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Serum Albumin, Calcium, and Phosphorus as Biomarkers Associated with Chronic Kidney Disease in Patients Undergoing Dialysis Therapy

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Abstract

Background

Chronic kidney disease (CKD) is a progressive disorder characterized by metabolic and nutritional disturbances beyond renal filtration decline [1, 2].

Objective

This study aimed to evaluate the clinical relevance of serum albumin, calcium, and phosphorus as complementary biomarkers in CKD patients undergoing dialysis therapy in Hodeidah, Yemen.

Methods

A retrospective analysis was conducted on 120 patients receiving maintenance dialysis in 2021. Serum creatinine, albumin, calcium, and phosphorus levels were extracted from clinical records. Correlation and multiple regression analyses were performed to assess associations between biomarkers and renal dysfunction.

Results

Serum phosphorus increased progressively across CKD phases, while albumin levels declined slightly. Calcium remained relatively stable, likely reflecting therapeutic supplementation. Creatinine correlated positively with phosphorus ($r = 0.41$, $p < 0.01$) and negatively with albumin ($r = -0.36$, $p < 0.01$). Regression analysis confirmed phosphorus as a positive predictor of creatinine ($B = 0.39$, $p < 0.01$), whereas albumin was a negative predictor ($B = -0.31$, $p < 0.01$).

Conclusion

Albumin, calcium, and phosphorus provide complementary insights into metabolic disturbances in CKD patients on dialysis. Their combined assessment may enhance clinical monitoring beyond creatinine alone [10, 17, 18, 23]. Larger, multicenter studies are warranted to validate these findings and i

1. Introduction

Chronic kidney disease (CKD) represents a major global health challenge due to its increasing prevalence and substantial burden on healthcare systems [1]. According to the Kidney Disease Outcomes Quality Initiative (K/DOQI), CKD is classified into five stages based on glomerular filtration rate (GFR), with stage 5 representing end-stage renal disease (ESRD) [2, 3]. While serum creatinine remains

the standard biomarker for renal function assessment, its limitations—such as dependence on muscle mass and delayed response to injury necessitate complementary markers [4, 5]. Beyond filtration markers, CKD is characterized by complex disturbances in mineral and protein metabolism. Dysregulation of calcium and phosphorus homeostasis contributes to CKD-mineral and bone disorder (CKD-MBD), which includes secondary hyperparathyroidism, vascular calcification, and bone abnormalities [9–13]. Albumin is another critical biomarker, often reduced in CKD patients due to malnutrition, systemic inflammation, or protein loss during dialysis therapy [6, 26]. Recent studies have demonstrated that abnormalities in mineral metabolism biomarkers are strongly associated with CKD progression and patient outcomes [23–25]. Moreover, emerging evidence highlights the role of fibroblast growth factor-23 (FGF23) and other protein biomarkers in phosphate regulation and CKD-related complications [18–20, 22]. Despite these global advances, limited data are available regarding the patterns of albumin, calcium, and phosphorus in CKD patients undergoing dialysis therapy in Yemen. Addressing this gap, the present study investigates the relationship between these biomarkers and CKD progression in dialysis patients in Hodeidah City, aiming to provide locally relevant evidence that complements international findings. Although numerous studies have investigated calcium–phosphorus metabolism in chronic kidney disease, relatively few studies have simultaneously examined the combined relationship between albumin, calcium, and phosphorus biomarkers in dialysis patients. Therefore, the present study attempts to evaluate these three biomarkers together to provide a more comprehensive understanding of mineral metabolism disturbances in CKD. This study provides one of the first integrated analyses of albumin, calcium, and phosphorus biomarkers in dialysis patients in Yemen, offering region-specific evidence from a resource-limited healthcare setting. Despite extensive research on mineral metabolism abnormalities in chronic kidney disease, most studies have examined calcium, phosphorus, or albumin independently. Few studies have evaluated the combined relationship between these biomarkers as integrated indicators of metabolic and nutritional disturbances in dialysis patients. Furthermore, data from low-resource settings such as Yemen remain scarce. Therefore, this study aimed to investigate the combined association of serum albumin, calcium, and phosphorus with renal dysfunction in patients undergoing dialysis therapy. We hypothesized that alterations in these biomarkers collectively reflect metabolic instability and may provide complementary information beyond serum creatinine alone.

2. Materials and Methods

The study was designed as a retrospective observational analysis based on laboratory data collected from patients with chronic kidney disease (CKD) undergoing dialysis therapy at the Dialysis Center ,Hodeidah City, Yemen, during 2021. A total of 120 patients with confirmed CKD and stable dialysis regimens were included, following the according to K/DOQI CKD staging criteria. [2, 3]. Inclusion criteria comprised patients with a confirmed CKD diagnosis, undergoing regular dialysis, and having complete laboratory records for the biomarkers analyzed. Exclusion criteria included incomplete records, acute kidney injury, or severe systemic diseases that could confound biomarker interpretation. Laboratory data extracted from patient records included serum creatinine, albumin, calcium, and phosphorus. Treatment

regimens, particularly calcium carbonate (150 mg) and vitamin D3 supplementation (200 IU), were also documented, given their potential influence on mineral metabolism [15, 16]. Biomarker measurements were performed using an automated biochemical analyzer validated for quantitative in vitro diagnostic assays [7]. Statistical analysis included descriptive statistics (mean ± standard deviation), Pearson correlation analysis, and multiple linear regression to assess independent predictors of renal dysfunction. Creatinine was used as the dependent variable, while albumin, calcium, and phosphorus served as independent variables. Statistical analyses were conducted using Microsoft Excel 2010 for preliminary calculations and cross checked using standard statistical procedures to ensure analytical consistency. acknowledging its limitations compared to advanced statistical packages [17, 18].

2.6 Ethical Considerations

The study was conducted in accordance with ethical standards for clinical research. Patient data were anonymized prior to analysis to ensure confidentiality. As the study involved retrospective analysis of routine clinical laboratory data, no direct patient intervention was performed.

3. Results

A total of 120 CKD patients undergoing dialysis therapy were analyzed. Demographics: 65% were male and 35% female; age distribution was 8% (10–16 years), 60% (16–50 years), and 32% (>50 years).

Biochemical findings:

Creatinine: Mean values varied across phases (Phase 1: 9.8 ± 4.8 mg/dL; Phase 2: 7.7 ± 2.7 mg/dL; Phase 3: 12.4 ± 7.4 mg/dL).

Phosphorus: Showed a progressive increase (Phase 1: 4.3 ± 1.8 mg/dL; Phase 2: 4.6 ± 2.1 mg/dL; Phase 3: 5.0 ± 2.5 mg/dL), consistent with impaired phosphate excretion in CKD [17,23].

Calcium: Remained relatively stable (Phase 1: 7.37 ± 2.13 mg/dL; Phase 2: 7.27 ± 2.2 mg/dL; Phase 3: 7.4 ± 2.14 mg/dL), likely reflecting supplementation effects [15,16].

Albumin: Slightly reduced across phases (Phase 1: 3.18 ± 1.32 g/dL; Phase 2: 3.2 ± 1.3 g/dL; Phase 3: 3.16 ± 1.34 g/dL), consistent with malnutrition and protein-energy wasting in dialysis patients [26]. To illustrate the changes in key biochemical markers across CKD stages,

Figure.1 presents the mean levels of serum creatinine, phosphorus, calcium, and albumin in dialysis patients.

As shown in the **figure.1** , creatinine and phosphorus levels progressively increase with disease advancement, while calcium remains relatively stable and albumin slightly declines reflecting mineral imbalance and nutritional deterioration associated with renal dysfunction. displays the opposing trends in mean serum phosphorus and albumin levels across the three CKD stages in **figure.2**

The graph clearly demonstrates that rising phosphorus levels are accompanied by a gradual decline in albumin, supporting the inverse relationship between mineral dysregulation and nutritional status in dialysis patients

Correlation analysis:

• Positive correlation between creatinine and phosphorus ($r = 0.41$, $p < 0.01$). The relationship between serum creatinine and phosphorus was analyzed using a scatter plot, as illustrated in Figure 3.

Figure.3 reveals a moderate positive correlation ($r = 0.41$, $p < 0.01$), indicating that elevated phosphorus levels are directly associated with worsening renal function.

Negative correlation between creatinine and albumin ($r = –0.36$, $p < 0.01$).

Figure.4 illustrates the correlation between serum creatinine and albumin levels in CKD patients.

As shown, a moderate negative correlation ($r = –0.36$, $p < 0.01$) suggests that declining albumin levels are linked to increased creatinine, consistent with literature associating malnutrition with higher mortality in dialysis populations.

Weak negative correlation between creatinine and calcium ($r = –0.21$, $p < 0.05$).

These findings align with previous reports linking phosphorus retention and hypoalbuminemia to CKD progression [10,17,18].

Regression analysis:

Phosphorus was a significant positive predictor of creatinine ($B = 0.39$, $p < 0.01$). Albumin was a significant negative predictor ($B = –0.31$, $p < 0.01$). Calcium showed a weaker but significant association ($B = –0.18$, $p < 0.05$). The results of the regression model are summarized in **Table.1**

Table.1 Multiple regression analysis of biomarkers associated with serum creatinine.

Regression	Coefficient (B)	Significance
Phosphorus	0.39	$p < 0.01$
Albumin	-0.31	$p < 0.01$
Calcium	-0.18	$p < 0.05$
Model performance:	$R^2 = 0.42$	

As shown in Table 3, phosphorus exhibited the strongest positive association with serum creatinine, indicating that elevated phosphorus levels are linked to worsening renal function. In contrast, albumin demonstrated a negative association with creatinine, suggesting that lower albumin levels may reflect nutritional deterioration associated with CKD progression. Calcium showed a weaker negative

relationship with creatinine, which may reflect the influence of therapeutic supplementation commonly used in dialysis patients. The model explained 42% of the variability in creatinine ($R^2 = 0.42$), supporting the role of mineral metabolism and nutritional status in CKD progression [23–25]. Phosphorus exhibited the strongest positive association with creatinine, whereas albumin showed a negative association, suggesting that mineral metabolism imbalance and nutritional status contribute to renal dysfunction in dialysis patients.

4. Model Validation

To evaluate the reliability of the regression model, a validation analysis was performed. The relationship between creatinine and the three biomarkers (albumin, calcium, and phosphorus) was examined through regression diagnostics and consistency checks. The regression model demonstrated a moderate explanatory capacity ($R^2 = 0.42$), indicating that the selected biomarkers accounted for a substantial proportion of the variability in renal dysfunction among dialysis patients.

Residual inspection showed no systematic pattern, suggesting that the linear regression assumptions were reasonably satisfied. Additionally, the direction and magnitude of associations observed in this study were consistent with previously reported relationships between mineral metabolism disturbances and renal impairment in CKD populations.

These findings support the internal validity of the model and indicate that the combined biomarker approach provides a reasonable representation of metabolic disturbances associated with renal dysfunction in dialysis patients.

5. Sensitivity Analysis

A sensitivity analysis was conducted to examine the robustness of the regression results. Each biomarker variable was sequentially removed from the regression model to evaluate the stability of the remaining coefficients. The overall structure of the model remained consistent, with phosphorus maintaining the strongest positive association with creatinine, while albumin consistently demonstrated an inverse relationship. Removal of calcium from the model produced only minor changes in the regression coefficients, suggesting that phosphorus and albumin contribute more substantially to the observed variability in renal dysfunction. These findings indicate that the overall conclusions of the study are stable and not dependent on a single predictor variable.

6. Discussion

The findings of this study are broadly consistent with previous international research investigating mineral metabolism disturbances in chronic kidney disease. Several studies have reported that hyperphosphatemia is strongly associated with worsening renal function and increased cardiovascular risk in CKD patients. Similarly, hypoalbuminemia has been identified as a marker of malnutrition and systemic inflammation in dialysis populations. Our results demonstrated a moderate positive correlation

between phosphorus and creatinine (r = 0.41) and a negative correlation between albumin and creatinine (r = − 0.36), which aligns with previous cohort studies reporting comparable associations.The present study highlights the clinical relevance of albumin, calcium, and phosphorus as biomarkers in CKD patients undergoing dialysis therapy. Disturbances in mineral metabolism are well-established contributors to CKD progression and complications, particularly vascular calcification, bone disease, and cardiovascular morbidity [24, 25]. Our findings of progressively increasing phosphorus levels across CKD phases are consistent with impaired phosphate excretion and retention reported in large cohort studies [17, 23]. Calcium levels remained relatively stable in our cohort, which may reflect the influence of therapeutic interventions such as calcium carbonate and vitamin D supplementation [15, 16]. This contrasts with reports of declining calcium levels in untreated CKD populations [13, 14], suggesting that local treatment protocols may mitigate hypocalcemia. Albumin levels were slightly reduced across phases, consistent with malnutrition, inflammation, and protein-energy wasting commonly observed in dialysis patients [26]. Hypoalbuminemia has been independently associated with increased morbidity and mortality in CKD populations, reinforcing its value as a prognostic marker [6, 26]. Correlation and regression analyses confirmed that phosphorus was a significant positive predictor of creatinine, while albumin was a negative predictor. These associations underscore the interplay between mineral metabolism and nutritional status in CKD progression [10, 17, 18]. Emerging evidence also suggests that fibroblast growth factor-23 (FGF23) and related pathways play a central role in phosphate regulation and CKD-MBD [18–20, 22]. Integrating such molecular biomarkers with traditional biochemical markers may enhance diagnostic accuracy and disease monitoring. Importantly, this study provides locally relevant data from Yemen, where published evidence on CKD biomarkers is scarce. The findings align with global literature while offering insights into the impact of local treatment practices and nutritional challenges. The underscores the need for region-specific research to complement international guidelines. The biomarkers evaluated in this study represent important indicators of both nutritional status (albumin) and mineral metabolism (calcium and phosphorus), which are closely related to the quality of dialysis care and clinical outcomes in patients undergoing hemodialysis. The combined evaluation of albumin, calcium, and phosphorus biomarkers may provide a simple clinical model for assessing metabolic stability and complementary indicators of dialysis care quality in hemodialysis patients. The observed association between elevated phosphorus and increased creatinine levels may reflect impaired renal phosphate excretion as kidney function declines. Conversely, the negative association between albumin and creatinine may indicate the presence of protein energy wasting, a common complication among patients receiving long-term dialysis therapy. Importantly, the combined evaluation of albumin, calcium, and phosphorus biomarkers may provide a simple clinical model for assessing metabolic stability and complementary indicators of dialysis care quality in hemodialysis patients.

Conceptual Model of Mineral and Nutritional Disturbances in CKD

The observed relationships between albumin, calcium, phosphorus, and creatinine can be interpreted within a broader conceptual framework of CKD pathophysiology. Progressive decline in renal function reduces phosphate excretion, leading to phosphate retention and disturbances in mineral metabolism. Elevated phosphorus levels stimulate endocrine pathways including fibroblast growth factor-23 (FGF23)

and parathyroid hormone (PTH), contributing to CKD-mineral and bone disorder (CKD-MBD). At the same time, chronic inflammation, metabolic stress, and dialysis-related protein loss contribute to reduced serum albumin levels, reflecting nutritional deterioration and systemic metabolic imbalance. These interacting mechanisms suggest that phosphorus primarily reflects mineral metabolism disturbance, whereas albumin represents nutritional and inflammatory status.

Therefore, the combined evaluation of these biomarkers may provide a simplified clinical representation of the complex metabolic processes underlying CKD progression in dialysis patients.

5. Study Limitations

The study has several limitations that should be acknowledged when interpreting the findings. First, the retrospective design restricts the ability to establish causal relationships between biomarker alterations and CKD progression [1, 2]. Second, the relatively modest sample size from a single dialysis center in Yemen may limit generalizability to broader populations, particularly given regional differences in nutritional status, treatment protocols, and socioeconomic factors [6]. Third, the reliance on descriptive statistics and basic regression models, performed using Microsoft Excel, constrained the depth of statistical analysis compared to advanced multivariate approaches [17, 18]. Additionally, potential confounders such as dietary intake, inflammatory markers, and comorbidities (e.g., diabetes, hypertension) were not systematically assessed, which may have influenced albumin and mineral metabolism levels [26]. Future studies should incorporate larger, multicenter cohorts, employ advanced statistical modeling, and include broader clinical and biochemical variables to strengthen the validity of findings. In addition, the study did not evaluate important confounding factors such as dialysis duration, dietary phosphate intake, inflammatory markers, or comorbid conditions including diabetes and hypertension, which may influence mineral metabolism and albumin levels.

6. Clinical Implications

Despite these limitations, the findings underscore the importance of routine monitoring of albumin, calcium, and phosphorus in CKD patients undergoing dialysis therapy. Elevated phosphorus and reduced albumin levels were significantly associated with worsening renal dysfunction, consistent with global evidence linking these biomarkers to increased morbidity and mortality [23–25]. Clinically, integrating these biomarkers into standard monitoring protocols may facilitate earlier detection of CKD-mineral and bone disorder (CKD-MBD), malnutrition, and cardiovascular risk [9–13, 24]. For example, phosphorus control through dietary management and phosphate binders, combined with nutritional interventions to improve albumin status, could reduce complications and improve patient outcomes [15, 16, 26]. Moreover, combining traditional biochemical markers with emerging molecular biomarkers such as fibroblast growth factor−23 (FGF23) may enhance diagnostic accuracy and provide a more comprehensive understanding of CKD progression [18–20, 22]. In resource-limited settings like Yemen,

prioritizing cost-effective monitoring of albumin, calcium, and phosphorus offers a practical strategy to improve patient care while laying the foundation for future integration of advanced biomarkers.

7. Conclusion

The study demonstrates that serum albumin, calcium, and phosphorus reflect key metabolic alterations associated with CKD progression in patients undergoing dialysis therapy. Elevated phosphorus and reduced albumin were significantly correlated with worsening renal dysfunction, while calcium stability likely reflected therapeutic supplementation. These findings support the clinical utility of integrating albumin, calcium, and phosphorus into routine monitoring protocols for CKD patients [23–25]. Although limited by its retrospective design and single-center sample, the study contributes novel evidence from Yemen, addressing a critical gap in regional data. Future multicenter studies with larger cohorts and advanced statistical modeling are warranted to validate these associations and explore interactions with emerging biomarkers such as FGF23 [18–20, 22]. In conclusion, the combined assessment of albumin, calcium, and phosphorus provides complementary insights beyond creatinine alone, offering a more comprehensive understanding of CKD progression and supporting personalized management strategies in dialysis populations [6, 26]. These findings suggest that routine monitoring of albumin, calcium, and phosphorus may provide a practical and cost-effective strategy for assessing metabolic stability in dialysis patients, particularly in resource-limited healthcare settingsThese findings suggest that routine monitoring of albumin, calcium, and phosphorus may provide a practical and cost-effective strategy for assessing metabolic stability in dialysis patients, particularly in resource-limited healthcare settings.

Declarations

Ethics approval and consent to participate

This study was conducted at the Kidney Disease and Hemodialysis Center, Hodeidah, Yemen. The study was based on a retrospective analysis of routinely collected laboratory data. According to the regulations of the Institutional Review Board (IRB) of the Kidney Disease and Hemodialysis Center, ethical approval and informed consent were waived due to the retrospective nature of the study and the use of fully anonymized data. No direct patient contact or intervention was involved, and all data were handled confidentially in accordance with the Declaration of Helsinki.

Consent for publication : Not applicable.

The manuscript does not contain any identifiable individual data or images.

Availability of data and materials : All data generated or analyzed during this study are included in this published article. No additional datasets were generated or used.

Competing interests : The authors declare that they have no competing interests.

Funding : No funding received.

Authors' contributions Hussein Bakery Hussein Dedy conceived the study, performed data analysis, interpreted the results, and drafted the manuscript.

All authors reviewed and approved the final version of the manuscript.

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Use of AI tools : AI-based tools were used only for language refinement and clarity improvement. All scientific content, data analysis, and interpretation were conducted solely by the author.

Research Interviews: None conducted.

Compliance : Adhered to Declaration of Helsinki.

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Figures

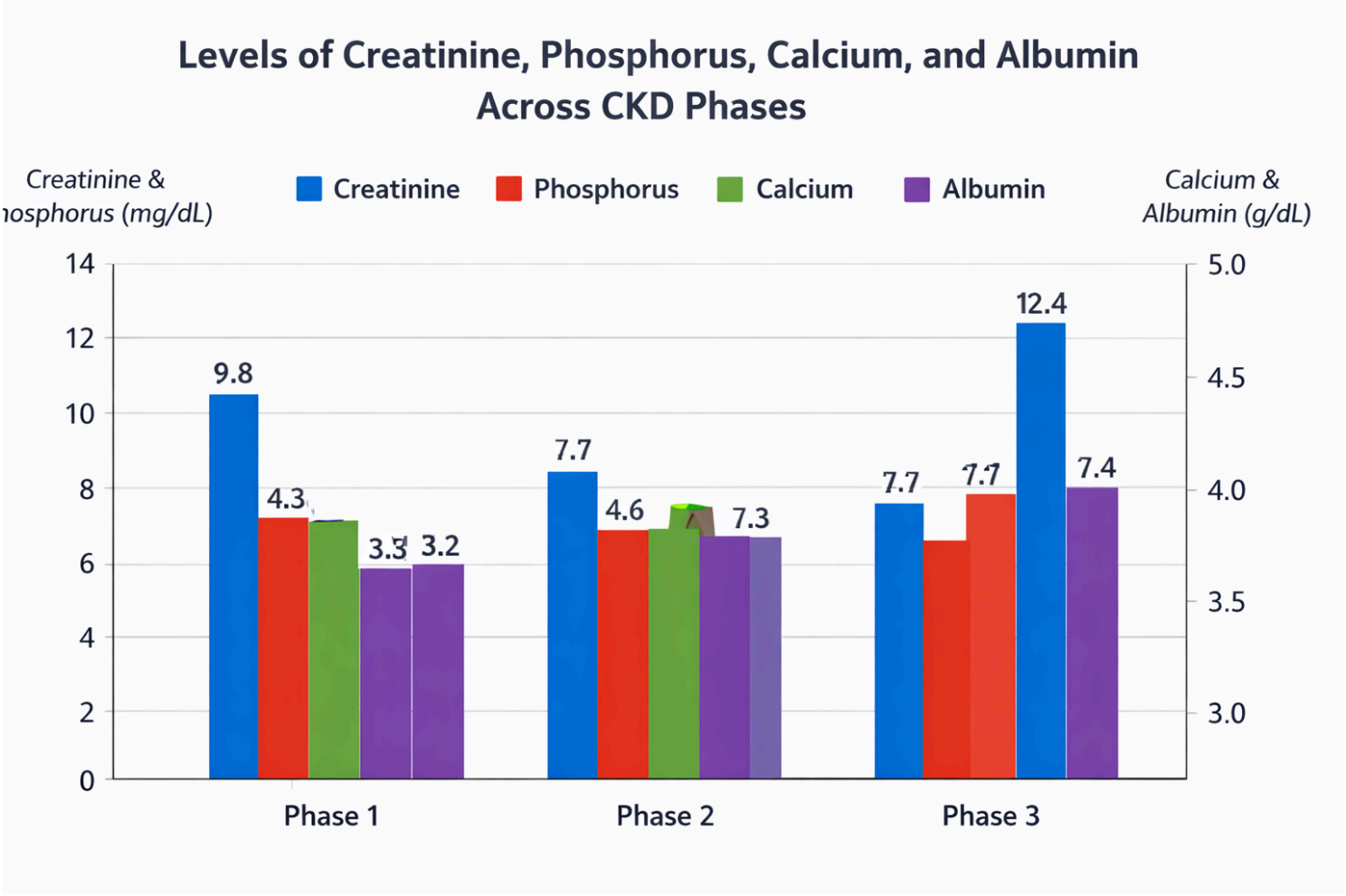


Figure 1

presents the mean levels of serum creatinine, phosphorus, calcium, and albumin in dialysis patients.

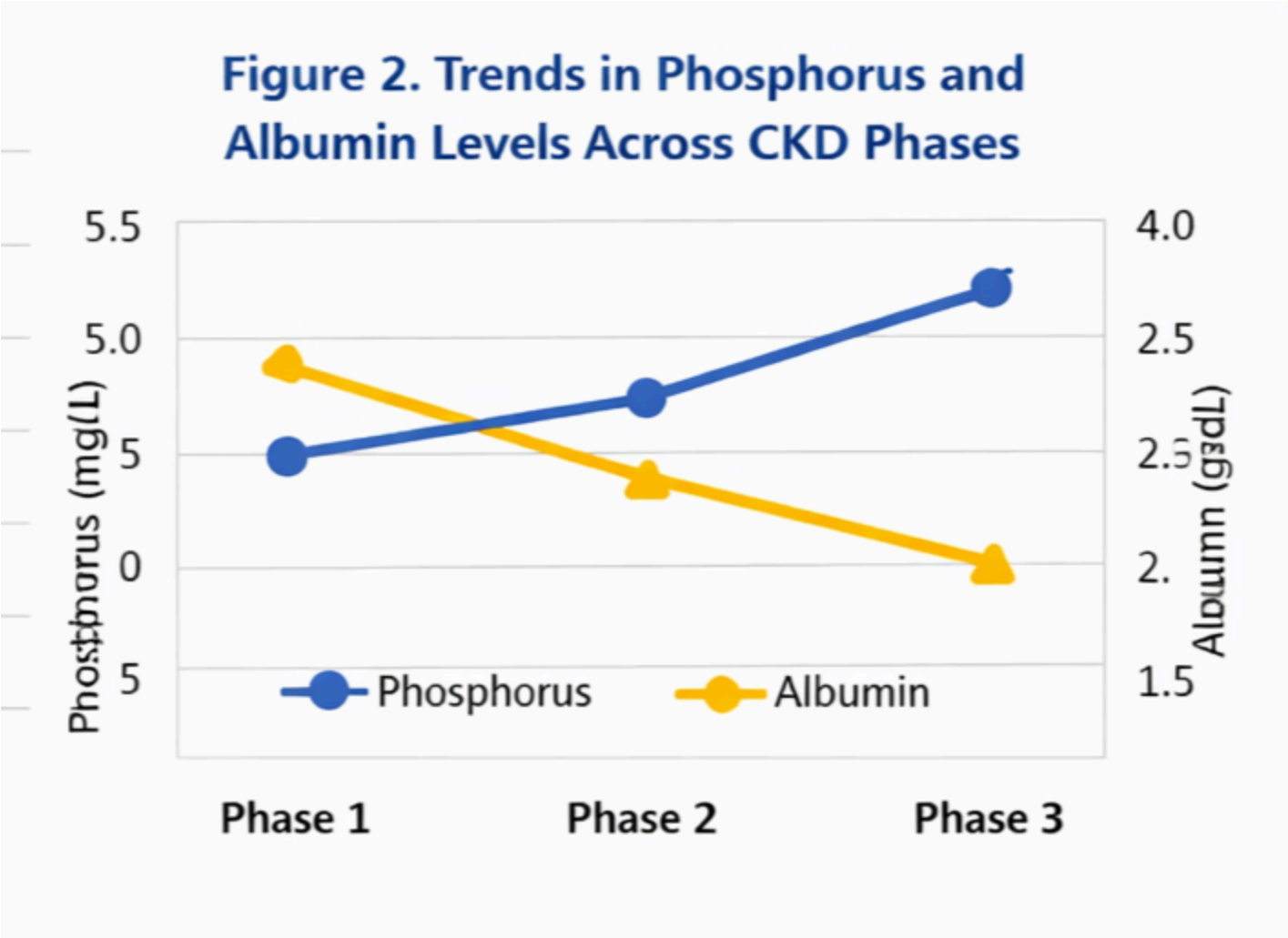


Figure 2

See image above for figure legend.

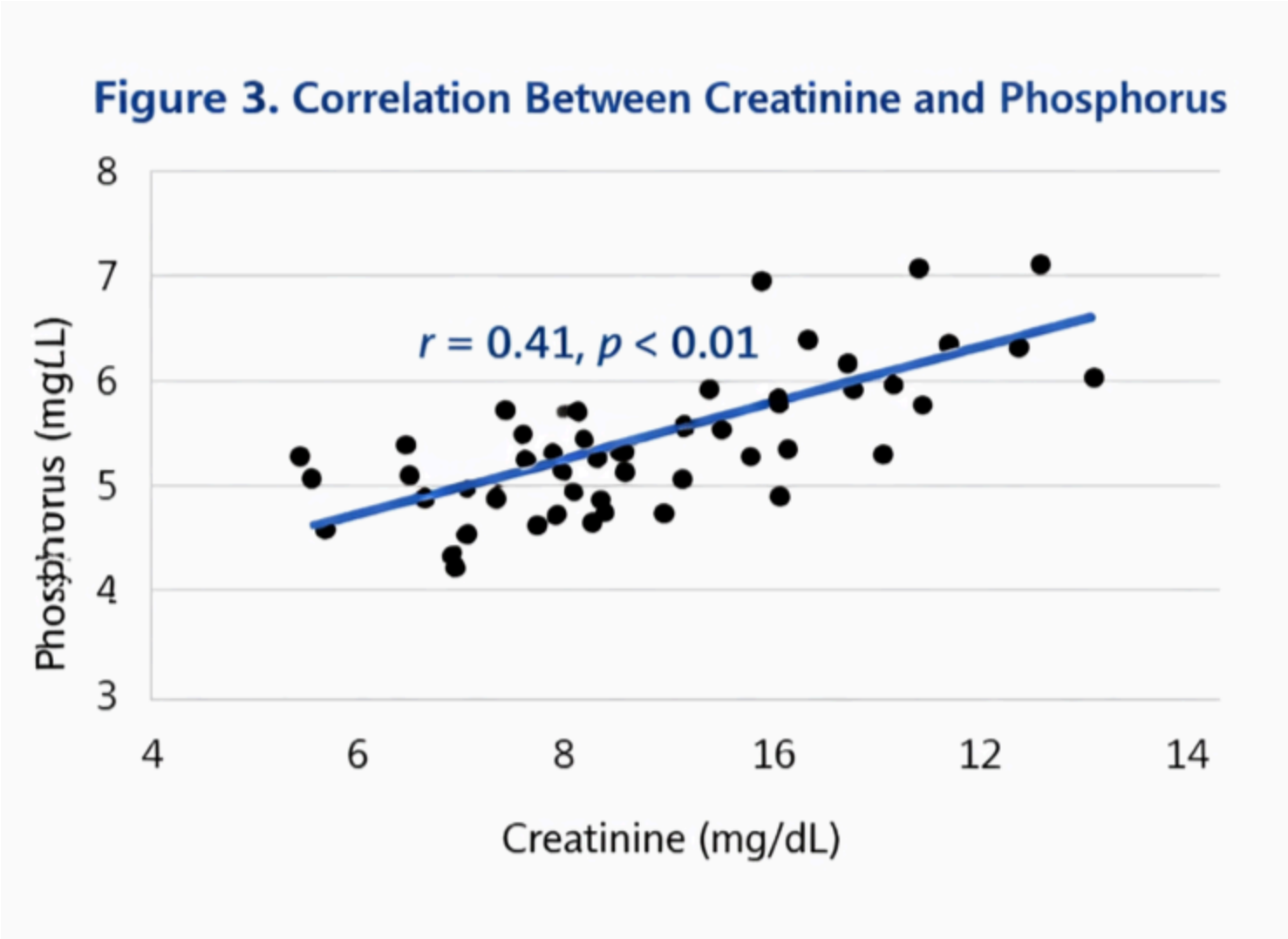


Figure 3

reveals a moderate positive correlation (r = 0.41, p < 0.01), indicating that elevated phosphorus levels are directly associated with worsening renal function.

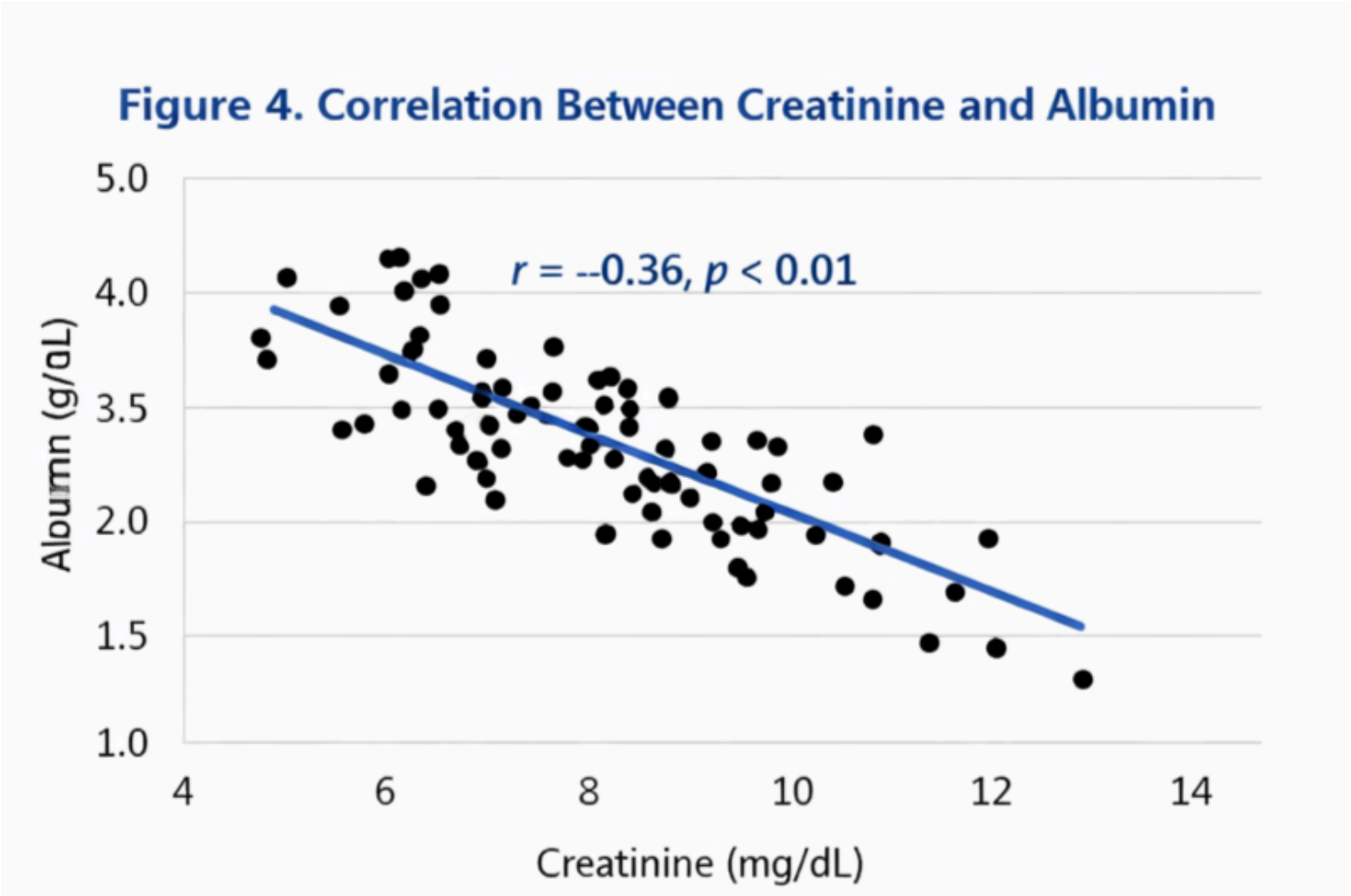


Figure 4

illustrates the correlation between serum creatinine and albumin levels in CKD patients.