Research Square

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Plasma levels of essential elements and their association with chronic kidney disease and dialysis: a cross-sectional study in the Chinese population

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Research Article

Keywords: CKD, Dialysis, Essential element

Posted Date: May 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9380319/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

The kidney critically regulates elemental homeostasis, and disruptions in elemental balance can lead to significant harm. Current research on the changes in elemental levels among chronic kidney disease (CKD) and dialysis patients presents conflicting results. This study aimed to investigate alterations in four common essential elements (selenium, calcium, copper, magnesium) in the plasma of Chinese CKD patients at different stages and dialysis patients.

Methods

A cross-sectional study involving 342 patients was conducted, and plasma levels of various elements were measured using atomic absorption spectrometry. Intergroup differences (ANOVA/Kruskal-Wallis/ Chi-square tests) and Bonferroni-adjusted comparisons were applied. Logistic regression (unadjusted/age-sex-adjusted) were used to evaluate the associations between essential elements and CKD progression. Pearson correlation analysis determined the correlation between elements and clinical indicators.

Results

As CKD progressed, plasma levels of copper and magnesium exhibited an upward trend, while selenium and calcium levels decreased. Hemodialysis improved plasma calcium and copper levels. Plasma levels of selenium, calcium, and magnesium exhibited statistically significant correlations with CKD progression. Elemental levels also correlated with various clinical indicators.

Conclusions

Various element levels undergo changes that may contribute to the onset and progression of CKD. Further research incorporating dietary assessment and longitudinal follow-up is needed to clarify the clinical implications of these alterations.

Background

Chronic kidney disease is a progressive condition affecting approximately 850 million cases globally [1]. According to current international guidelines, CKD is defined as a decrease in glomerular filtration rate (GFR) below 60mL/min/1.73m^2 and/or the presence of kidney injury markers persisting for at least 3 months. The decline in GFR classifies CKD into five stages, reflecting the progression from early-stage disease to kidney failure [2]. CKD is associated with numerous complications and increases the risk of CKD-related deaths and adverse cardiovascular outcomes [3], presenting an important public health issue. As the disease advances, various types of kidney disease will eventually develop into end-stage kidney disease (ESKD), necessitating kidney replacement therapy (dialysis and kidney transplantation) for patients to maintain normal life activities. In China, a study based on data from the sixth China Chronic Disease and Risk Factor Surveillance (CCDRFS) revealed that the current prevalence of CKD among adults in mainland China at 8.2% [4], which is a significant decrease from the 10.8% prevalence reported in 2009 [5], signifying that approximately 82 million Chinese adults continue to grapple with CKD. The management of CKD

involves long-term medication aimed at slowing the progression of renal function decline, often culminating in the need for renal replacement therapy. The associated high medical costs pose substantial burdens on both families and society. Hence, there is an urgent need to identify effective prevention and treatment strategies to delay CKD progression to ESKD, enhancing overall clinical outcomes and alleviating the associated medical and economic challenges.

Currently, approximately 20 known elements are defined as essential elements. These include "organic" elements such as Hydrogen (H), Carbon (C), Nitrogen (N) and Oxygen (O), seven "macro-minerals" - Sodium (Na), Potassium (K), Magnesium (Mg), Calcium (Ca), Chlorine (Cl), Phosphorus (P) and Sulfur (S), along with “trace elements” like Selenium (Se), Zinc (Zn), Iron (Fe), Copper (Cu), among others, which adults require in amounts less than 100mg per day [6]. Essential elements play a crucial role in maintaining normal life activities, contributing to fundamental functions such as constituting body tissues, participating in many physiological and biochemical processes as cofactors of cellular enzymes and regulators of molecular structure. They play an important role in growth and development, metabolism, immune regulation, anti-infection and antioxidant stress [7]. For example, iron is a key component of hemoglobin [8], and selenium is integral component of numerous antioxidant metalloenzymes [9]. Therefore, the homeostasis of essential elements is paramount for human well-being.

Since the kidney is a pivotal organ in regulating the levels of various elements in the human body. The disruption of essential elements homeostasis may occur in CKD patients with the decline in GFR and the gradual loss of kidney function. Additionally, clinical manifestations in CKD patients, such as loss of appetite, dietary restriction, persistent inflammatory reaction and high metabolism, can alter the state of various elements [10, 11]. Dialysis patients, undergoing diffusion, convection and adsorption, may experience the loss or the accumulation of certain elements, resulting in abnormal state of essential elements [10, 12]. Importantly, these abnormal statuses are linked to immune disorders, infections, cardiovascular complications, anemia, and mineral and bone disorders, all closely related to adverse events in CKD patients [13]. Therefore, understanding the changes in essential elements in CKD patients is imperative.

In this study, we measured the levels of four common essential elements (selenium, copper, calcium, magnesium) in the plasma of CKD patients at various stages and dialysis patients. Our aim is to explore differences in these elements among different patient groups, examine their correlation with specific clinical indicators, and discuss the relationship between various elements and CKD progression. Additionally, we aim to elucidate the potential effects of essential element homeostasis disruption in the body.

Methods

Research population

This study focused on adult patients (age ≥ 18 years old) at varying stages of CKD or those undergoing regular dialysis (hemodialysis or peritoneal dialysis) for more than six months. Participants were selected from the Department of Nephrology at the Second Affiliated Hospital of Xi'an Jiaotong University, China and Shaanxi Provincial Academy of Traditional Chinese Medicine, China. Following the KDIGO 2012 clinical practice guidelines, CKD was categorized into five stages based on eGFR levels calculated using the CKD-EPI equation: CKD1 (eGFR ≥ 90 ml/min/1.73m²), CKD2 (eGFR 60–89 ml/min/1.73m^2), CKD3 (eGFR 30–59 ml/min/1.73m^2), CKD4 (eGFR 15–29 ml/min/1.73m^2), and CKD5 (eGFR < 15ml/min/ 1.73m^2). Exclusion criteria comprised pregnant or lactating women, patients with recent infections, a history of malignant tumors, or other serious chronic diseases (including heart failure, liver disease, chronic inflammatory diseases). Additionally, individuals with recent or long-term use of

glucocorticoids, cytotoxic drugs, and antiepileptic drugs were excluded. A total of 342 patients underwent standardized clinical interviews, physical examinations, and laboratory tests.

Sample Collection

The participants' blood samples were collected in the morning after overnight fasting (fasting ≥ 8 hours). Clinical indicators (serum creatinine, urea nitrogen, red blood cells, white blood cells, hemoglobin, etc.) were analyzed in the clinical laboratory of the Second Affiliated Hospital of Xi'an Jiaotong University. The remaining blood samples were centrifuged, and the plasma was collected and stored at -80°C for subsequent determination of various elements.

Element determination

Plasma samples of the participants were sent to the Trace Element Research Institute of Xi'an, Shaanxi Province, China, where a 180 – 80 Zeeman polarized atomic absorption spectrometer was utilized to detect the contents of selenium, copper, calcium and magnesium.

Statistical analysis

Descriptive data were summarized as mean ± standard deviation (SD) or medians with interquartile ranges (IQRs) for continuous variables, and frequencies with percentages (%) for categorical variables. Baseline characteristics and intergroup differences across CKD stages were assessed with one-way ANOVA (normal data), Kruskal-Wallis (non-normal data), or Chi-square tests (categorical data), followed by Bonferroni-adjusted pairwise comparisons. To evaluate the associations between essential elements and CKD progression, logistic regression analyses were performed in two sequential models: Model 1 (unadjusted) and Model 2 (adjusted for age and sex), and results were visualized using forest plots. Pairwise correlations between element levels and participant characteristics were quantified with Pearson correlation coefficients (*r*) and displayed via heatmaps. *P* value < 0.05 was considered statistically significant. All analyses were conducted using IBM SPSS Statistics 26.0.

Results

Participant characteristics

During the study period, a total of 342 patients were enrolled, comprising 183 males (53.5%) and 159 females (46.5%), with a median age of 54 years. The baseline characteristics of the participants, stratified by CKD stages 1–5, hemodialysis (HD), and peritoneal dialysis (PD), are presented in Table 1. As CKD advanced, the median age of patients gradually was increased, (*P* for trend < 0.001), with median ages of 53 and 47 years for HD and PD, respectively. In terms of clinical indicators: blood urea nitrogen and creatinine levels increased gradually with CKD progression (*P* for trend < 0.001 and < 0.001, respectively); Uric acid was displayed an upward trend (*P* for trend < 0.001), while cholesterol, red blood cells, and hemoglobin were showed a declining trend (*P* for trend = 0.004, < 0.001 and < 0.001, respectively). Albumin was highest in CKD1 patients. Triglyceride and white blood cell levels were lowest in CKD5 patients. Compared with non-dialysis CKD5 patients, HD patients were demonstrated significant improvements in serum albumin, red blood cells, hemoglobin, and white blood cells (*P* < 0.001, < 0.001, < 0.001 and < 0.001, respectively).

Table 1
Demographics and clinical characteristics at baseline

	Total	CKD1	CKD2	CKD3	CKD4	CKD5	HD	PD	*P*	*P* for trend (CKD1-5)
	(n = 342)	(n = 49)	(n = 25)	(n = 47)	(n = 26)	(n = 58)	(n = 108)	(n = 29)		
Age, median (Q1, Q3)	54 (43, 63)	43 (27, 53.25)	54 (46.5, 64.5)	58 (46, 68)	56 (41.5, 77.75)	60 (47, 70)	53 (44, 62)	47 (36.5, 57.5)	< 0.001	< 0.001
Gender, n (%)										
Male	183 (53.5)	18 (36.7)	12 (48)	20 (42.6)	14 (53.8)	33 (56.9)	70 (64.8)	16 (55.2)	0.030	
Female	159 (46.5)	31 (63.3)	13 (52)	27 (57.4)	12 (46.2)	25 (43.1)	38 (35.2)	13 (44.8)		
Urea nitrogen (mmol/L)	16.94 ± 17.29	4.16 ± 1.33	5.95 ± 2.32	8.68 ± 4.27	15.57 ± 7.73	20.98 ± 7.88	26.84 ± 25.69	19.08 ± 6.21	< 0.001	< 0.001
Creatinine (μmol/L)	511.1 ± 424.7	59.8 ± 11.8	85.6 ± 15.5	138.0 ± 26.7	270.1 ± 75.3	651.2 ± 312.0	859.6 ± 348.0	899.0 ± 265.3	< 0.001	< 0.001
Uric acid (μmol/L)	371.8 ± 135.4	276.4 ± 86.3	319.8 ± 88.7	420.7 ± 110.8	490.0 ± 188.7	394.9 ± 138.0	357.9 ± 133.5	389.2 ± 89.1	< 0.001	< 0.001
Albumin (g/L)	38.0 ± 7.6	40.0 ± 7.0	35.9 ± 12.6	37.2 ± 8.7	37.3 ± 7.2	36.1 ± 6.5	40.3 ± 5.8	33.8 ± 6.8	< 0.001	0.099
Triglycerides (mmol/L)	1.73 ± 1.30	2.16 ± 2.04	1.97 ± 1.26	2.29 ± 1.66	2.18 ± 1.08	1.28 ± 0.68	1.38 ± 0.65	1.66 ± 1.39	< 0.001	0.028
Cholesterol (mmol/L)	4.54 ± 1.58	5.09 ± 2.13	5.52 ± 2.21	5.09 ± 1.58	4.78 ± 1.46	4.24 ± 1.32	4.00 ± 1.04	4.20 ± 1.20	< 0.001	0.004
RBC ($\times 10^9$/L)	3.55 ± 0.87	4.46 ± 0.57	4.19 ± 0 .72	3.83 ± 0.75	3.44 ± 0.76	2.89 ± 0.60	3.41 ± 0.66	2.89 ± 0.89	< 0.001	< 0.001
Hemoglobin (g/L)	105.8 ± 26.8	132.6 ± 19.7	125.4 ± 20.8	116.8 ± 25.3	102.4 ± 22.4	85.5 ± 17.1	100.8 ± 20.4	85.5 ± 25.0	< 0.001	< 0.001
WBC ($\times 10^9$/L)	6.45 ± 2.53	6.69 ± 2.87	6.71 ± 2.95	7.17 ± 2.83	7.34 ± 2.12	5.68 ± 2.13	6.22 ± 2.41	6.14 ± 2.01	0.027	0.263

Data are means ± SD or medians (IQRs) or numbers (percentage).

Overall group difference was determined by ANOVA, Kruskal–Wallis test, or Chi-square test for normal, skewed continuous, or categorical variables, respectively.

Abbreviation: HD, hemodialysis; PD, peritoneal dialysis; RBC, red blood cell; WBC, white blood cell

Plasma levels of essential elements in different stages of CKD and dialysis patients

Table 2 outlines the plasma levels of essential elements (selenium, calcium, copper, magnesium) in various CKD groups. There were significant differences in plasma contents of selenium, calcium, copper and magnesium between groups ($P < 0.001$, < 0.001, $= 0.009$ and < 0.001, respectively). With CKD progression, copper and magnesium levels in patient plasma increased gradually (P for trend $= 0.015$ and < 0.001), while selenium and calcium levels decreased gradually (P for trend < 0.001 and < 0.001) (Fig. 1).

Table 2. Plasma essential elements concentration in CKD1-5 groups

	CKD1	CKD2	CKD3	CKD4	CKD5	*P*	*P* for trend
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		
Se(μg/L)	82.35 ± 36.09	71.12 ± 19.22	63.49 ± 18.20	53.38 ± 12.83	44.12 ± 10.93	<0.001	<0.001
Ca(μg/mL)	80.68 ± 14.84	79.14 ± 10.20	76.14 ± 7.603	76.27 ± 6.828	71.06 ± 10.75	<0.001	<0.001
Cu(μg/mL)	1.104 ± 0.473	0.906 ± 0.371	1.057 ± 0.364	1.136 ± 0.500	1.243 ± 0.431	0.009	0.015
Mg(μg/mL)	19.63 ± 5.082	20.38 ± 3.136	20.81 ± 3.226	21.43 ± 3.512	22.19 ± 4.292	<0.001	<0.001

P values were determined by Multivariable linear regression model, adjusted for age and gender.

The plasma levels of essential elements in CKD5, HD and PD groups were shown in Table 3. Compared to CKD5 patients, HD patients exhibited reduced plasma copper levels ($P = 0.003$), while calcium and magnesium levels increased ($P < 0.001$ and < 0.001); PD patients showed reduced plasma selenium levels ($P < 0.001$).

Table 3
Serum trace elements concentration in CKD5, HD, PD groups

	CKD5	**HP**	**PD**	***P***
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	
Se(μg/L)	44.12 ± 10.93	48.01 ± 13.41	33.69 ± 10.74 **	< 0.001
Ca(μg/mL)	71.06 ± 10.75	78.78 ± 9.964 **	73.01 ± 10.92	< 0.001
Cu(μg/mL)	1.243 ± 0.431	1.077 ± 0.263 **	1.077 ± 0.336	0.02
Mg(μg/mL)	22.19 ± 4.292	27.75 ± 5.111 **	21.59 ± 3.638	< 0.001

P values were determined by Multivariable linear regression model, adjusted for age and gender. Compared with CKD 5 groups, *, $P < 0.05$, **, $P < 0.01$.

Abbreviation: HD, hemodialysis; PD, peritoneal dialysis;

Association Between Essential Elements and CKD Stages

After adjusting for age, sex, multivariate logistic regression analysis revealed associations between plasma levels of four essential trace elements and advanced CKD stages (Fig. 2). Selenium, calcium, and magnesium levels were

exhibited statistically significant correlations with CKD progression. Elevated plasma selenium levels were significantly associated with reduced risk of advanced CKD. Compared with CKD1, the adjusted odds ratios (ORs) values (95% CI) for CKD3, CKD4, and CKD5 were 0.963 (95% CI: 0.943–0.985), 0.930 (95% CI: 0.898–0.962), and 0.886 (95% CI: 0.852–0.922), respectively. Similarly, higher calcium levels were demonstrated an inverse association with CKD progression risk. Conversely, increased plasma magnesium levels were significantly associated with elevated risk of advanced CKD. Compared with CKD1, the adjusted ORs (95% CI) for CKD3, CKD4, and CKD5 were 1.268 (1.078–1.491), 1.323 (1.095–1.599), and 1.493 (1.239–1.798), respectively. No statistically significant associations were observed for plasma copper levels with any CKD stage ($P > 0.05$).

Correlation between essential elements and participant characteristics

The correlation between plasma levels of essential elements and demographic/clinical characteristics of the participants is shown in Fig. 3. Selenium levels were negatively correlated with urea nitrogen ($P < 0.001$, r= -0.259), creatinine ($P < 0.001$, r = -0.466) and uric acid ($P = 0.006$, r = -0.160), and positively correlated with cholesterol ($P = 0.005$, r = 0.157), red blood cells ($P < 0.001$, r = 0.319) and hemoglobin ($P < 0.001$, r = 0.331); Calcium levels were positively correlated with albumin ($P < 0.001$, r = 0.375), red blood cells ($P < 0.001$, r = 0.221), and hemoglobin ($P < 0.001$, r = 0.230); Copper levels were negatively correlated with cholesterol, red blood cells and hemoglobin ($P = 0.025$, 0.001 and < 0.001, r = -0.124, -0.182 and − 0.212, respectively); Magnesium levels were positively correlated with urea nitrogen ($P < 0.001$, r = 0.254), creatinine ($P < 0.001$, r = 0.399), and albumin ($P < 0.001$, r = 0.267), and negatively correlated with triglycerides ($P = 0.005$, r = -0.156), cholesterol ($P = 0.008$, r = -0.146), red blood cells ($P = 0.026$, r = -0.125), and hemoglobin ($P = 0.010$, r = − 0.145).

Discussion

This cross-sectional study of 342 patients across various CKD stages and dialysis modalities delineates the characteristic alterations in plasma levels of four essential elements (selenium, calcium, copper, magnesium) and their associations with clinical parameters. We observed a progressive decline in plasma selenium and calcium levels alongside a progressive increase in copper and magnesium levels with advancing CKD. Dialysis exerted differential effects on these elements: HD improved calcium and reduced copper levels but failed to reverse the decline in selenium and significantly elevated magnesium levels; PD patients exhibited further reduced selenium levels. Furthermore, selenium, calcium, and magnesium were significantly associated with CKD stages (selenium and calcium as protective factors, magnesium as a risk factor), and all four elements exhibited distinct correlations with renal function, hemoglobin, and other clinical indicators. These findings provide crucial data supporting the understanding of elemental metabolic disturbances and potential clinical interventions in CKD.

Selenium, as a core component of selenoproteins such as glutathione peroxidase [14], exhibits a bidirectional relationship with kidney function. The kidneys, being one of the organs richest in selenium distribution in the human body [15], not only rely on selenium's antioxidant activity to maintain cellular homeostasis but also regulate systemic selenium balance through filtration and reabsorption [16]. Our study found a gradual decline in plasma selenium with CKD progression, a trend not reversed by dialysis, which aligns with previous reports of significantly reduced selenium and glutathione peroxidase levels in CKD patients [17], a positive correlation between plasma selenium and eGFR [11], and the protective effects of selenium supplementation [18]. Further analysis revealed a positive correlation between selenium and hemoglobin/red blood cells, potentially attributable to selenium's role in inhibiting oxidative stress and mitigating inflammation [19], thereby improving iron utilization efficiency.

Calcium metabolism disorder is a central feature of chronic kidney disease-mineral and bone disorder, which involves impaired phosphorus excretion, reduced vitamin D activation, and secondary hyperparathyroidism [20, 21]. Our results showing a gradual decline in plasma calcium with CKD progression, significantly alleviated by HD/PD. Early-stage CKD patients can maintain calcium homeostasis through compensatory mechanisms; however, in advanced CKD (stages 4–5), calcium homeostasis is disrupted due to elevated serum phosphate, impaired intestinal calcium absorption, and skeletal resistance to parathyroid hormone [22]; dialysis can effectively remove excess serum phosphorus. Notably, we observed positive correlations between calcium and hemoglobin/red blood cells, consistent with previous studies indicating a close relationship between serum calcium and anemia in CKD [23] and *in vitro* evidence that calcium promotes erythropoiesis [24].

Due to impaired renal excretion and alterations in protein metabolism, copper imbalance is common in CKD patients [25]. Our study observed a gradual increase in plasma copper levels with CKD progression. Previous research has suggested that elevated blood and urinary copper are directly associated with an increased risk of CKD incidence and aggravated kidney injury [26–29]. A Mendelian randomization study demonstrated that higher circulating copper levels are linked to lower eGFR and accelerated renal function decline [30]. The mechanism likely involves copper-induced oxidative stress and promotion of inflammatory cytokine release, leading to damage of renal cells [31]. Moreover, elevated blood copper increases the risk of cardiovascular adverse events in CKD patients [32]. We observed a negative correlation between plasma copper and hemoglobin/red blood cells, consistent with findings from a study in children with CKD [33].

The kidney plays a central role in regulating magnesium homeostasis through glomerular filtration and tubular reabsorption [34], with excretion efficiency directly related to GFR [35]. Our results showed a gradual increase in plasma magnesium with CKD progression, significantly elevated in HD patients. This occurs because the compensatory capacity for fractional magnesium excretion is exhausted as GFR declines [36]. The elevation in HD patients could be related to magnesium concentration in the dialysate [37]. The clinical significance of magnesium disturbances in CKD patients remains debated. Some studies suggest magnesium deficiency is a risk factor for CKD progression [36, 38], while others have found a survival benefit associated with mild hypermagnesemia in HD patients [38], and severe hypermagnesemia increases the risk of adverse outcomes [39]. We found a positive correlation between magnesium and albumin, suggesting a potential association with nutritional status. Consistent with previous findings that magnesium is associated with dyslipidemia [40], this study observed a similar relationship. Additionally, plasma magnesium levels were negatively correlated with hemoglobin and red blood cells in our CKD patients, aligning with the results of Yan et al [41]. However, another study reported lower hemoglobin levels in individuals with lower blood magnesium levels [38]. Further research is needed to clarify the relationship between magnesium and CKD progression and outcomes.

This study has several limitations. First, as an observational cross-sectional study, correlation analysis cannot establish a causal relationship. Second, the small sample sizes in some subgroups and the potential influence of extreme values may introduce bias. Third, using plasma elemental levels to reflect total body elemental status has inherent limitations. Finally, the lack of data on participants' dietary habits and nutritional supplements, which are crucial factors influencing elemental levels.

Conclusions

This study describes the alterations in several essential elements in the plasma of Chinese patients across different CKD stages and on dialysis. These changes are associated with various clinical indicators. Dialysis interventions can modulate some elemental imbalances and improve clinical parameters but may concurrently exacerbate the

elevation of magnesium and the decline of selenium. These findings underscore the complexity of elemental dysregulation in CKD and suggest that monitoring elemental status in this population may be clinically relevant. Future multi-center, large-sample prospective studies and basic research are crucial for elucidating the causal relationships between elemental disturbances and CKD prognosis and their underlying mechanisms.

Abbreviations

CKD
Chronic kidney disease
GFR
Glomerular filtration rate
ESKD
End-stage kidney disease

Declarations

Ethics approval and consent to participate

The study was approved by the Institutional Review Board of Xi'an Jiaotong University health science center (protocol code 2020-936 and date of approval 27 March 2020), and all participants provided informed consent.

Clinical Trial Number: not applicable.

Consent for publication: not applicable.

Availability of data and materials

The data are not publicly available due to privacy restrictions of the research participants. The data that support the findings of this study are available from the corresponding author upon reasonable request (tianlifang@xjtu.edu.cn).

Competing interest

The authors have no conflicts of interest to declare.

Funding

This research was funded by National Natural Science Foundation of China [82000699], Natural Science Foundation of Shaanxi Province [2023-JC-YB-776, 2022JM-472] and Backbone of scientific research program of the Second Affiliated Hospital of Xi'an Jiaotong University [RC(GG)201906].

Authors' contributions

Chenkai Cui: Methodology, Formal analysis, Writing—original draft preparation, Writing—review and editing, Visualization. Xuefei Tian: Writing—review and editing. Yunfeng Li: Methodology, Formal analysis, Writing—original draft preparation. Weihao Zhao: Investigation. Yuxin Li: Investigation. Lu Zhang: Methodology. Xianghui Chen: Data curation, Resources, Funding acquisition. Linting Wei: Data curation, Resources, Funding acquisition. Muzaffar Xattabov: Writing—review and editing. Rongguo Fu: Conceptualization, Resources, Writing—review and editing, Supervision. Lifang Tian: Conceptualization, Resources, Writing—review and editing, Supervision, Project administration, Funding acquisition.

Acknowledgments

The authors thank all of the study participants and thank the National Natural Science Foundation of China, the Natural Science Foundation of Shaanxi Province and Backbone of scientific research program of the Second Affiliated Hospital of Xi'an Jiaotong University.

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Figures

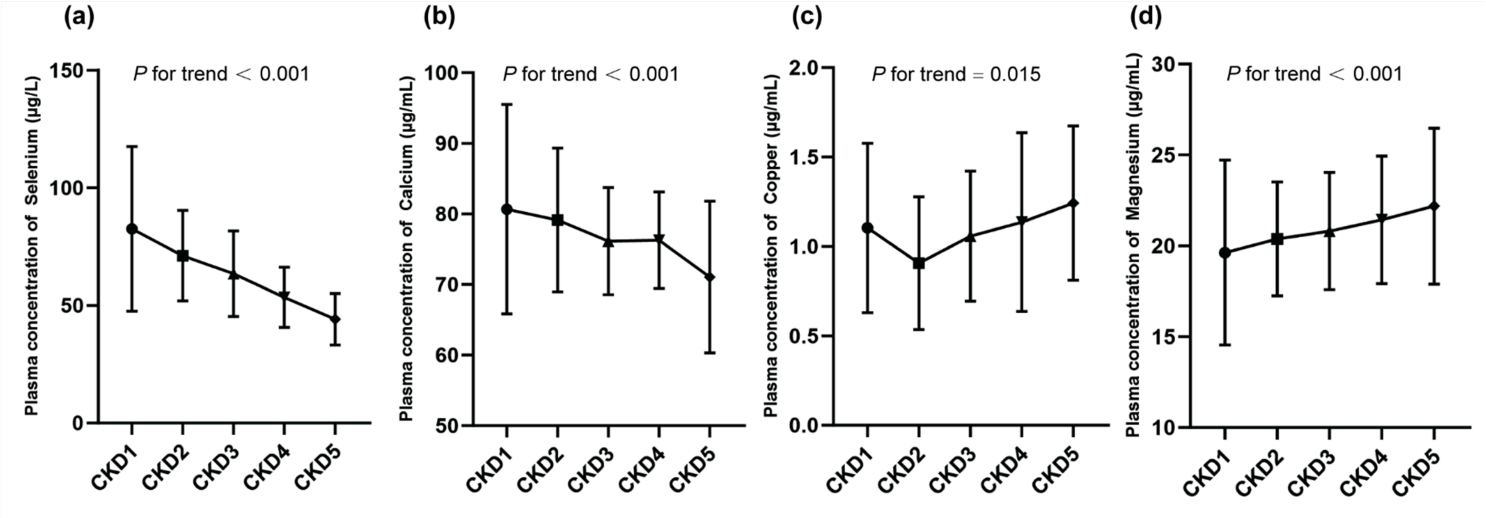


Figure 1

Changes of plasma essential elements levels with the progression of CKD. (a) Changes of plasma selenium levels with the progression of CKD. (b) Changes of plasma calcium levels with the progression of CKD. (c) Changes of plasma copper levels with the progression of CKD. (d) Changes of plasma magnesium levels with the progression of CKD.

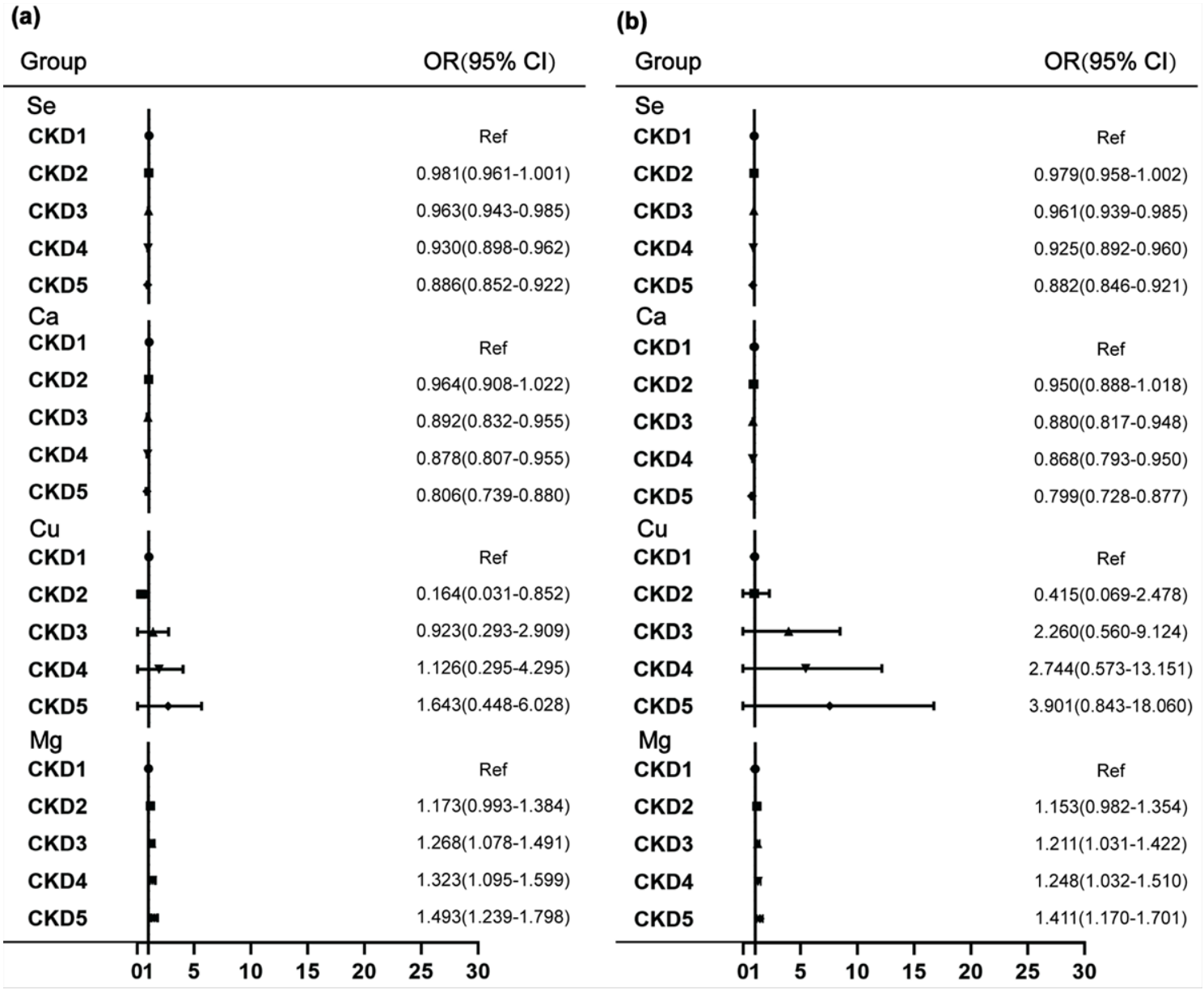


Figure 2

Association Between Essential Elements and CKD Stages. (a) Crude model. (b) Adjusted with age and sex. CKD, chronic kidney disease; OR, odds ratio; CI, confidence interval.

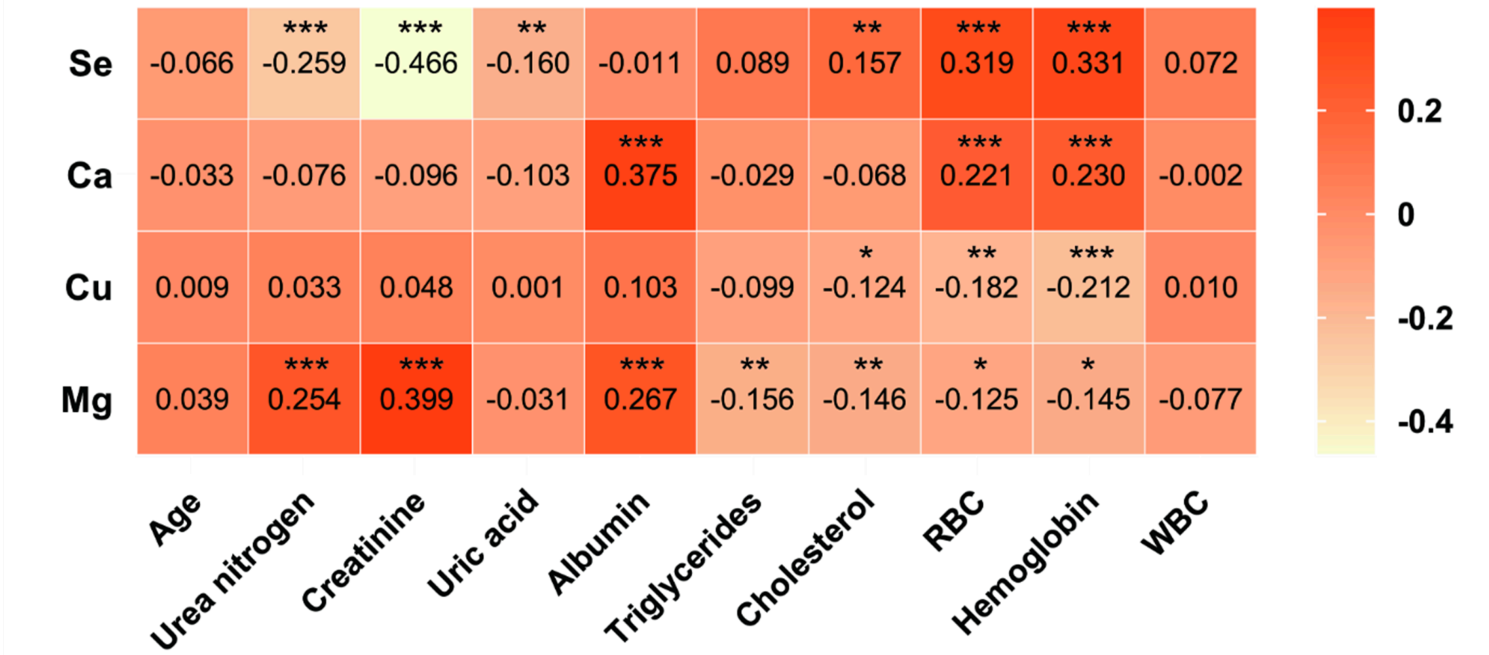


Figure 3

Correlation between essential elements and participant characteristics. RBC, red blood cell; WBC, white blood cell. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.