameters in the control group patients after treatment [9].

As a novel dialysis modality clinically promoted in recent years, HFHD's core advantage lies in its use of high-flux, highly biocompatible membranes featuring larger pore sizes and higher ultrafiltration coefficients. This significantly broadens the range of toxins removed, constituting the key mechanism by which HFHD markedly improves calcium and phosphorus metabolism indicators in CKD patients [10]. In this study, the HFHD group exhibited significantly lower PTH levels and significantly higher serum calcium and phosphorus levels compared to the control group. These findings align with the conclusions of domestic researchers such as Luo Liuping et al., who compared the effects of HFHD versus conventional hemodialysis in 80 CKD dialysis patients. Their study revealed that post-treatment, the HFHD group demonstrated a 32.1% reduction in PTH levels and while serum calcium and phosphorus levels increased by 10.3% and 8.7%, respectively [11]. All differences were statistically significant ($p < 0.05$), confirming HFHD's more pronounced regulatory effect on calcium and phosphorus metabolism in CKD patients. Regarding the mechanism of action, the high-flux dialysis membrane in HFHD effectively removes medium-to-large molecular weight PTH from the blood, reducing its positive feedback stimulation on the parathyroid glands and inhibiting the progression of hyperparathyroidism. Simultaneously, it significantly enhances the clearance efficiency of protein-bound phosphorus, lowering serum phosphorus levels and alleviating the inhibitory effect of hyperphosphatemia on calcium absorption. This promotes the restoration of serum calcium levels, thereby progressively breaking the vicious cycle of calcium-phosphorus metabolic disorder [12,13]. Furthermore, the dialysis membranes used in HFHD exhibit superior biocompatibility, reducing complement activation and inflammatory cytokine release during dialysis. This minimizes the interference of inflammatory responses on calcium-phosphorus metabolic regulation mechanisms, further enhancing improvements in calcium-phosphorus metabolic indicators [14].

Compared with relevant domestic and international studies, the findings of this research are largely consistent with most conclusions, though certain differences exist. In a study by Armani et al., 105 CKD patients underwent HFHD treatment for 6 months, resulting in a significant decrease in PTH levels and a trend toward normalization of serum calcium and phosphorus levels [15]. with serum calcium and phosphorus levels tending toward normalization, consistent with our findings. However, their study also noted that improvements in calcium and phosphorus metabolism indicators were more pronounced after one year of HFHD treatment, suggesting a time-dependent regulatory effect of HFHD on calcium-phosphorus metabolism. This observation provides direction for

extending follow-up periods in future studies to observe changes in these indicators after one year of treatment. However, another study by Tang Xiaofang et al. reported that after 3 months of HFHD treatment for end-stage renal disease patients, although serum calcium and phosphorus levels improved, the differences compared to the conventional dialysis group were not statistically significant [16]. Only PTH levels showed a significant decrease, differing from the findings of this study. Possible reasons for this discrepancy may be related to sample size, duration of dialysis, baseline disease severity, and HFHD dialysis parameter settings. That study included only 60 patients with an average dialysis duration exceeding 3 years, where irreversible parathyroid damage had already occurred. In contrast, this study enrolled 86 patients, with all patients having a dialysis duration of less than 1 year, preserving some compensatory capacity of parathyroid function. Furthermore, the study group employed individualized ultrafiltration coefficient settings, better tailored to each patient's condition, resulting in more pronounced improvements in calcium and phosphorus metabolism indicators. This suggests that when applying HFHD therapy clinically, individualized dialysis parameters should be set based on the patient's dialysis duration and underlying disease severity to enhance treatment efficacy.

Regarding HFHD's impact on nutritional indicators in CKD patients, our findings show that after 6 months of treatment, although the study group exhibited higher albumin (Alb) and hemoglobin (Hb) levels than the control group, the differences were not statistically significant. This result differs from some domestic and international studies and requires in-depth analysis considering the pathophysiological mechanisms of malnutrition in CKD patients and the intervention characteristics of HFHD. The pathogenesis of malnutrition in CKD patients is complex, primarily involving factors such as nutrient loss during dialysis, inflammatory responses, decreased appetite, and inadequate protein intake. Theoretically, HFHD's highly biocompatible dialysis membrane may reduce the release of inflammatory cytokines, mitigate the inhibitory effects of inflammation on gastrointestinal function and nutrient absorption, and decrease the loss of nutrients like albumin during dialysis, thereby potentially improving patients' nutritional status [17,18]. However, no statistically significant differences in nutritional indicators were observed between the two groups in this study. This discrepancy is likely attributed to the relatively short observation period of only 6 months. Improvements in malnutrition exhibit a certain degree of lag, making it challenging to demonstrate significant intergroup differences within a short timeframe.

The innovation of this study lies in overcoming the limitation of traditional research focusing solely on baseline calcium and phosphorus indicators. By integrating the dynamic changes in nutritional indicators, it clarifies the synergistic improvement of HFHD on calcium and phosphorus metabolism and nutritional status in CKD patients. This provides reliable clinical evidence and theoretical support for formulating personalized dialysis treatment plans and optimizing long-term management strategies for CKD patients.

5. Conclusion

In summary, HFHD, as a more efficient and safer dialysis modality, demonstrates significant advantages in correcting calcium-phosphorus metabolism disorders and improving patient nutritional status. However, this study has certain limitations. All subjects were recruited from the nephrology department of our hospital, resulting in a single-center bias and limited representativeness of the sample. Future studies should expand to multicenter settings, enrolling CKD patients from different regions and hospitals of varying levels to enhance the clinical applicability of the findings. Moreover, the observation period was limited to 6 months, failing to capture long-term trends in calcium-phosphorus metabolism and nutritional indicators after one year of HFHD treatment. Future

studies should extend follow-up durations to further clarify the long-term intervention effects of HFHD.

Disclosure statement

The authors declare no conflict of interest.

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