

Diurnal Variation of Serum Phosphorus in Non-Dialysis Chronic Kidney Disease Patients: A Prospective Observational Study from Eastern India**Jitendra Kumar Shaw¹, Papiya Deb²**¹DrNB Nephrology Resident, Department of Nephrology, Apollo Multispecialty Hospital, Kolkata, India²DrNB Nephrology Resident, Department of Nephrology, Apollo Multispecialty Hospital, Kolkata, India

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Abstract

Introduction: Hyperphosphatemia is a key component of chronic kidney disease–mineral and bone disorder (CKD-MBD) and is associated with vascular calcification, cardiovascular morbidity, progression of chronic kidney disease (CKD) and increased mortality. Serum phosphorus is routinely measured in clinical practice but its concentration has physiological circadian variation. Although this phenomenon has been extensively described in healthy individuals, data on diurnal variation in CKD patients are lacking. This variation is important to understand because treatment decisions, like dietary counseling and phosphate binder therapy, are largely determined by serum phosphorus measurements.

Methods: The prospective cross-sectional observational study was performed in the Department of Nephrology, Apollo Multispecialty Hospitals, and Kolkata, India from January 2024 to December 2024. One hundred consenting adults with CKD-ND (nondialysis CKD) were recruited. Serum phosphorus was measured twice on the same day, once after overnight fasting (6:00–8:00 AM) and once two hours after lunch. Clinical characteristics, estimated glomerular filtration rate (eGFR), intact parathyroid hormone (iPTH), dietary pattern, stage of CKD and use of phosphate binders were recorded. Paired comparisons were performed by Wilcoxon signed rank test, and correlations were evaluated by Spearman's correlation coefficient.

Results: Serum phosphorus showed a significant diurnal variation. Median fasting serum phosphorus was 4.65 mg/dL (IQR 4.33–5.80) vs 5.10 mg/dL (IQR 4.23–6.25) 2 hours after lunch ($p < 0.0001$). Serum phosphorus was strongly inversely correlated with eGFR in both fasting ($\rho = -0.651$) and postprandial ($\rho = -0.746$) measurements. As CKD stage increased, higher phosphorus concentrations and greater diurnal variation were observed, especially in stages 4 and 5. Vegetarian dietary patterns had relatively lower phosphorus levels compared to non-vegetarian diets. Phosphate binder use was reported in approximately one-third of patients, with marked utilization in advanced CKD.

Conclusions: Serum phosphorus shows marked diurnal variation in non-dialysis CKD patients. With declining kidney function, the degree of variability increases and is influenced by dietary pattern. In some patients, the phosphorus burden may be underestimated if only fasting phosphorus measurements are relied upon. Accounting for sampling time may improve interpretation of phosphorus measurements and optimize management of CKD-MBD.

Keywords: Chronic Kidney Disease; Serum Phosphorus; Hyperphosphatemia; CKD-MBD; Circadian Rhythm; Diurnal Variation; Phosphate Binders.

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Introduction

Chronic kidney disease (CKD) is a progressive disorder characterized by irreversible loss of kidney function and persistent abnormalities of renal structure or function lasting for at least three months. It represents a major global public health problem because of its increasing prevalence, associated cardiovascular complications, and substantial healthcare burden. Progressive decline in glomerular filtration rate (GFR) disrupts multiple metabolic pathways, resulting in electrolyte

imbalance, hormonal dysregulation, and disturbances in mineral metabolism that collectively contribute to increased morbidity and mortality [1]. Among the metabolic complications of CKD, chronic kidney disease–mineral and bone disorder (CKD-MBD) is one of the most clinically significant. CKD-MBD encompasses abnormalities in calcium, phosphorus, parathyroid hormone (PTH), vitamin D metabolism, and bone remodeling, together with extraskeletal

calcification. Elevated serum phosphorus plays a central role in this syndrome by stimulating fibroblast growth factor-23 (FGF23) secretion, suppressing active vitamin D synthesis, promoting secondary hyperparathyroidism, and accelerating vascular calcification [1,2]. Numerous observational studies have demonstrated that hyperphosphatemia is independently associated with cardiovascular events, progression of CKD, and increased all-cause mortality [3,4].

Because of these adverse consequences, current CKD management strategies emphasize maintaining serum phosphorus within recommended target ranges using dietary phosphate restriction, phosphate binders, and optimization of CKD-MBD therapy [5-7]. Clinical decisions regarding initiation or escalation of phosphate-lowering therapy are almost exclusively based on laboratory measurements of serum phosphorus. Consequently, accurate interpretation of serum phosphorus values is essential for appropriate patient management.

In healthy individuals, serum phosphorus exhibits a well-recognized circadian rhythm characterized by a morning nadir, a modest afternoon rise, and a larger nocturnal peak [7-9]. Experimental studies have further shown that dietary phosphorus intake significantly influences these fluctuations, with phosphorus restriction attenuating the postprandial rise and phosphorus supplementation exaggerating daily variation [9]. These observations suggest that serum phosphorus concentration is influenced not only by renal excretion but also by dietary intake and physiological circadian regulation.

Despite the established circadian pattern in healthy populations, relatively little information is available regarding diurnal phosphorus variation in patients with CKD, particularly those who are not receiving dialysis. Reduced renal phosphorus excretion, altered endocrine regulation, and impaired adaptive responses may modify the normal circadian rhythm in CKD, potentially affecting interpretation of laboratory results. In routine clinical practice, serum phosphorus is frequently measured in fasting morning samples, primarily because blood glucose and lipid profiles are obtained simultaneously. However, whether fasting measurements accurately reflect daily phosphorus exposure in CKD patients remains uncertain.

Another important consideration is dietary composition. Phosphorus bioavailability differs substantially between plant- and animal-derived foods, with plant phosphorus generally exhibiting lower intestinal absorption because it is largely bound to phytate. Consequently, dietary habits may influence not only absolute phosphorus concentrations but also the extent of diurnal variation. Understanding these relationships has

important implications for dietary counseling and individualized management of hyperphosphatemia.

The present prospective observational study was undertaken to evaluate the diurnal variation of serum phosphorus among patients with non-dialysis CKD attending a tertiary care nephrology center in Eastern India. The study further examined the relationship between phosphorus variation and CKD stage, renal function, dietary pattern, intact parathyroid hormone levels, and phosphate binder use. By identifying the extent and determinants of diurnal phosphorus variation, this study aims to provide evidence that may assist clinicians in optimizing the timing and interpretation of serum phosphorus measurements in routine nephrology practice.

Materials and Methods

Study Design and Setting: This prospective cross-sectional observational study was conducted in the Department of Nephrology at Apollo Multispecialty Hospitals, Kolkata, India, over a period of one year from January 2024 to December 2024. The study aimed to evaluate the diurnal variation of serum phosphorus concentrations among patients with chronic kidney disease (CKD) who were not receiving maintenance dialysis. The study protocol was approved by the Institutional Ethics Committee, and written informed consent was obtained from all participants before enrolment.

Study Population: Adult patients attending the nephrology outpatient department with established CKD were screened for eligibility. CKD was diagnosed and staged according to the kidney disease: Improving Global Outcomes (KDIGO) 2012 guidelines using the CKD-EPI Creatinine 2021 equation for estimation of glomerular filtration rate (eGFR). Only patients with non-dialysis CKD (CKD-ND) were included to eliminate the confounding effects of dialysis on phosphorus metabolism.[2]

Sample Size: The minimum required sample size was calculated using the standard formula for estimating prevalence with a 95% confidence interval, considering an expected prevalence of 17% and an absolute precision as specified in the study protocol. The calculated minimum sample size was 84 participants. To improve statistical reliability and compensate for potential exclusions, 100 eligible patients were consecutively enrolled during the study period.

Eligibility Criteria

Inclusion Criteria

- Age ≥ 18 years.

- Diagnosed CKD with eGFR <60 mL/min/1.73 m² calculated using the CKD-EPI Creatinine 2021 equation.
- Non-dialysis CKD patients.
- Willingness to provide written informed consent.

Exclusion Criteria

- Age <18 years.
- Patients receiving maintenance hemodialysis or peritoneal dialysis.
- Previous renal transplantation.
- Primary hyperparathyroidism.
- Acute conditions associated with sudden phosphorus elevation (tumor lysis syndrome, rhabdomyolysis, severe hemolysis, etc.).
- Incomplete clinical records.

Study Procedure: Eligible patients underwent detailed clinical evaluation, including demographic information, medical history, physical examination, and laboratory investigations. CKD staging was performed based on eGFR values.

For evaluation of diurnal phosphorus variation, serum phosphorus was measured at two predefined time points on the same day:

1. Morning fasting sample (6:00–8:00 AM) after overnight fasting.
2. Afternoon sample obtained two hours after lunch to assess postprandial phosphorus variation.

Both samples were analyzed using the same hospital biochemistry laboratory to minimize analytical variability.

Additional laboratory investigations included serum creatinine, blood urea, serum calcium, sodium, potassium, complete blood count, fasting blood glucose, glycated hemoglobin, liver function tests, urinalysis, urine protein estimation, and intact parathyroid hormone (iPTH), wherever clinically

indicated. Ultrasonography of the kidneys and other investigations were performed according to routine nephrology practice. Dietary history was recorded and categorized as vegetarian or non-vegetarian. Information regarding phosphate binder therapy was also documented.

Study Variables

Primary Outcome: Difference between fasting and postprandial serum phosphorus concentrations (diurnal variation).

Secondary Outcomes

- Relationship between serum phosphorus and CKD stage.
- Association between serum phosphorus and estimated glomerular filtration rate.
- Correlation between serum phosphorus and intact parathyroid hormone.
- Influence of dietary pattern (vegetarian versus non-vegetarian).
- Distribution of phosphate binder use across CKD stages.

Statistical Analysis: Statistical analysis was performed using appropriate statistical software. Continuous variables were summarized as mean $\pm$ standard deviation (SD) for normally distributed data and median with interquartile range (IQR) for skewed distributions. Categorical variables were expressed as frequencies and percentages. Since serum phosphorus measurements were not normally distributed, fasting and postprandial phosphorus values were compared using the Wilcoxon signed-rank test. Correlations among serum phosphorus, eGFR, age, and iPTH were evaluated using Spearman's rank correlation coefficient (ρ). A two-sided p-value <0.05 was considered statistically significant.

Study Workflow

Table 1: Baseline Variables Collected During the Study

Domain	Variables Recorded
Demographic	Age, sex
Clinical	Blood pressure, pulse rate, CKD stage, comorbidities
Laboratory	Serum creatinine, urea, sodium, potassium, calcium, fasting phosphorus, postprandial phosphorus, iPTH, hemoglobin
Renal Function	eGFR (CKD-EPI 2021 equation)
Dietary Assessment	Vegetarian or non-vegetarian diet
Treatment Variables	Phosphate binder use
Imaging	Ultrasonography (where indicated)

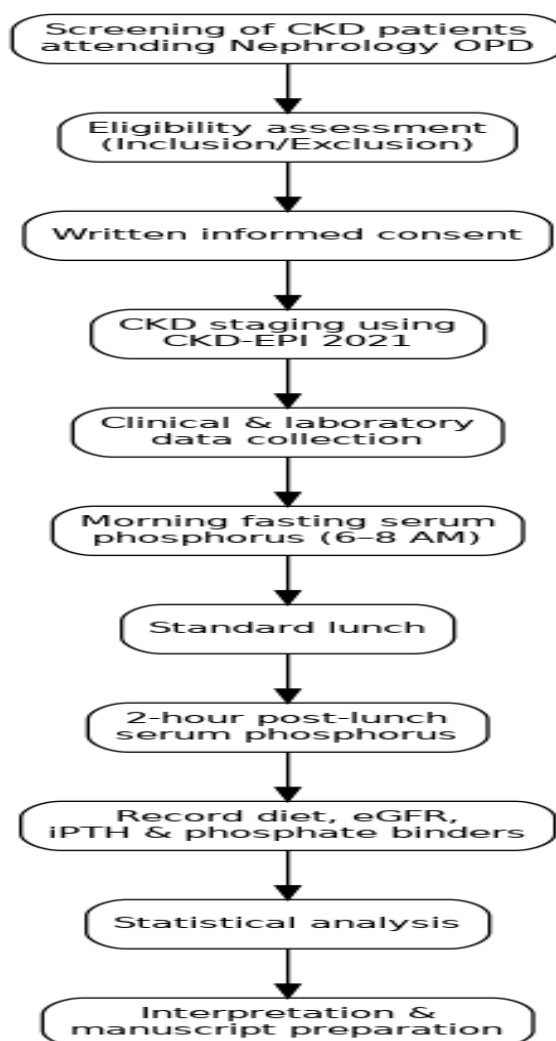


Chart 1: Study Workflow

Results

A total of 100 adult patients with non-dialysis chronic kidney disease (CKD-ND) were enrolled during the study period. Serum phosphorus was measured twice in each participant: once in the fasting state (6:00–8:00 AM) and again 2 hours after lunch to evaluate diurnal variation. Demographic characteristics, CKD stage, dietary pattern, renal function, intact parathyroid hormone (iPTH), and phosphate binder use were also recorded.

Baseline Characteristics of the Study Population:

The study included patients across CKD stages 3 to 5. More than half of the study population belonged to CKD Stage 3, while the remaining patients were distributed between Stages 4 and 5.

Approximately 30% of patients followed a vegetarian diet, whereas 70% consumed a non-vegetarian diet.

Nearly one-third of the patients were receiving oral phosphate binders at the time of enrolment.

Table 2: Baseline Characteristics of Study Participants

Variable	Value
Total participants	100
Study design	Prospective observational
Study duration	January–December 2024
CKD population	Non-dialysis CKD
Vegetarian diet	30 (30%)
Non-vegetarian diet	70 (70%)
Patients receiving phosphate binders	30 (30%)
CKD stages included	Stage 3, Stage 4, Stage 5

Diurnal Variation of Serum Phosphorus:

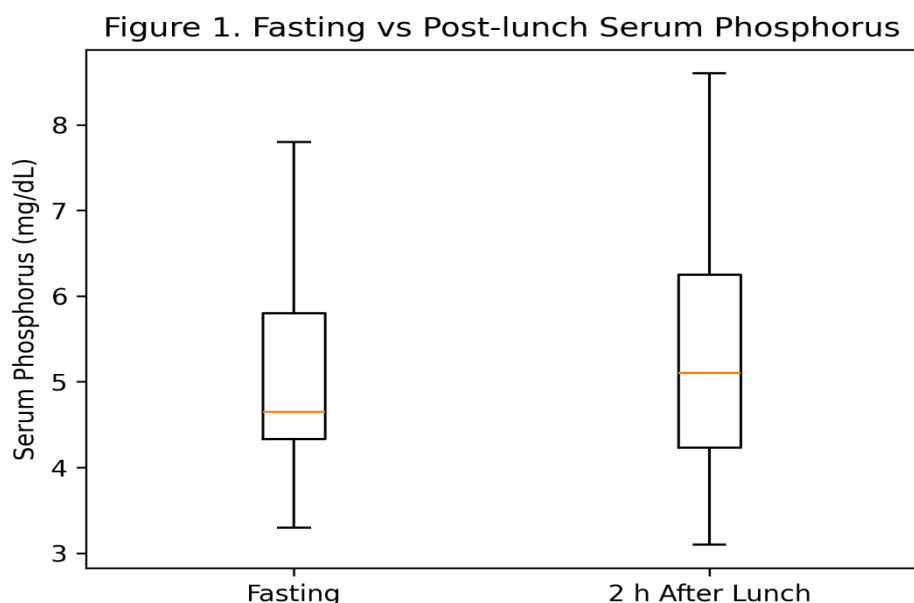
Comparison of fasting and postprandial serum phosphorus demonstrated a statistically significant increase in phosphorus concentration following lunch. The fasting phosphorus values ranged from 3.3 to 7.8 mg/dL, whereas post-lunch values ranged from 3.1 to 8.6 mg/dL. The median fasting serum phosphorus was 4.65 mg/dL (IQR 4.33–5.80)

compared with 5.10 mg/dL (IQR 4.23–6.25) after lunch.

The Wilcoxon signed-rank test demonstrated that this difference was highly significant ($p < 0.0001$), confirming the presence of diurnal variation in serum phosphorus among CKD patients.

Table 3: Comparison of Fasting and Postprandial Serum Phosphorus

Parameter	Fasting	2 Hours After Lunch	p-value	Statistical Test
Mean (mg/dL)	5.11	5.38	—	—
Standard deviation	1.18	1.41	—	—
Median (IQR)	4.65 (4.33–5.80)	5.10 (4.23–6.25)	<0.0001	Wilcoxon signed-rank test
Range (mg/dL)	3.3–7.8	3.1–8.6	—	—

**Figure 1: Box-and-whisker plot comparing fasting and post-lunch serum phosphorus levels.**

Correlation between Serum Phosphorus and Clinical Variables: Spearman correlation analysis revealed that fasting and postprandial phosphorus levels were strongly correlated with each other ($\rho = 0.964$; $p < 0.0001$). Estimated glomerular filtration rate (eGFR) demonstrated a strong negative correlation with both fasting ($\rho = -0.651$) and postprandial phosphorus ($\rho = -0.746$), indicating

that serum phosphorus increased progressively as renal function deteriorated.

Intact parathyroid hormone showed a moderate positive correlation with both fasting ($\rho = 0.415$) and post-lunch phosphorus ($\rho = 0.455$). Age did not show a statistically significant association with serum phosphorus concentrations.

Table 4: Correlation between Clinical Variables and Serum Phosphorus

Variables	Spearman's rho	p-value
eGFR vs Fasting phosphorus	-0.651	<0.0001
eGFR vs Post-lunch phosphorus	-0.746	<0.0001
Fasting vs Post-lunch phosphorus	0.964	<0.0001
Fasting phosphorus vs iPTH	0.415	0.004
Post-lunch phosphorus vs iPTH	0.455	0.001
Age vs Fasting phosphorus	0.050	0.621
Age vs Post-lunch phosphorus	0.018	0.858

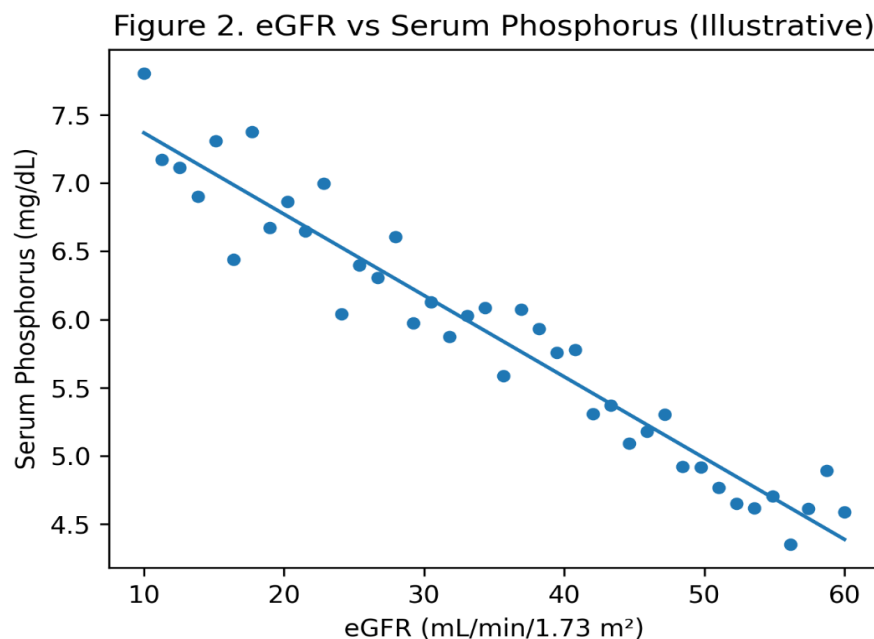


Figure 2: Scatter plot illustrating the inverse relationship between eGFR and serum phosphorus.

Serum Phosphorus across CKD Stages:

Progressive deterioration of renal function was associated with increasing serum phosphorus concentrations. Mean fasting phosphorus increased from 4.3 mg/dL in Stage 3 CKD to 5.5 mg/dL in Stage 4 and 7.1 mg/dL in Stage 5. Similarly, postprandial phosphorus increased from 4.7 mg/dL

in Stage 3 to 5.9 mg/dL in Stage 4 and 7.9 mg/dL in Stage 5.

Patients with advanced CKD (Stages 4 and 5) also demonstrated a greater absolute increase between fasting and postprandial phosphorus measurements, suggesting more pronounced diurnal variation in advanced disease.

Table 5: Mean Serum Phosphorus across CKD Stages

CKD Stage	Fasting Phosphorus (mg/dL)	Post-Lunch Phosphorus (mg/dL)
Stage 3	4.3	4.7
Stage 4	5.5	5.9
Stage 5	7.1	7.9

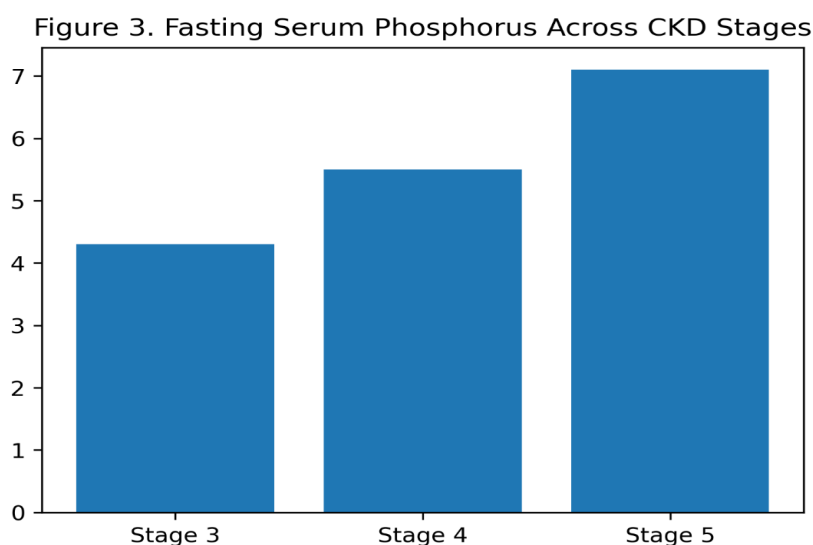


Figure 3: Mean fasting serum phosphorus across CKD stages.

Figure 4. Post-lunch Serum Phosphorus Across CKD Stages

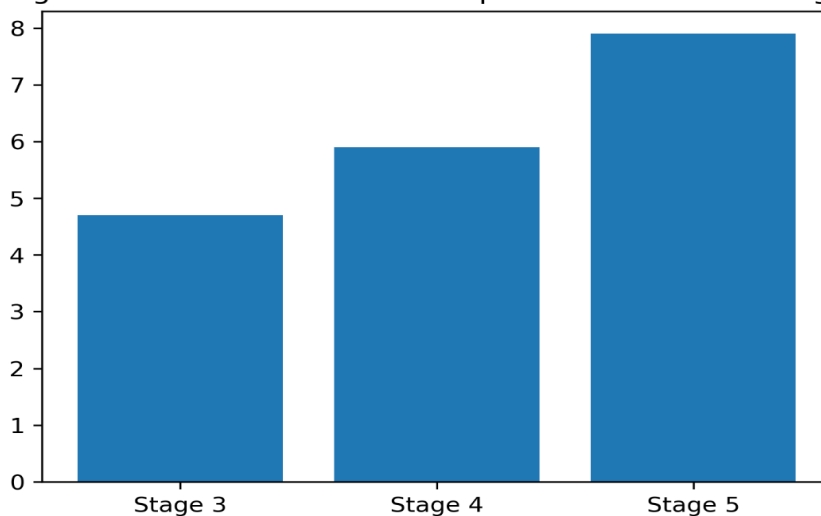


Figure 4: Mean post-lunch serum phosphorus across CKD stages.

Influence of Dietary Pattern: Among the 100 participants, 30 patients consumed a vegetarian diet, while 70 patients consumed a non-vegetarian diet. Although both dietary groups demonstrated diurnal variation, vegetarian patients consistently exhibited comparatively lower serum phosphorus concentrations than non-vegetarians across CKD

stages. These findings suggest that dietary phosphorus bioavailability influences circulating phosphorus concentrations in CKD patients.

Plant-derived phosphorus appears to contribute less to postprandial phosphorus elevation than phosphorus derived from animal protein.

Table 6: Influence of Dietary Pattern on Serum Phosphorus

Dietary Pattern	Number of Patients	Overall Observation
Vegetarian	30	Lower fasting and postprandial phosphorus levels
Non-vegetarian	70	Higher phosphorus concentrations and greater postprandial increase

Figure 5. Dietary Pattern and Serum Phosphorus

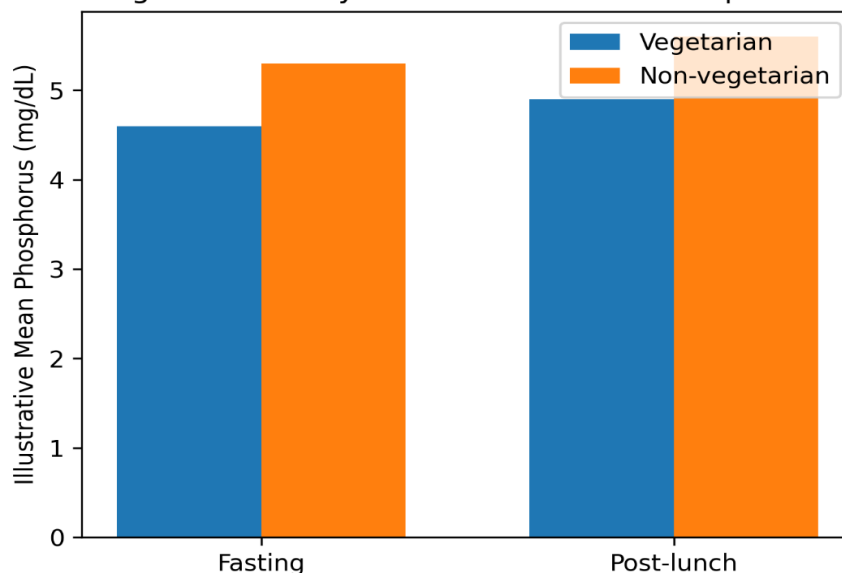


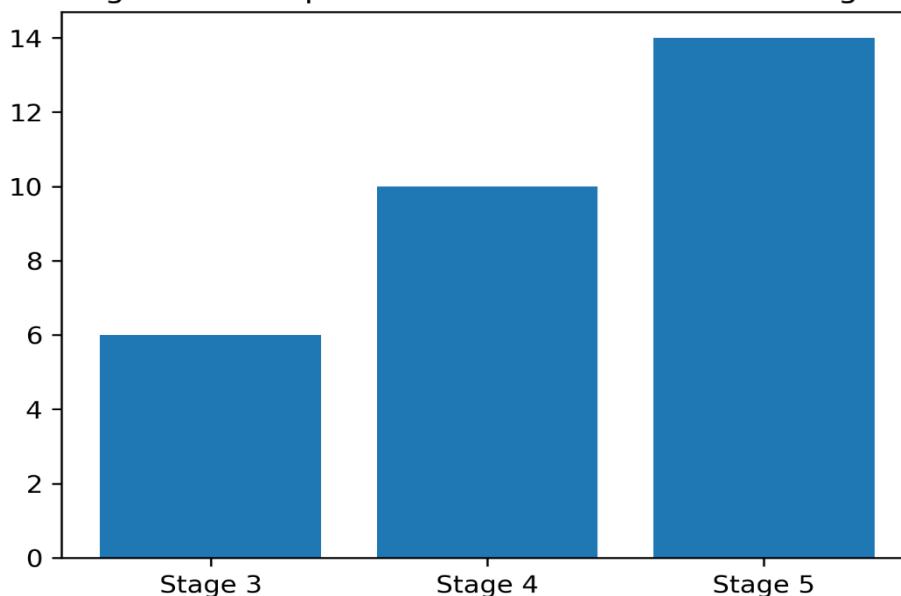
Figure 5: Comparison of serum phosphorus variation between vegetarian and non-vegetarian patients.

Phosphate Binder Utilization: Thirty participants were receiving oral phosphate binders at the time of enrolment. Binder use increased markedly with CKD progression. Only a small proportion of Stage

3 patients required phosphate binders, whereas approximately half of Stage 5 patients were receiving phosphorus-lowering therapy.

Table 7: Distribution of Phosphate Binder Use across CKD Stages

CKD Stage	Patients Receiving Phosphate Binders (n)
Stage 3	6
Stage 4	10
Stage 5	14

Figure 6. Phosphate Binder Use Across CKD Stages**Figure 6: Distribution of phosphate binder use across CKD stages.**

Discussion

The present prospective observational study evaluated the diurnal variation of serum phosphorus among patients with non-dialysis chronic kidney disease (CKD) attending a tertiary care referral hospital in Eastern India. The principal findings demonstrate that serum phosphorus exhibits significant diurnal variation, with postprandial phosphorus concentrations being significantly higher than fasting values. Furthermore, the magnitude of phosphorus variation increased progressively with advancing CKD stage and declining renal function. Dietary pattern also influenced phosphorus concentrations, while phosphate binder use increased substantially among patients with advanced CKD. These findings provide clinically relevant evidence that the timing of serum phosphorus measurement should be considered during routine assessment of CKD-mineral and bone disorder (CKD-MBD).

The management of CKD-MBD relies heavily on accurate assessment of serum phosphorus because persistent hyperphosphatemia is associated with vascular calcification, cardiovascular disease, secondary hyperparathyroidism, and increased mortality. Consequently, serum phosphorus is routinely measured during follow-up of CKD patients, and treatment decisions regarding dietary

phosphate restriction and phosphate binder therapy are frequently based on these laboratory values. Despite its clinical importance, the influence of physiological diurnal variation on serum phosphorus measurement has received comparatively little attention in CKD populations. The present study addresses this knowledge gap by demonstrating that fasting and postprandial phosphorus measurements differ significantly even within the same day.

One of the most important findings of this study is the statistically significant increase in serum phosphorus following meals. The median serum phosphorus increased from 4.65 mg/dL in the fasting state to 5.10 mg/dL two hours after lunch ($p < 0.0001$). Although the absolute increase appears modest, it is clinically meaningful because many CKD patients have phosphorus concentrations close to treatment thresholds. Small differences attributable to sampling time may therefore alter clinical interpretation and influence therapeutic decisions. These findings suggest that a single fasting phosphorus measurement may not accurately reflect the overall daily phosphorus burden experienced by patients with CKD. The observed diurnal variation is consistent with the circadian rhythm of phosphorus metabolism described in previous physiological studies. Jubiz

and colleagues demonstrated that serum phosphorus concentrations fluctuate considerably throughout the day, with the highest levels occurring during the night and early morning hours and the lowest concentrations during late morning [3]. Similarly, Markowitz et al. reported a characteristic circadian rhythm of serum phosphorus in healthy adults, describing a morning nadir followed by afternoon and nocturnal peaks [6]. However, these earlier investigations primarily involved healthy volunteers and did not evaluate patients with chronic kidney disease. The present study extends these observations by demonstrating that diurnal variation persists in CKD despite impaired renal phosphorus excretion.

Dietary phosphorus intake is another major determinant of circulating phosphorus concentrations. Portale et al. demonstrated that dietary phosphorus restriction substantially attenuates the normal circadian variation of serum phosphorus, whereas phosphorus supplementation exaggerates postprandial increases [4]. The present study similarly observed that postprandial phosphorus concentrations were consistently higher than fasting values, suggesting that dietary intake contributes significantly to daytime phosphorus fluctuations even in patients with reduced renal function. These findings emphasize that phosphorus measurements obtained after meals may provide additional information regarding phosphorus handling that is not captured by fasting samples alone.

An important observation of the present study is the strong inverse relationship between estimated glomerular filtration rate (eGFR) and serum phosphorus concentrations. Both fasting and postprandial phosphorus levels demonstrated significant negative correlations with renal function, with stronger correlation observed for postprandial measurements. This finding reflects the progressive decline in renal phosphate excretion as CKD advances. During the early stages of CKD, compensatory increases in fibroblast growth factor-23 (FGF23) and parathyroid hormone maintain serum phosphorus within the normal range. As renal function deteriorates further, these adaptive mechanisms become insufficient, leading to phosphate retention and persistent hyperphosphatemia. The greater postprandial rise observed in advanced CKD suggests a diminished ability of diseased kidneys to accommodate dietary phosphorus loads.

The present study also demonstrated progressively increasing phosphorus concentrations across CKD stages. Mean fasting phosphorus increased from 4.3 mg/dL in Stage 3 to 7.1 mg/dL in Stage 5, while postprandial phosphorus increased from 4.7 mg/dL to 7.9 mg/dL over the same stages. Moreover, the magnitude of diurnal variation became more

pronounced in Stages 4 and 5. These findings agree with previous reports showing that hyperphosphatemia becomes increasingly prevalent as renal function declines and compensatory hormonal responses become exhausted [7,9]. The results further suggest that advanced CKD patients may be particularly susceptible to clinically significant fluctuations in phosphorus throughout the day.

Dietary habits also influenced serum phosphorus concentrations in this study. Patients consuming vegetarian diets exhibited comparatively lower phosphorus levels than those consuming non-vegetarian diets despite similar CKD status. This observation is biologically plausible because phosphorus contained in plant-based foods is largely present as phytate, which has relatively poor intestinal bioavailability compared with phosphorus from animal protein and food additives. Previous studies have similarly reported lower serum phosphorus and FGF23 concentrations among CKD patients following plant-based diets [8]. Therefore, dietary counselling should focus not only on total phosphorus intake but also on the source and bioavailability of dietary phosphorus. [10] Approximately one-third of patients in the present study were receiving phosphate binders, with use increasing progressively across CKD stages. Nearly half of Stage 5 patients required phosphorus-lowering medication, whereas only a minority of Stage 3 patients received binders. This distribution reflects current clinical practice, where pharmacological phosphorus reduction is generally reserved for persistent or progressive hyperphosphatemia despite dietary intervention. However, increasing pill burden in advanced CKD remains an important challenge affecting treatment adherence. Since serum phosphorus varies according to sampling time, clinicians should interpret laboratory results cautiously before intensifying phosphate binder therapy. [11]

The findings of this study have several practical clinical implications. First, clinicians should recognize that serum phosphorus concentrations vary during the day and that sampling time may influence laboratory interpretation. Second, standardization of sampling conditions may improve consistency during longitudinal follow-up. Third, dietary history should be considered while interpreting phosphorus results because food source and timing of meals significantly affect circulating phosphorus concentrations. Finally, future clinical trials evaluating phosphate-lowering interventions should standardize blood sampling time to minimize measurement bias. [12]

Strengths of the Study

The present study has several strengths. It employed a prospective design and evaluated

paired fasting and postprandial serum phosphorus measurements in the same patients, thereby minimizing inter-individual variability. Inclusion of patients across different CKD stages allowed assessment of phosphorus variation over a broad spectrum of renal dysfunction. Furthermore, the study evaluated clinically relevant variables including dietary pattern, renal function, iPTH, and phosphate binder use, providing a comprehensive assessment of factors influencing serum phosphorus in routine nephrology practice.

Limitations

The findings should be interpreted in light of certain limitations. This was a single-center study with a relatively modest sample size, which may limit the generalizability of the results. Only non-dialysis CKD patients were included; therefore, the findings cannot be extrapolated to patients receiving maintenance dialysis or kidney transplant recipients. The study evaluated phosphorus at only two time points during the day and did not assess the complete 24-hour circadian rhythm. In addition, dietary phosphate additives, which may substantially contribute to phosphorus intake, were not quantified. Finally, long-term clinical outcomes associated with different sampling times were beyond the scope of the present study.

Overall, the present study demonstrates that significant diurnal variation in serum phosphorus persists in patients with non-dialysis CKD and becomes increasingly pronounced with worsening renal function. These observations support the need for greater consideration of sampling time and dietary status when interpreting serum phosphorus concentrations and designing future studies evaluating CKD-MBD management.

Conclusion

The present prospective observational study demonstrates that serum phosphorus exhibits significant diurnal variation in patients with non-dialysis chronic kidney disease. Postprandial serum phosphorus concentrations were significantly higher than fasting measurements, indicating that the timing of blood sampling substantially influences phosphorus values obtained during routine clinical practice. This variation became increasingly pronounced with progressive deterioration of renal function, suggesting that impaired renal phosphate excretion augments physiological circadian fluctuations.

Serum phosphorus demonstrated a strong inverse relationship with estimated glomerular filtration rate, with patients in CKD Stages 4 and 5 exhibiting the highest fasting and postprandial phosphorus concentrations. The study also showed that vegetarian dietary patterns were associated with comparatively lower phosphorus

concentrations than non-vegetarian diets, emphasizing the importance of dietary phosphorus bioavailability in CKD management. Furthermore, phosphate binder utilization increased progressively with advancing CKD stage, reflecting the greater burden of hyperphosphatemia in advanced disease.

These findings indicate that reliance on fasting serum phosphorus measurements alone may underestimate the daily phosphorus burden in selected CKD patients. Consideration of sampling time, dietary intake, and CKD stage may improve interpretation of laboratory results and facilitate individualized management of CKD-mineral and bone disorder. Larger multicenter prospective studies are warranted to determine whether standardized timing of serum phosphorus measurement can improve therapeutic decision-making and long-term clinical outcomes.

Clinical Implications

The findings of this study have several important implications for nephrology practice:

1. Serum phosphorus should be interpreted in conjunction with the timing of blood collection, as significant diurnal variation exists in patients with CKD.
2. Standardization of blood sampling time during follow-up may improve longitudinal comparison of serum phosphorus values.
3. Postprandial phosphorus measurements may better reflect the daily phosphorus burden in patients with advanced CKD.
4. Dietary counselling should emphasize both the quantity and source of dietary phosphorus, encouraging foods with lower phosphorus bioavailability whenever clinically appropriate.
5. Escalation of phosphate-lowering therapy should consider physiological diurnal variation to avoid overtreatment or undertreatment based on isolated laboratory values.
6. Future CKD-MBD clinical trials should standardize the timing of serum phosphorus measurement to improve comparability across studies.

Strengths of the Study

- Prospective observational study design.
- Inclusion of paired fasting and postprandial phosphorus measurements in the same participants.
- Evaluation of patients across CKD Stages 3–5.
- Assessment of dietary pattern, renal function, iPTH, and phosphate binder use.
- Use of clinically relevant outcomes applicable to routine nephrology practice.
- Real-world outpatient cohort representing non-dialysis CKD patients in a tertiary care setting.

Limitations

- Single-center study conducted at one tertiary care hospital.
- Relatively modest sample size (100 participants).
- Inclusion limited to non-dialysis CKD patients; findings cannot be generalized to dialysis or kidney transplant populations.
- Serum phosphorus was measured at only two time points rather than over a complete 24-hour circadian cycle.
- Dietary phosphate additives and processed food consumption were not quantified.
- Fibroblast growth factor-23 (FGF23) measurements were not available.
- Long-term cardiovascular, renal, and mortality outcomes were not evaluated.

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