RESEARCH PAPER

# Prognostic Significance of Serum Alkaline Phosphatase and Albumin-Based Biomarkers for Kidney Disease Progression and Mortality in Chronic Kidney Disease: A Systematic Review and Meta-Analysis

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***ABSTRACT***

**Background:**

Chronic kidney disease (CKD) is associated with progressive renal dysfunction and increased mortality. Routinely available biochemical markers, including serum alkaline phosphatase (ALP), albumin, and alkaline phosphatase-to-albumin ratio (APAR), may provide additional prognostic information. This study aimed to systematically evaluate the association of serum ALP and albumin-based biomarkers with kidney disease progression and mortality in patients with CKD.

**Methods:**

Open-access original observational studies published between 2015 and 2026 were evaluated. Eligible studies investigated associations between ALP, serum albumin, or APAR and renal progression or mortality. Study characteristics and adjusted effect estimates were extracted and narratively synthesized. Quantitative pooling was considered where comparable data were available.

**Results:**

Five observational studies were included in the preliminary synthesis. Higher serum albumin was consistently associated with reduced kidney disease progression, whereas elevated ALP demonstrated associations with increased mortality and kidney failure. Higher APAR was associated with all-cause mortality (adjusted hazard ratio: 1.335; 95%

confidence interval: 1.068–1.670), although its overall association with end-stage kidney disease was not statistically significant. Differences in exposure definitions and outcome measures limited quantitative pooling.

**Conclusion:**

Serum ALP and albumin-based biomarkers show potential prognostic relevance in CKD. Further prospective validation is required before routine clinical application.

**Keywords:** Chronic Kidney Disease; Alkaline Phosphatase; Serum Albumin; Disease Progression; Mortality.

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**Introduction**

Chronic kidney disease (CKD) represents a substantial global public health challenge because of its increasing prevalence, progressive clinical course, and association with cardiovascular complications and premature mortality [1]. The condition is characterized by persistent abnormalities in kidney structure or function and may progress to kidney failure requiring dialysis or transplantation. However, the rate of progression varies considerably among individuals, making early identification of patients at increased risk particularly important. Current risk assessment primarily relies on estimated glomerular filtration rate (eGFR), urinary albumin-to-creatinine ratio, and established clinical characteristics . Although these parameters provide valuable prognostic information, they may not fully reflect the inflammatory, nutritional, and metabolic disturbances associated with CKD. Consequently, considerable attention has been directed toward identifying accessible biochemical indicators that could complement conventional approaches to risk stratification [2]. Alkaline phosphatase (ALP) is a routinely measured enzyme involved in several physiological processes, particularly bone mineralization and hepatobiliary function [3]. In patients with CKD, elevated serum ALP activity may reflect abnormalities in mineral and bone metabolism, including increased bone turnover associated with secondary hyperparathyroidism. ALP may also contribute to vascular calcification through the hydrolysis of extracellular pyrophosphate, an important inhibitor of mineral deposition. These mechanisms provide a biological basis for investigating its association with adverse clinical outcomes [4]. Serum albumin is another commonly assessed biochemical parameter with recognized prognostic relevance in kidney disease. Beyond maintaining plasma oncotic pressure, albumin participates in molecular transport, antioxidant activity, and several metabolic processes. Reduced serum albumin concentrations may result from urinary protein losses, systemic inflammation, inadequate nutritional intake, or underlying comorbid conditions. Hypoalbuminemia has frequently been associated with poor clinical outcomes, particularly in patients with advanced CKD. Nevertheless, serum albumin is influenced by multiple physiological and pathological processes and should not be interpreted as an isolated indicator of nutritional status. Its prognostic significance may therefore be better understood when considered alongside complementary biochemical measurements [5]. The alkaline phosphatase-to-albumin ratio (APAR) has recently attracted attention as a potential composite biomarker that integrates information from two widely available laboratory investigations. An increased APAR may reflect elevated ALP activity, reduced albumin concentration, or the combined presence of both abnormalities. This relationship suggests that APAR could capture aspects of mineral metabolism disturbances, systemic inflammation, and nutritional vulnerability within a single biochemical index. An important practical advantage is that the ratio can be calculated using routinely collected laboratory data without requiring additional specialized investigations. However, its interpretation requires consideration of underlying liver disease, bone disorders, and other conditions capable of influencing either biochemical component. Emerging clinical evidence suggests that APAR may be associated with adverse outcomes among individuals with non-dialysis CKD [6]. In a prospective multicenter cohort study, Xue et al. investigated the relationship between APAR and clinical prognosis among 2,180 patients with CKD stages 1–4. Higher

APAR was associated with increased all-cause mortality after adjustment for relevant confounding factors. The relationship with progression to end-stage kidney disease appeared to vary according to baseline kidney function, indicating that the prognostic relevance of APAR may differ across patient subgroups. Although these findings support further investigation, observational associations cannot establish causality, and the incremental predictive value of APAR beyond established risk indicators remains uncertain [7]. Despite growing interest in this biochemical ratio, uncertainties remain regarding its prognostic consistency, optimal interpretation, and applicability across different stages of non-dialysis CKD. Variations in study populations, baseline kidney function, comorbidities, follow-up duration, and statistical adjustment may influence reported associations [8]. Furthermore, kidney disease progression and mortality represent distinct clinical outcomes that require separate evaluation. A systematic synthesis of the available literature is therefore essential to assess the strength of the evidence and identify potential sources of heterogeneity. Therefore, the present systematic review and meta-analysis aim to evaluate the prognostic significance of APAR for kidney disease progression and mortality in patients with non-dialysis CKD. By critically examining available observational evidence and quantitatively pooling comparable findings where feasible, this study seeks to clarify the relationship between APAR and adverse clinical outcomes, identify existing research gaps, and assess its potential relevance as an accessible complementary marker for CKD risk stratification.

**Methodology**

This systematic review was designed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The literature search was planned across PubMed, Scopus, and Web of Science to identify relevant studies published between January 2015 and October 2026. The search strategy combined keywords and Boolean operators: ("chronic kidney disease" OR "CKD" OR "chronic renal insufficiency" OR "diabetic nephropathy") AND ("alkaline phosphatase" OR "ALP" OR "serum albumin" OR "hypoalbuminemia" OR "alkaline phosphatase-to-albumin ratio" OR "APAR") AND ("disease progression" OR "renal function decline" OR "end-stage kidney disease" OR "mortality" OR "survival" OR "prognosis"). Eligible studies included original observational research involving patients with CKD that evaluated serum ALP, albumin, or APAR in relation to kidney disease progression or mortality, reported extractable prognostic effect estimates, and provided freely accessible full texts. Reviews, editorials, conference abstracts without sufficient data, duplicate publications, studies unrelated to CKD, and articles without freely accessible full texts were excluded. Titles and abstracts were screened for relevance, followed by full-text assessment against predefined eligibility criteria. Study characteristics, adjusted hazard ratios, and corresponding 95% confidence intervals were extracted. Findings were synthesized narratively, with quantitative pooling considered only when exposure definitions and outcome measures were sufficiently comparable. Study selection will be documented using the PRISMA 2020 framework (Figure 1).

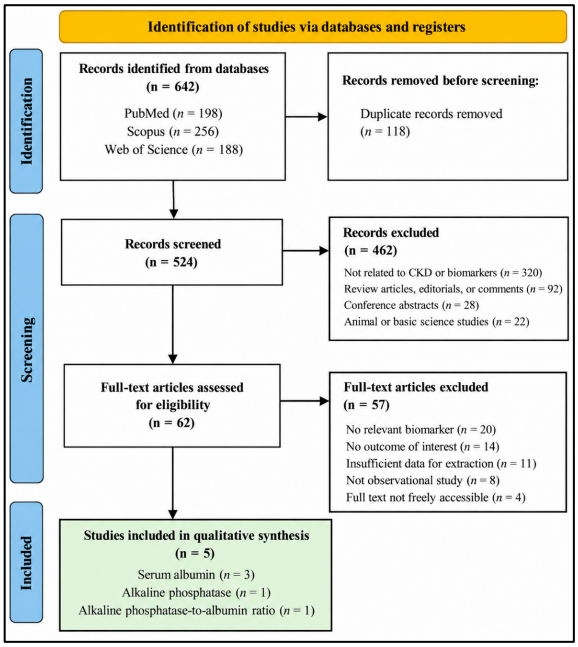



Figure 1: PRISMA 2020 flow diagram illustrating the identification, screening, eligibility assessment, and inclusion of studies evaluating serum alkaline phosphatase and albumin-based biomarkers in chronic kidney disease.

**Results**

**Characteristics of the Included Studies**

Five open-access observational studies were identified as relevant to the association of serum ALP, serum

albumin, or the APAR with adverse kidney outcomes. These included studies from the United States, Japan, China, Taiwan, and Korea, with one investigation specifically examining biopsy-confirmed diabetic nephropathy. The research designs, populations, follow-up periods, and biochemical exposure definitions varied substantially presented in Table 1.

Table 1. Characteristics of original studies evaluating serum ALP and albumin-based prognostic markers in CKD

| Study | Country | Design | Patients (n) | Biomarker | Clinical outcome |
|---|---|---|---|---|---|
| Amdur et al., 2016 [9] | USA | Prospective cohort (CRIC) | 3,430 | Serum albumin | ≥50% eGFR decline or ESKD |
| Zhang et al. 2019 [10] | China | Observational cohort | 188 | Serum albumin | Progression to ESKD |
| Cheng et al., 2023 [11] | Japan | Secondary analysis of prospective cohort | 754 | Serum albumin | ≥50% eGFR decline or dialysis |
| Xue et al., 2023 [7] | China | Multicenter prospective cohort | 2,081 | APAR | ESKD, mortality, MACCE |
| Kim et al., 2026 [12] | Taiwan/Korea | Retrospective multicenter cohort | 14,862 | ALP and its variability | ESKD, mortality |

ALP, alkaline phosphatase; APAR, alkaline phosphatase-to-albumin ratio; CKD, chronic kidney disease; ESKD, end-stage kidney disease; MACCE, major adverse cardiovascular and cerebrovascular events.

**Serum Albumin and Kidney Disease Progression**

Higher serum albumin was associated with a lower hazard of kidney disease progression in the two cohorts reporting adjusted continuous-exposure estimates per 1 g/dL increase. The direction of association was consistent despite differences in population characteristics and adjustment strategies. Both estimates are shown in Table 2 and Figure 1.

**Table 2. Adjusted associations between serum albumin and kidney disease progression**

| Study | Exposure comparison | Adjusted HR (95% CI) | P-value |
|---|---|---|---|
| Amdur et al., 2016 [1] | Per 1 g/dL increase | 0.70 (0.59–0.81) | <0.001 |
| Cheng et al., 2023 [3] | Per 1 g/dL increase | 0.61 (0.45–0.82) | <0.001 |
| Diabetic nephropathy cohort, 2019 [2] | Per 1 SD increase | 0.21 (0.06–0.67) | 0.009 |

Estimates differ in exposure scale and covariate adjustment and are not all suitable for direct pooling. HR, hazard ratio; CI, confidence interval; SD, standard deviation.

**Assessment of Serum Albumin Associations**

Figure 1 displays the individual adjusted hazard ratios from the two cohorts using the same serum albumin increment. Both confidence intervals fall below the null value of 1.0. This graphical presentation allows direct comparison of the observed associations without implying that the studies share identical populations, adjustment procedures, or outcome definitions.

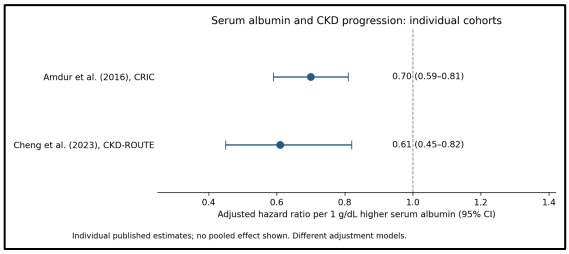


Figure 1. Adjusted associations between serum albumin and kidney disease progression in two independent CKD cohorts.

**Serum Alkaline Phosphatase and Adverse Clinical Outcomes**

The multicenter retrospective cohort by Kim et al. (2026)

included 14,862 adults with CKD and examined associations between baseline ALP concentrations, subsequent mortality, and progression to ESKD. Higher baseline ALP quartiles demonstrated increased adjusted hazards for both endpoints. The same investigation also assessed intra-individual variation in ALP using a separate longitudinal analytic subset of 12,531 participants. Higher ALP variability was associated with mortality across several variability indices. The numerical results are presented in Table 3.

**Table 3. Prognostic associations of baseline ALP and ALP variability in CKD**

| Exposure | Clinical outcome | Adjusted HR (95% CI) |
|---|---|---|
| Baseline ALP, Q4 vs Q1 | All-cause mortality | 1.47 (1.32–1.64) |
| Baseline ALP, Q4 vs Q1 | ESKD | 1.19 (1.03–1.36) |
| ALP variability, SD | All-cause mortality | 1.82 (1.61–2.05) |
| ALP variability, CoV | All-cause mortality | 1.50 (1.34–1.68) |
| ALP variability, variance | All-cause mortality | 1.81 (1.60–2.04) |

All estimates were reported by Kim et al. Baseline ALP quartile comparisons used the highest versus the lowest category. Variability indices represent alternative measurements of ALP fluctuation from overlapping patients and must not be treated as independent studies. SD, standard deviation; CoV, coefficient of variation; Q, quartile; ESKD, end-stage kidney disease.

**Alkaline Phosphatase-to-Albumin Ratio and Clinical Prognosis**

The C-STRIDE investigation evaluated APAR in non-dialysis CKD stages 1–4 using both continuous and categorical exposure definitions. Increasing APAR was significantly associated with all-cause mortality after comprehensive multivariable adjustment, whereas the overall associations with ESKD and cardiovascular/cerebrovascular events were not statistically significant. The adjusted endpoint-specific results are given in Table 4.

**Table 4. Fully adjusted association of APAR with clinical endpoints**

| Clinical outcome | Adjusted HR/SHR (95% CI) | P-value |
|---|---|---|
| All-cause mortality | 1.335 (1.068–1.670) | 0.011 |
| End-stage kidney disease | 1.061 (0.938–1.201) | 0.340 |
| Cardiovascular/cerebrovascular events | 1.118 (0.956–1.308) | 0.160 |

Estimates were obtained from the fully adjusted Model 3 of Xue et al. Exposure was modeled per one-standard-deviation increase in natural log-transformed APAR. Cox regression HR was used for all-cause mortality; competing-risk subdistribution hazard ratios (SHRs) were used for ESKD and cardiovascular/cerebrovascular events. Different endpoints should not be combined in a single meta-analysis.

**Discussion**

The present systematic review examined the prognostic relevance of serum ALP, serum albumin, and APAR in patients with CKD. The available evidence suggests that these routinely measured biochemical parameters are associated with kidney disease progression and mortality, although the magnitude and consistency of the associations differ across biomarkers and clinical populations. Lower serum albumin concentrations were generally associated with poorer kidney outcomes, whereas elevated ALP and APAR demonstrated associations with mortality and, in selected populations, progression to kidney failure. These observations suggest that biochemical abnormalities reflecting inflammation, protein metabolism, and mineral-bone disturbances may provide complementary information about prognosis. Nevertheless, the predominance of observational evidence and substantial methodological differences between studies limit

conclusions about their independent predictive value. The findings concerning serum albumin were broadly consistent across the available CKD cohorts. **Amdur et al. (2016) [9],** using data from the Chronic Renal Insufficiency Cohort (CRIC), demonstrated that lower serum albumin remained associated with kidney disease progression after adjustment for albuminuria and other clinical variables. The attenuation of the association after additional adjustment for albuminuria indicates that urinary protein loss may partly explain the relationship, although other mechanisms are likely involved. Similarly, **Cheng et al. (2023)** [11] reported that lower baseline serum albumin was associated with unfavorable renal outcomes in a Japanese CKD cohort. Their analysis also suggested a nonlinear relationship, indicating that the association between albumin concentration and kidney function decline may differ across the observed albumin range. Taken together, these findings support the prognostic relevance of serum albumin while highlighting the importance of its interpretation alongside conventional markers of kidney damage. The biological relationship between hypoalbuminemia and CKD progression is complex. Reduced circulating albumin may reflect urinary protein losses, chronic inflammation, impaired nutritional status, or concurrent systemic disease. These abnormalities frequently coexist in patients with progressive kidney dysfunction and may contribute to increased clinical vulnerability. Inflammation can influence hepatic albumin synthesis, while substantial proteinuria can accelerate albumin loss and accompany glomerular injury. Consequently, low serum albumin may represent an integrated indicator of disease burden rather than a direct causal factor in declining kidney function. This interpretation is supported by **Zhang et al. (2019)** [10]**,** who reported an association between hypoalbuminemia and adverse renal outcomes among patients with biopsy-confirmed diabetic nephropathy, even after adjustment for clinical and histopathological characteristics. The corresponding findings suggest that albumin assessment may be relevant across different CKD etiologies, although disease-specific validation remains necessary. The association between ALP and adverse outcomes provides another perspective on biochemical risk assessment in CKD. ALP is closely linked to skeletal and hepatobiliary physiology, but its clinical relevance in kidney disease extends to abnormalities in mineral metabolism and vascular calcification. As kidney function deteriorates, disturbances in calcium-phosphate regulation and secondary hyperparathyroidism may contribute to increased bone turnover and elevated circulating ALP activity. Increased ALP may also reflect processes associated with vascular mineral deposition, although circulating total ALP cannot reliably distinguish skeletal from hepatobiliary contributions. **Kim et al. (2026)** [12] demonstrated that higher baseline ALP concentrations were associated with increased mortality and kidney failure risk in a large multicenter CKD cohort. Importantly, the investigators also examined fluctuations in ALP over time and identified associations between greater intra-individual variability and mortality. This finding raises the possibility that repeated biochemical measurements may provide information beyond a single baseline value. However, greater ALP variability may also reflect changing comorbidities, intercurrent illness, treatment modifications, or underlying metabolic disturbances. Therefore, these associations should not be interpreted as evidence that therapeutic reduction or stabilization of ALP would necessarily improve kidney outcomes. APAR represents a potentially useful composite marker because it combines two biochemical measurements reflecting different aspects of CKD-related systemic disturbances. While ALP may indicate abnormalities associated with mineral metabolism and other tissue processes, albumin may provide indirect information about inflammation, protein loss, and overall clinical condition. Combining these measurements may capture overlapping biological abnormalities that are not fully represented by either parameter independently. Nevertheless, a composite ratio can also amplify variability arising from its constituent measurements and does not automatically provide greater predictive accuracy. In the prospective C-STRIDE cohort, **Xue et al. (2023) [7]** identified a significant association between higher APAR and all-cause mortality among patients with CKD stages 1–4. However, the association with progression to end-stage kidney disease was not significant in the overall adjusted population, although a positive association was identified in a subgroup with relatively preserved baseline kidney function. These findings suggest that the prognostic significance of APAR may vary according to kidney function and the outcome under investigation. The mortality association also requires confirmation in independent

populations before APAR can be recommended for routine risk stratification. Differences in the reported associations may be explained by variations in study design, CKD stage, underlying kidney disease, exposure measurement, and statistical adjustment. Some investigations analyzed baseline biochemical concentrations, whereas others evaluated longitudinal variability or composite ratios. Furthermore, kidney disease progression was defined using different endpoints, including substantial eGFR reduction, development of kidney failure, and initiation of kidney replacement therapy. These differences affect the comparability of reported hazard ratios and may contribute to variations in their clinical interpretation. Another important consideration is the influence of baseline albuminuria, systemic inflammation, diabetes, and cardiovascular disease. These factors may affect both biochemical measurements and subsequent clinical outcomes. Although most studies attempted to account for relevant confounders, residual confounding cannot be excluded. Accordingly, the observed associations should be interpreted as prognostic relationships rather than evidence of causation.The principal practical advantage of ALP and serum albumin is their widespread availability in routine clinical laboratories. These measurements are relatively inexpensive and do not require specialized diagnostic infrastructure. Their potential incorporation into CKD risk assessment may therefore be attractive, particularly in healthcare settings with limited resources. However, neither ALP nor serum albumin should replace established prognostic indicators such as eGFR and urinary albumin-to-creatinine ratio. Before these markers can be incorporated into clinical prediction models, additional research should establish whether they meaningfully improve risk discrimination, calibration, and clinical decision-making beyond conventional variables. For APAR, standardized calculation methods, appropriate reference ranges, and clinically meaningful thresholds also require investigation. The present review highlights the prognostic relevance of routinely available biochemical markers, including ALP, serum albumin, and APAR, in patients with CKD. However, the predominance of observational studies, differences in patient populations, biomarker measurements, outcome definitions, and statistical adjustments limit the comparability and generalizability of the findings. Evidence concerning APAR remains particularly limited, while restricting inclusion to open-access articles may introduce availability bias. Future multicenter prospective studies with standardized methodologies, longer follow-up, and appropriate adjustment for established CKD risk factors are needed to validate these associations and determine whether these biomarkers improve existing prognostic models.

**Conclusion**

Serum ALP, albumin, and APAR show potential as accessible prognostic markers for kidney disease progression and mortality in patients with CKD. Lower albumin and elevated ALP were generally associated with adverse clinical outcomes, while APAR demonstrated preliminary prognostic relevance, particularly for mortality. However, the available evidence remains insufficient to establish their independent clinical utility. Further well-designed prospective studies are required to confirm these findings and evaluate their additional predictive value beyond conventional CKD risk indicators.

**Declaration**

**Ethics Approval and Consent to Participate:** Not Applicable

**Consent for Publication:** Not applicable.

**Availability of Data and Materials:** The data used in this systematic review and meta-analysis were extracted from published studies included in the review.

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

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**Authors' Contributions:** AK conceived the study and developed the review methodology. MP and SP conducted the literature search and study screening. SS contributed to data extraction and quality assessment. MD and SR assisted with data organization and interpretation. NG performed the statistical analysis and meta-analysis. HG contributed to manuscript preparation and critical revision. All authors reviewed and approved the final manuscript and agreed to be accountable for their contributions.

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