

Serum Zinc Concentration and Its Association With Nutritional Status in Hemodialysis Patients: A Cross-Sectional Study

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Abstract

Background: Serum zinc concentrations are frequently reduced in patients with end-stage kidney disease receiving maintenance hemodialysis (MHD), but their association with nutritional status remains unclear. This study primarily examined the relationship between predialysis serum zinc and 7-point Subjective Global Assessment (SGA) scores, with secondary analyses exploring clinical and biochemical correlations and factors associated with serum zinc <60 µg/dL.

Methods: This analytical cross-sectional study enrolled 73 adults receiving MHD at a tertiary-care teaching hospital from January to March 2026. Nutritional status was evaluated using the 7-point SGA, and serum zinc was measured in midweek predialysis blood samples. Associations with nutritional, clinical, and biochemical parameters were examined using Spearman's correlation, while factors associated with low serum zinc (<60 µg/dL) were explored using univariable logistic regression.

Results: The mean age was 43.62 ± 15.51 years, and 34 patients (46.6%) were females. The mean serum zinc concentration was 51.20 ± 12.61 µg/dL, and 63 patients (86.3%) had low serum zinc (<60 µg/dL). Based on SGA scores, 18 patients (24.7%) were well nourished, 53 (72.6%) had mild-to-moderate malnutrition, and two (2.7%) had severe malnutrition. Serum zinc concentrations did not differ significantly across nutritional status groups ($p = 0.243$), though the small severe-malnutrition group limited interpretation. Serum zinc was not significantly correlated with SGA score (Spearman's $\rho = -0.177$; $p = 0.135$), albumin, high-sensitivity C-reactive protein (hs-CRP), BMI, hemoglobin, or dialysis vintage. The correlation between zinc and albumin-corrected calcium was nominally significant ($p = 0.255$; $p = 0.029$) but did not meet the Bonferroni-adjusted significance threshold ($p < 0.0038$). No variables were significantly associated with low serum zinc (<60 µg/dL) in univariable logistic regression.

Conclusions: Low serum zinc concentration (<60 µg/dL) was common, but serum zinc was not significantly associated with SGA-defined nutritional status in this cohort. Future larger studies using standardized zinc sampling and reproducible nutritional assessment methods are needed to determine the association between nutritional status and serum zinc concentrations.

Categories: Nutrition, Internal Medicine, Nephrology

Keywords: hemodialysis, malnutrition, protein-energy wasting, subjective global assessment, trace elements, zinc

Introduction

Protein-energy wasting is common in patients receiving maintenance hemodialysis (MHD) due to reduced dietary intake, uremic symptoms, inflammation, metabolic acidosis, hormonal disturbances, comorbidities, and dialysis-related nutrient losses [1]. It is associated with impaired physical function, increased susceptibility to infection, reduced quality of life, hospitalization, cardiovascular events, and mortality [2]. Clinical assessment in dialysis patients should integrate dietary history, anthropometry, biochemical parameters, and validated composite tools to characterize nutritional status adequately. The 7-point Subjective Global Assessment (SGA) is a practical instrument to evaluate protein-energy wasting and nutritional status. Studies have demonstrated its validity and reproducibility in the MHD population, and the 2020 Kidney Disease Outcomes Quality Initiative (KDOQI) Clinical Practice Guideline for Nutrition in Chronic Kidney Disease (CKD) recommends it for nutritional assessment in adult patients on dialysis [3-5].

Zinc is an essential trace element involved in protein and nucleic-acid synthesis, immune function, antioxidant defense, wound healing, appetite, and taste perception [6]. Patients with CKD may develop low circulating zinc because of dietary restrictions, anorexia, impaired absorption, inflammation-related redistribution, altered protein binding, medication interactions, and dialysis-associated losses [7]. A systematic review and meta-analysis found lower serum zinc concentrations in both CKD and hemodialysis

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populations than in healthy controls [8].

Serum or plasma zinc is the most widely accepted biomarker for population-level assessment [6,9]. Low serum zinc has been linked to adverse nutritional and body-composition profiles in some hemodialysis cohorts [10,11]. However, serum zinc is influenced by inflammation, albumin, food intake, diurnal variation, hydration status, specimen processing, and contamination, and may therefore not reliably reflect total-body zinc stores [6,9]. Evidence that zinc supplementation improves clinical outcomes remains limited, whereas prolonged supplementation may impair copper absorption and lead to copper-deficiency anemia or neurological complications [12,13].

Despite the recognized importance of nutritional assessment in MHD patients, data on the association between serum zinc and 7-point SGA are limited, particularly in Indian hemodialysis populations. Therefore, this study was conducted at a tertiary-care teaching hospital in northern India to assess the association between predialysis serum zinc concentration and 7-point SGA score. Secondary objectives were to examine correlations of serum zinc with anthropometric, inflammatory, hematological, and mineral-bone parameters and to explore factors associated with low serum zinc concentration (<60 µg/dL).

Materials And Methods

Study design and setting

This analytical cross-sectional study was conducted in the hemodialysis unit of a tertiary-care teaching hospital in Varanasi, northern India, from January to March 2026.

Study population

Adults aged ≥18 years with end-stage kidney disease who had received MHD for at least three months on a stable schedule of two or three four-hour sessions per week were eligible. All eligible patients who provided informed consent during the predefined study period were included.

Exclusion criteria were acute infection at the time of assessment, major surgery, hospitalization or blood transfusion during the preceding four weeks, active malignancy, chronic liver disease, current zinc supplementation or use of zinc-containing nutritional preparations, and inability to complete nutritional assessment.

Nutritional assessment

Nutritional status was assessed using the 7-point SGA [14–16]. The 7-point SGA is a validated, public-domain clinical instrument that evaluates six core parameters: weight change, dietary intake, gastrointestinal symptoms, functional capacity, subcutaneous fat loss, and muscle wasting. Assessments were performed by two trained co-authors under the supervision of the first author to standardize assessment procedures and minimize variability. Both assessors were blinded to the patients' serum zinc levels at the time of assessment to reduce potential assessment bias. Each patient was assigned an overall SGA score from 1 to 7; scores of 6–7 denoted well-nourished status (category A), 3–5 mild-to-moderate malnutrition (category B), and 1–2 severe malnutrition (category C).

Clinical, demographic, and laboratory variables

Clinical and demographic data, including age, sex, weight, height, BMI, mid-upper-arm circumference (MUAC), and triceps skinfold thickness, comorbidities such as diabetes mellitus, hypothyroidism, cerebrovascular accident, and coronary artery disease, dialysis vintage, and frequency of hemodialysis, were recorded. Routine laboratory investigations were performed on a single day at regular intervals according to institutional protocol. Hemoglobin, serum albumin, total cholesterol, total calcium, phosphorus, alkaline phosphatase, intact parathyroid hormone (iPTH), and 25-hydroxyvitamin D values were retrieved from medical records. Total serum calcium was adjusted for albumin using the standard Payne formula.

Venous blood was collected immediately before a midweek hemodialysis session to measure serum zinc and high-sensitivity C-reactive protein (hs-CRP). Fasting status, recent dietary intake, and sampling time were not standardized, and hydration status was not formally assessed. Hemolyzed specimens were excluded from analysis, and fresh samples were collected for repeat testing.

Serum zinc was quantified in duplicate using a PerkinElmer PinAAcle 900T graphite furnace atomic absorption spectrophotometer (AAS) (Shelton, USA) with a zinc-specific Lumina hollow cathode lamp and deuterium background correction. Serum samples (200 µL) were diluted with 800 µL of 2% HNO₃ containing 0.4% Triton X-100 UltraPure. Nitric acid rinsing and acid-cleaned laboratory ware were used to minimize carryover and cross-contamination. Calibration was performed using zinc standards of 20, 40, 60, and 80 µg/dL prepared from a 1,000 µg/mL stock solution. Serum zinc concentrations were determined from the calibration curve. hs-CRP was measured using a Human CRP Enzyme-Linked Immunosorbent Assay (ELISA) kit (ELK Biotechnology; Cat. No. ELK1040), with absorbance read on a BioTek Epoch 2 microplate

spectrophotometer and concentrations calculated from standard curves.

According to Japanese Society of Clinical Nutrition guidelines, serum zinc concentrations are classified as deficient (<60 µg/dL), marginally deficient (60–<80 µg/dL), or normal (≥80 µg/dL) [17,18]. As these thresholds have not been validated in Indian hemodialysis populations and serum zinc is influenced by inflammation, albumin, recent food intake, collection time, sex, and preanalytical factors [6,9], these categories were interpreted as indicators of biochemical zinc status rather than definitive clinical deficiency. Serum zinc was therefore also analyzed as a continuous variable.

Ethical considerations

The Institutional Ethics Committee of the Institute of Medical Sciences, Banaras Hindu University, Varanasi, approved the study (Ref: IMS/IEC/2025/8184), and it was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all patients before enrollment. Patient confidentiality was maintained throughout the study.

Statistical analysis

All statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) software, version 29. Continuous variables were summarized as mean ± SD or median (interquartile range (IQR)), according to data distribution, and categorical variables as frequencies and percentages. Serum zinc concentrations were compared across SGA-defined nutritional categories using the Kruskal-Wallis test, given the small and markedly unequal group sizes. Associations between serum zinc concentrations and SGA score, clinical parameters, and biochemical parameters were evaluated using Spearman's rank correlation coefficient. A 95% bias-corrected and accelerated (BCa) bootstrap confidence interval (CI) was calculated for the correlation between serum zinc concentration and SGA score using 5,000 bootstrap samples. To account for multiple comparisons, a Bonferroni-adjusted significance threshold of $p < 0.0038$ was applied to the 13 correlation analyses. Univariable binary logistic regression was performed to explore factors associated with serum zinc concentrations <60 µg/dL, with results expressed as odds ratios (ORs) and corresponding 95% CIs. Multivariable logistic regression was not performed because only 10 participants had serum zinc concentrations ≥60 µg/dL, resulting in sparse outcome data and an increased risk of unstable adjusted estimates. All statistical tests were two-tailed, and $p < 0.05$ was considered statistically significant, except for correlation analyses, for which the Bonferroni-adjusted significance threshold was applied.

Results

Baseline characteristics

The study included 73 adult patients on MHD. The baseline characteristics of all patients are summarized in Table 1. The mean age was 43.62 ± 15.51 years, and 34 (46.6%) participants were female. Diabetes mellitus was present in 17 (23.3%) patients, hypertension in 35 (47.9%), and hypothyroidism in one (1.4%). The median dialysis vintage was 24 months (IQR 14–37).

Characteristic	Value
Age, years, mean $\pm$ SD	43.62 $\pm$ 15.51
Female sex, n (%)	34 (46.6%)
Weight, kg, mean $\pm$ SD	54.45 $\pm$ 9.78
Height, cm, mean $\pm$ SD	162.30 $\pm$ 9.22
BMI, kg/m ² , mean $\pm$ SD	20.57 $\pm$ 3.01
MUAC, cm, mean $\pm$ SD	24.66 $\pm$ 2.01
Triceps fold thickness, mm, mean $\pm$ SD	10.38 $\pm$ 2.56
Hypertension, n (%)	35 (47.9%)
Diabetes mellitus, n (%)	17 (23.3%)
Hypothyroidism, n (%)	1 (1.4%)
Dialysis vintage, months, median (IQR)	24 (14-37)
Serum zinc, μ g/dL, mean $\pm$ SD	51.20 $\pm$ 12.61
Hemoglobin, g/dL, median (IQR)	9.2 (8.5-10.8)
Serum albumin, g/dL, mean $\pm$ SD	3.28 $\pm$ 0.43
Total serum cholesterol, mg/dL, mean $\pm$ SD	144.21 $\pm$ 40.15
hs-CRP, mg/L, mean $\pm$ SD	0.005 $\pm$ 0.001
Corrected serum calcium, mg/dL, mean $\pm$ SD	8.77 $\pm$ 1.08
Serum phosphorus, mg/dL, mean $\pm$ SD	4.96 $\pm$ 1.45
Alkaline phosphatase, U/L, median (IQR)	134 (98.5-210.3)
Parathyroid hormone, pg/mL, median (IQR)	430 (194.25-707)
25-hydroxyvitamin D, ng/mL, median (IQR)	32.7 (20.5-47.1)

TABLE 1: Baseline characteristics of patients (n=73)

hs-CRP: High-sensitivity C-reactive protein; IQR: Interquartile range; MUAC: Mid-upper-arm circumference

The mean BMI was 20.57 $\pm$ 3.01 kg/m², the mean MUAC was 24.66 $\pm$ 2.01 cm, and the mean triceps fold thickness was 10.38 $\pm$ 2.56 mm. The mean serum zinc was 51.20 $\pm$ 12.61 μ g/dL. Serum zinc concentrations were <60 μ g/dL in 63 (86.3%), 60 to <80 μ g/dL in 9 (12.3%), and $\geq$ 80 μ g/dL in 1 (1.4%) patient. The mean serum albumin was 3.28 $\pm$ 0.43 g/dL, while the mean hs-CRP was 0.005 $\pm$ 0.001 mg/L.

Nutritional status and serum zinc

According to SGA classification, 18 patients (24.7%) were well nourished (category A), 53 (72.6%) had mild-to-moderate malnutrition (category B), and 2 (2.7%) had severe malnutrition (category C). Serum zinc concentrations did not differ significantly across the three SGA-defined nutritional-status categories (Kruskal-Wallis H = 2.827, df = 2, p = 0.243) (Table 2). This exploratory analysis should be interpreted cautiously because only two patients were classified as severely malnourished. Figure 1 displays the individual serum zinc concentrations across SGA-defined nutritional-status categories.

SGA score	Nutritional category	n (%)	Serum zinc, median (IQR) µg/dL
6-7	A - Well nourished	18 (24.7)	46.03 (41.46-57.33)
3-5	B - Mild-to-moderate malnutrition	53 (72.6)	51.43 (43.94-57.60)
1-2	C - Severe malnutrition	2 (2.7)	44.10 [#]
—	Overall	73 (100)	50.32 (42.59-56.83)

TABLE 2: Serum zinc concentration according to SGA category

#IQR not estimable

IQR: Interquartile range; SGA: Subjective Global Assessment

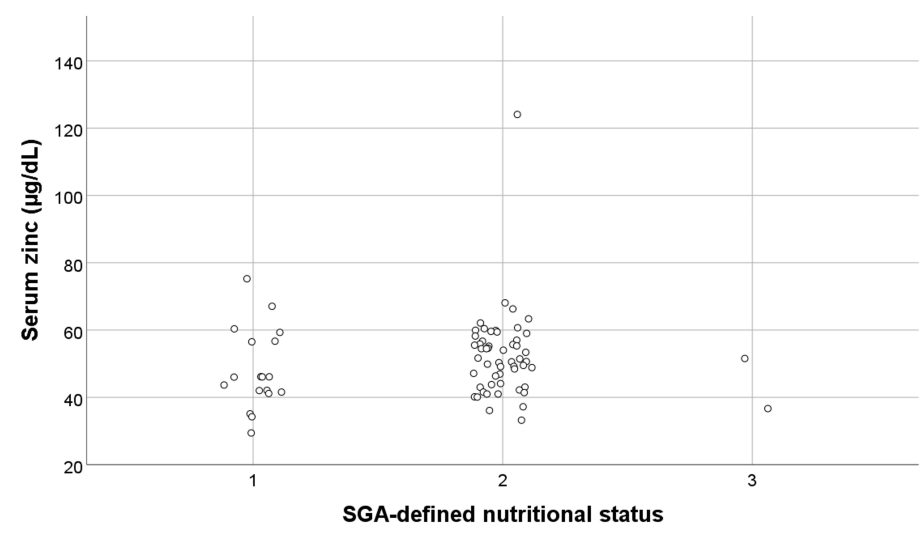


FIGURE 1: Individual serum zinc concentrations according to SGA-defined nutritional-status category

Each dot represents one patient; minor horizontal displacement was applied to visualize overlapping observations. Categories were coded as: 1, well nourished (n=18); 2, mild-to-moderate malnutrition (n=53); and 3, severe malnutrition (n=2).

SGA: Subjective Global Assessment

Correlation analysis

Serum zinc concentration was not significantly correlated with the 7-point SGA score (Spearman’s $\rho = -0.177$; 95% BCa CI -0.417 to 0.067 ; $p = 0.135$) or with serum albumin, hs-CRP, age, iPTH, total cholesterol, hemoglobin, alkaline phosphatase, phosphorus, 25-hydroxyvitamin D, BMI, or dialysis vintage. A weak positive correlation with corrected serum calcium ($\rho = 0.255$; $p = 0.029$) was nominally significant but did not meet the Bonferroni-adjusted threshold ($p < 0.0038$ for 13 comparisons), and may represent a chance finding (Table 3).

Parameter	Spearman's ρ	p-value
SGA score	-0.177	0.135
Serum albumin	-0.074	0.533
hs-CRP	0.007	0.953
Age	0.077	0.515
iPTH	-0.160	0.176
Total cholesterol	0.151	0.202
Hemoglobin	-0.043	0.719
Alkaline phosphatase	-0.027	0.820
Corrected serum calcium	0.255	0.029*
Serum phosphorus	-0.128	0.281
25-hydroxyvitamin D	0.204	0.084
BMI	-0.107	0.366
Dialysis vintage	0.128	0.279

TABLE 3: Correlation of serum zinc with clinical and biochemical parameters

*Nominal $p < 0.05$. No correlation met the Bonferroni-adjusted threshold ($p < 0.0038$ for 13 comparisons).

SGA: Subjective Global Assessment; hs-CRP: High-sensitivity C-reactive protein; iPTH: Intact parathyroid hormone

Factors associated with low serum zinc (<60 $\mu\text{g/dL}$)

No variables were significantly associated with low serum zinc concentrations (<60 $\mu\text{g/dL}$) in univariable logistic regression (Table 4). Multivariable analysis was not performed because only 10 patients had serum zinc concentrations ≥ 60 $\mu\text{g/dL}$, limiting the reliability of an adjusted model.

Variable	Unadjusted OR (95% CI)	p value
Age	0.979 (0.937-1.023)	0.348
Female sex	2.260 (0.536-9.539)	0.267
BMI	0.973 (0.784-1.207)	0.801
MUAC	1.063 (0.764-1.479)	0.715
SGA score	1.098 (0.617-1.956)	0.750
Diabetes mellitus	0.667 (0.152-2.920)	0.591
Hypertension	4.400 (0.865-22.378)	0.074
Dialysis vintage	0.984 (0.950-1.019)	0.361
Hemoglobin	1.056 (0.751-1.486)	0.753
Serum albumin	1.334 (0.285-6.257)	0.714
hs-CRP	1.000 (1.000-1.001)	0.766

TABLE 4: Univariable factors associated with low serum zinc concentration <60 µg/dL

CI: Confidence interval; hs-CRP: High-sensitivity C-reactive protein; OR: Odds ratio; SGA: Subjective Global Assessment; MUAC: Mid-upper-arm circumference

Discussion

This study found a high prevalence of low serum zinc concentrations (<60 µg/dL) among patients receiving MHD, affecting 63 of 73 patients (86.3%). The mean serum zinc concentration was 51.20 ± 12.61 µg/dL; however, serum zinc concentrations were not significantly associated with SGA category or correlated with SGA score, BMI, serum albumin, hs-CRP, hemoglobin, or dialysis vintage. The only nominally significant finding was a weak positive correlation between zinc and corrected serum calcium. Univariable logistic estimates were imprecise, and no clinical or laboratory variable was associated with low serum zinc levels <60 µg/dL.

The low zinc concentration in our cohort is consistent with the published literature. A meta-analysis of 42 studies involving 4,161 participants found lower serum zinc in both CKD and hemodialysis groups than in healthy controls [8]. In a cohort of 142 hemodialysis patients, the mean serum zinc concentration was 52.5 ± 12.5 µg/dL, with 70.4% having levels <60 µg/dL [11]. Similarly, in another hemodialysis study, all 40 patients had serum zinc <60 µg/dL, with a mean concentration of 38.8 ± 7.72 µg/dL; 55% also had inadequate dietary zinc intake [19]. The particularly high prevalence in the present study may reflect dietary restriction, low intake of zinc-rich protein foods, impaired gastrointestinal absorption, uremia-related metabolic changes, medication interactions, inflammation-related redistribution, and dialysis-associated loss. However, differences in assay method, fasting status, sampling time, timing relative to dialysis, and diagnostic thresholds also limit comparisons across various studies [6,9].

The principal finding was the absence of a statistically significant association between serum zinc and the 7-point SGA. Although both measures relate to nutritional status, they may capture different domains of health. SGA assesses clinical nutritional depletion through weight change, dietary intake, gastrointestinal symptoms, functional capacity, and fat or muscle loss [3,5], whereas serum zinc is influenced by intake, absorption, albumin binding, inflammation, redistribution, and hydration [6,9]. Consequently, low serum zinc may occur without overt clinical malnutrition, while protein-energy wasting may develop without reduced circulating zinc. However, the observed imprecise correlation estimate and nonsignificant result do not exclude a clinically meaningful association or establish that the measures are independent or interchangeable. The modest sample size and marked imbalance across SGA categories, particularly the inclusion of only two patients with severe malnutrition, limited the ability to detect modest but potentially clinically relevant associations. Larger, adequately powered studies with balanced SGA categories and standardized zinc sampling are needed to estimate this relationship more precisely.

Previous studies have reported associations of lower zinc concentrations with nutritional risk or body composition. Liu et al. found that lower blood zinc was associated with nutritional risk in 118 patients receiving MHD [10]. Toida et al. reported positive associations between serum zinc and nutritional indices and inverse associations with fluid-volume markers in 142 hemodialysis patients [11]. Garagarza et al. found that inadequate dietary zinc intake was associated with lower energy and protein intake, poorer body

composition, and higher mortality risk [20]. In our cohort, no factors were significantly associated with low serum zinc (<60 µg/dL) in univariable analysis. This finding should be interpreted cautiously because only 10 participants had zinc levels ≥60 µg/dL, limiting statistical power and precision; multivariable analysis was therefore not feasible. Differences from previous studies may reflect variations in populations, specimen types, nutritional assessment methods, body-composition measures, residual kidney function, and inflammatory status.

Neither serum albumin nor hs-CRP was associated with serum zinc in this cohort. Albumin is a major zinc-binding protein and a negative acute-phase reactant, and inflammation can lower circulating zinc by redistributing it to tissues [6,9]. The null findings may reflect restricted variability in albumin after excluding patients with acute infection or recent hospitalization, the high prevalence of low zinc, or limited power to detect weak associations. They do not establish that albumin and inflammation are biologically unrelated to zinc status. These findings further emphasize that clinicians should interpret a single serum zinc measurement within the broader clinical and nutritional context and not assume it reflects total-body zinc stores.

Serum zinc showed a weak positive correlation with corrected serum calcium ($p = 0.255$, unadjusted $p = 0.029$); however, this association did not meet the Bonferroni-corrected significance threshold and may have occurred by chance. Zinc may potentially influence CKD-mineral and bone disorder (CKD-MBD) by inhibiting vascular calcification and improving bone metabolism. Zinc's inhibitory effect on cellular calcification may be partly mediated through the zinc-sensing receptor GPR39, while TNFAIP3-mediated suppression of Nuclear Factor Kappa B (NF-κB) signaling may provide an additional mechanism [21,22]. However, the present study found no corresponding associations between zinc and phosphorus, iPTH, alkaline phosphatase, or 25-hydroxyvitamin D. The study did not record the use of calcium-containing phosphate binders, vitamin D analogs, or calcimimetics, which may also have confounded the observed relationship. Further studies incorporating ionized calcium measurements and detailed medication and dialysis-related data are needed to clarify the clinical relevance of this association.

Serum zinc was not associated with hemoglobin. Zinc has been implicated in erythropoiesis, and some hemodialysis studies have reported increased hemoglobin levels and reduced erythropoiesis-stimulating agent requirements after zinc supplementation, although hemoglobin responses have not been consistent [23,24]. However, renal anemia is multifactorial and is influenced by iron availability, inflammation, blood loss, hyperparathyroidism, dialysis adequacy, and treatment intensity [25,26]. Our cross-sectional analysis did not include erythropoiesis-stimulating agent dose or iron indices and cannot determine whether correcting biochemical zinc deficiency would affect anemia. Hemoglobin alone should not be used to identify low zinc status.

The clinical implication is that SGA and serum zinc are complementary rather than interchangeable measures. SGA remains useful for identifying protein-energy nutritional deterioration, but a normal or near-normal score does not exclude biochemical zinc deficiency. Conversely, a low serum zinc value should not by itself establish protein-energy wasting or an indication for supplementation. Consider targeted zinc assessment in patients with persistent poor appetite, dysgeusia, impaired wound healing, recurrent infection, gastrointestinal disease or malabsorption, or selected cases of erythropoiesis-stimulating agent hyporesponsiveness. Interpret low values in relation to diet, inflammation, albumin, medications, fasting status, collection time, and analytical quality, and repeat standardized testing when feasible [6,9]. The present cross-sectional findings do not support routine empiric supplementation. If treatment is used for persistent low serum zinc in a compatible clinical context, monitor zinc, copper, hematological indices, and clinical response because prolonged zinc exposure can cause copper-deficiency anemia and neurological complications [13].

This study has several strengths, including protocolized pre-dialysis blood collection, exclusion of patients with acute infection, recent hospitalization, or zinc supplementation, and comprehensive nutritional and biochemical assessment in an underrepresented Indian hemodialysis population. Limitations include the cross-sectional, single-center design, small sample, consecutive sampling, and absence of a comparison group, limiting generalizability and causal inference. Although SGA assessments were standardized and assessors blinded to zinc results, inter-rater reliability was not formally assessed. Fasting status, dietary intake, sampling time, and hydration were not standardized; dialysis adequacy, residual kidney function, dietary zinc intake, copper status, and relevant medications were not assessed, leaving potential measurement variability and residual confounding. The small severe-malnutrition group ($n = 2$) limited comparisons across SGA categories. The zinc-calcium correlation was not significant after Bonferroni correction and was further limited by the absence of ionized calcium measurements. Finally, serum zinc is an imperfect marker of total-body zinc status, so the findings indicate biochemical rather than confirmed clinical zinc deficiency.

Conclusions

Low serum zinc concentration (<60 µg/dL) was frequent in this Indian maintenance-hemodialysis cohort. SGA-defined nutritional status was not significantly associated with serum zinc; however, the small sample and marked imbalance among SGA categories limited the ability to detect modest associations. The nominal

zinc-calcium correlation did not remain significant after correction for multiple testing and may represent a chance finding. Future larger, adequately powered studies using standardized zinc sampling and reproducible nutritional assessments are needed to determine whether SGA and serum zinc provide independent or additional information.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Abdullah ., Sana Shadab, Shivendra Singh, Royana Singh

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Critical review of the manuscript for important intellectual content: Abdullah ., Sana Shadab, Shivendra Singh, Royana Singh

Supervision: Abdullah ., Sana Shadab, Shivendra Singh, Royana Singh

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. Banaras Hindu University, Institute of Medical Sciences, Institutional Ethics Committee issued approval IMS/IEC/2025/8184. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** This study was supported by Banaras Hindu University under the Institute of Eminence (IoE) Seed Grant (Ref. No. R/Dev/D/IOE/Seed Grant-VI/2024-25/82859; dated 11 January 2025). **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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