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Evaluation of Renal Function Biomarkers, Hematological Indices, and Electrolyte Disturbances in Chronic Hemodialysis Patients

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ABSTRACT

Background: *Chronic kidney disease (CKD) and end-stage renal disease (ESRD) are associated with significant hematological, biochemical, and electrolyte abnormalities, particularly in patients undergoing maintenance hemodialysis. Impaired renal function leads to the accumulation of metabolic waste products, anemia, and electrolyte disturbances that may contribute to cardiovascular complications, metabolic instability, and increased morbidity and mortality.* ***Aim:****This study aimed to evaluate the relationship between renal function biomarkers, hematological parameters, and electrolyte disturbances in patients undergoing chronic hemodialysis and to determine their clinical significance in assessing disease severity and dialysis-related complications.* ***Methods:*** *A cross-sectional study was conducted on 177 patients receiving maintenance hemodialysis. Hematological, biochemical, and electrolyte analyses were performed using automated laboratory analyzers. Parameters evaluated included serum creatinine, urea, sodium, potassium, chloride, hemoglobin, white blood cell count, and platelet count. Correlation and comparative statistical analyses were used to assess the relationships among the studied variables.* ***Results:*** *The results showed significantly increased serum urea and creatinine levels, together with a definitive diagnosis of renal dysfunction as compared to the healthy controls. A high proportion of patients had renal anemia, with hemoglobin levels being low in many individuals. Electrolyte derangements were common, particularly hyperkalemia and hyponatremia. Correlation analysis showed that serum creatinine had positive correlations with potassium and chloride, while hemoglobin levels had reverse correlations with sodium and urea concentrations. Trial registration: The differential alterations in white blood cell and platelet counts indicated a chronic inflammatory activation, which may also be the background for uremic platelet dysfunction in ESRD patients.* ***Conclusion:*** *Chronic hemodialysis patients exhibit significant interrelated hematological, biochemical, and electrolyte disturbances associated with progressive renal dysfunction. Integrated monitoring of these laboratory parameters may improve dialysis adequacy assessment, risk stratification, and clinical management of ESRD patients.*

Keywords: Chronic Hemodialysis, Renal Biomarkers, Electrolyte Disturbance.

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INTRODUCTION

Chronic kidney disease (CKD) is a progressive and irreversible disorder defined by loss of kidney structure or function, leading to end-stage renal disease (ESRD), with associated morbidity, mortality, reduced quality of life, and increased resource utilization. As a result of its increasing prevalence, high mortality rates, and significant association with cardiovascular and metabolic complications, CKD has become a global public health burden. Based on recent epidemiological studies, CKD is present in 10–

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13% of the global population and has a considerable burden on health care expenditures as well as quality of life (Chen et al., 2019; Webster et al., 2017). Kidneys maintain electrolyte balance, acid–base homeostasis, fluid balance, and removal of metabolic products. Thus, faulty renal function means the build-up of uremic toxins (e.g., urea and creatinine), as well as severe derangements in sodium, potassium, chloride, and bicarbonate balance (Levey & Coresh, 2012; Palmer & Clegg, 2016). These abnormalities are exacerbated in patients on chronic hemodialysis as dialysis-induced variabilities may further exacerbate cardiovascular instability, arrhythmias, hypertension, and fluid overload (Dilaver & Ikizler, 2024).

Anemia is one of the most prevalent and clinically relevant complications that can occur due to CKD or ESRD. The pathophysiology behind renal anemia is complex and consists of erythropoietin deficiency, dysregulation of iron homeostasis, chronic inflammation, shortened red blood cell life span, nutritional deficiencies as well as repeated blood loss due to dialysis procedures (Macdougall 2024; Badura et al. 2024). Chronic inflammation and oxidative stress are common in hemodialysis patients and play a role in impaired hematopoiesis, with consequent morbidity and mortality (Stenvinkel, 2010; Himmelfarb & Ikizler, 2010). In addition, platelet dysfunction and leukocyte abnormalities are quite prevalent in ESRD patients leading to an increase in bleeding, thrombosis, and infection (Vanholder et al., 2003). Electrolyte disorders (hyperkalemia, hyponatremia) are also extremely important in clinical practice since it is associated with SCD and poor prognosis of dialysis (Costa et al., 2023; Kovesdy, 2015).

Biochemical and hematological disturbances in CKD patients on maintenance hemodialysis have been studied extensively recently. Costa et al. Advances in Fluid and Electrolyte Research hyperkalemia developing from declining GFR indicates poor cardiovascular prognosis in CKD ([13], October 2023). Similarly, Lew et al. (2023) indicated that sodium imbalance and interdialytic fluid overload are still important causes of hypertension and cardiovascular complications in patients with dialysis. Research by Yakupova et al. Abstract background: Serum creatinine and urea continue to be the gold standard biomarkers in the assessment of kidney function deterioration, as well as dialysis adequacy (2023). Additionally, multiple studies emphasized the need for individualized electrolyte management in dialysis patients to mitigate metabolic fragility and enhance survival (Dilaver & Ikizler, 2024).

Recent literature has also evaluated the association between anemia and progression to chronic kidney disease. Macdougall (2024) observed that the prevalence of anemia rises steadily with reduced kidney function, and among ESRD patients treated by hemodialysis, it is also highly prevalent. Likewise, Badura et al. Anemia of CKD has been characterized as a complex disorder involving erythropoietin deficiency, dysregulation in iron metabolism, inflammation, and impaired marrow response by G den C van der (2024). van Lieshout et al. (2018) conducted a systematic review. In their study, Dharmendra et al.(2024) further evidenced that iron metabolism and anemia treatment can vary by dialysis modality, so guidelines may need to consider a personalized approach. In the context of renal anemia correction, meta-analyses suggest that therapy for iron depletion might improve hematological outcomes (i.e., hemoglobin levels) and cardiovascular stability in dialysis populations (Zhang et al., 2024).

The growing number of studies focused on CKD complications has revealed several important gaps in knowledge. Abstract: Most

previous studies have examined either solitary biochemical markers, electrolyte abnormalities, or anemia as separate issues; however, there have been relatively few studies that looked at the interrelationships among hematological indices, renal biomarkers, and electrolyte disorders in the same hemodialysis population. However, only a few regional studies have investigated these associations among Iraqi ESRD patients, as the prevalence of chronic kidney disease is increasing in groups of developing countries. Moreover, integrated analysis of hematological and biochemical parameters may facilitate the identification of dialysis-related early complications as well as appropriate management strategies; however, this approach has not yet been systematically investigated (Young et al., 2025).

Therefore, the present study aimed to evaluate the correlation between renal function biomarkers, hematological parameters, and electrolyte disturbances in patients undergoing chronic hemodialysis. Specifically, the study investigated the relationships among serum creatinine, urea, sodium, potassium, chloride, hemoglobin concentration, white blood cell count, and platelet count in ESRD patients receiving maintenance hemodialysis. The novelty of this research lies in its integrated assessment of biochemical, hematological, and electrolyte markers within a single analytical framework, which may provide a broader understanding of the metabolic and hematological complications associated with chronic renal failure and dialysis therapy. The findings may contribute to improved risk stratification, dialysis adequacy assessment, and personalized clinical management of hemodialysis patients.

METHODS

Study Design and Setting

This study is a cross-sectional descriptive analytical study that was performed to evaluate the correlation of renal function biomarkers, hematological indices, and electrolyte disturbances in patients with end-stage kidney disease who were on chronic hemodialysis. It was performed in Al-Hussein Teaching Hospital's Haemodialysis Unit. The cross-sectional design was also thought to be appropriate because it permitted simultaneous measurement of biochemical, hematological, and electrolyte parameters in a cohort of end-stage renal disease (ESRD) patients receiving maintenance hemodialysis and facilitated computation of correlations between these.

Study Population and Sample Collection

Patients diagnosed with chronic kidney disease (CKD) and end-stage renal disease (ESRD) who were on regular maintenance hemodialysis at the institution from Jan 2018 to December 2020. A total of 177 patients were enrolled in the study. Patients of both sexes and of any age group who underwent regular hemodialysis sessions were included. We excluded patients who had acute kidney injury, active infections, malignancies, or severe systemic diseases unrelated to renal dysfunction to minimise confounding factors that may affect hematological or biochemical parameters.

All participants, after obtaining their written consent, provided samples of venous blood aseptically before initiation of the dialysis session. Each sampling consisted of 5–7 mL of blood, which was placed into EDTA tubes for hematological analysis and plain gel tubes for biochemical and electrolyte studies. After centrifugation, serum samples were analyzed immediately or stored under proper laboratory conditions until testing.

Hematological, Biochemical, and Electrolyte Analysis

Laboratory analysis: Hematological analysis, hemoglobin concentration (Hb), white blood cell count (WBC), and platelet count were performed using a fully automated hematology analyzer until 2023-Ad, according to the standard laboratory protocols. Serum

creatinine and urea concentrations were determined by fully automated chemistry analyzers using an enzymatic method for creatinine, and a colorimetric method for urea. All electrolyte parameters, including sodium (Na^+), potassium (K^+), and chloride ions (Cl^-), were measured using an ion-selective electrode method.

Routine laboratory methods were performed according to the manufacturer's guidelines and normal quality control measures. Calibration and internal quality control measures were performed prior to the analysis of samples.

Data Collection and Instrumentation

Clinical and demographic characteristics, such as age, sex, and dialysis status, were obtained from patient medical records, complemented with personal interviews when needed. Laboratory data were entered into a custom-designed data collection sheet developed specifically for the study. The study instruments and analyzers were routinely maintained and validated for precision and accuracy of measurements by the hospital laboratory.

Statistical Analysis

Data were entered and analyzed using Statistical Package for the Social Sciences (SPSS) software version 26. Any available hematological, biochemical, and electrolyte parameters were summarized using descriptive statistics (mean ± SD; range). This was followed by correlation analysis of renal biomarkers with hematological or electrolyte variables. Where appropriate, analyses were done comparing male vs female patients. We defined statistical significance as $p < 0.05$. Methods: The statistical methods we propose are suitable for the analysis of interrelationships between continuous laboratory variables to achieve this study's objectives.

RESULTS

The study population comprised chronic hemodialysis patients (N=177). Objective: to determine the relationships between renal dysfunction, anemia, and electrolyte imbalance during maintenance hemodialysis in patients with end-stage renal disease (ESRD) prospective observational study: comprehensive hematological, biochemical, and electrolyte analyses were performed in patients with ESRD. Table 1 shows the demographic and laboratory characteristics for the study population.

Descriptive Characteristics of the Study Population

The descriptive analysis showed that serum urea and creatinine levels were significantly higher compared with the normal range, and this confirmed the presence of severe renal damage in this study population. Reductions in hemoglobin were evident in a large number of patients, suggesting the common occurrence of renal loss–related anemia in chronic kidney disease (CKD). Serum electrolyte abnormalities, specifically hyperkalemia and hyponatremia, were additionally common.

Table 1. Descriptive Statistics of Renal Function Biomarkers, Electrolytes, and Hematological Parameters

Parameters	n	Mean ± SD	Minimum	Maximum
Urea (mg/dL)	148	126.39 ± 66.50	10.0	338.0
Serum Creatinine (mg/dL)	143	6.06 ± 3.42	0.5	15.2
Sodium (mmol/L)	108	137.83 ± 6.25	121.0	173.0
Potassium (mmol/L)	107	4.98 ± 0.94	3.2	7.3

Parameters	n	Mean ± SD	Minimum	Maximum
Chloride (mmol/L)	108	99.97 ± 5.32	85.0	127.0
Hemoglobin (g/dL)	152	10.00 ± 2.30	4.2	17.4
White Blood Cells (×10³/µL)	152	8.16 ± 3.50	2.0	33.6
Platelets (×10³/µL)	154	244.97 ± 101.04	71.0	597.0

The mean serum urea and creatinine concentrations were 126.39 ± 66.50 mg/dL and 6.06 ± 3.42 mg/dL, respectively. The mean serum sodium, potassium, and chloride concentrations were 137.83 ± 6.25 mmol/L, 4.98 ± 0.94 mmol/L, and 99.97 ± 5.32 mmol/L, respectively. The mean hemoglobin level was 10.00 ± 2.30 g/dL.

To further characterize the clinical burden of renal dysfunction and electrolyte imbalance among the study population, the prevalence of major biochemical abnormalities was assessed. The frequencies of anemia, electrolyte disturbances, and elevated renal biomarkers are summarized in Table 2.

Table 2. Prevalence of Major Biochemical and Electrolyte Abnormalities Among Hemodialysis Patients

Abnormality	Number of Patients (n)	Percentage (%)
Anemia (Hb < 11 g/dL)	**105/154**	68.2
Hyperkalemia (K > 5.5 mmol/L)	**26/108**	24.1
Hyponatremia (Na < 135 mmol/L)	**26/108**	24.1
Elevated Urea (> 50 mg/dL)	**123/148**	83.1
Elevated Serum Creatinine (> 1.3 mg/dL)	**123/147**	83.7

Chronic hemodialysis patients had frequent biochemical abnormalities. Anemia was present in 68.2% of patients, while raised serum urea and creatinine were detected in over 83%. Electrolyte disorders were common as well, with hyperkalemia and hyponatremia in about a quarter of the studied subjects.

Distribution Analysis and Detection of Outliers

Box plot analysis revealed a wide variability of potassium, sodium, and urea between patients on hemodialysis. Many high or low values were identified in the Kps and Ure, which is consistent with responses to metabolic instability due to ESRD-Kidney Failure/Failure of Critical Systems and Dialysis fluctuations.

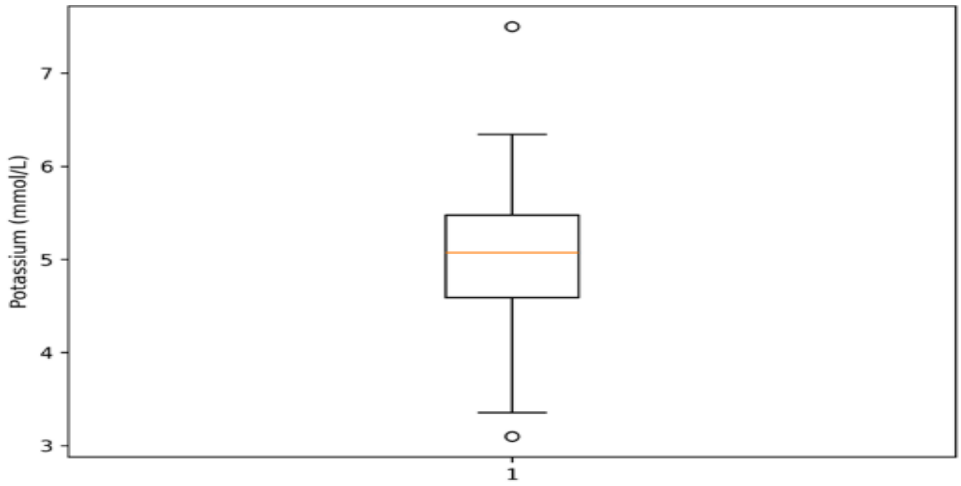

Figure 1: Box Plot of Potassium Levels Showing Hyperkalemia and Outliers.

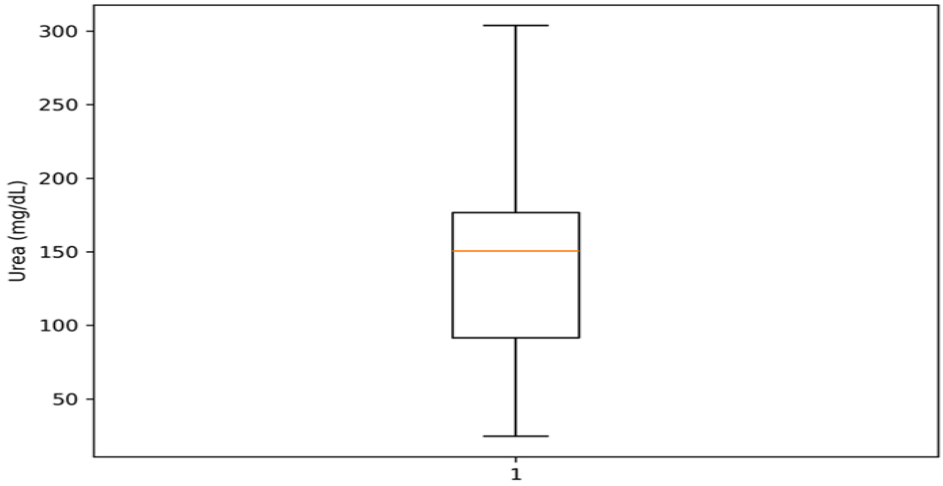

Figure 2: Box Plot of Urea Levels Showing Variability and Extreme Values.

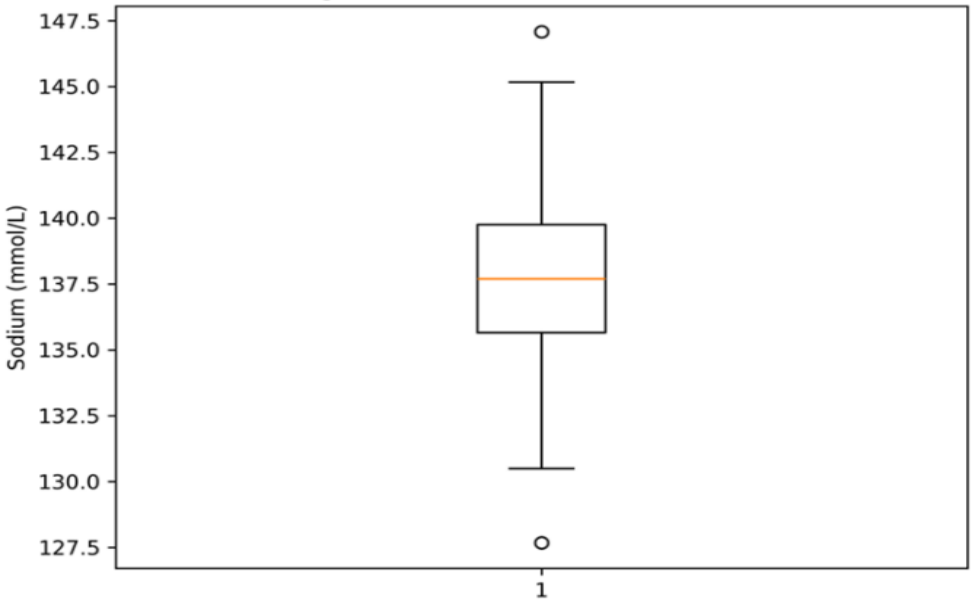

Figure 3: Box Plot of Sodium Levels Showing Distribution and Hyponatremia Cases.

To investigate the relationships among renal function biomarkers, electrolyte concentrations, and hematological parameters, Pearson correlation analysis was performed. The correlation coefficients are summarized in Table 4.

Table 4. Pearson Correlation Matrix of Renal Biomarkers, Electrolytes, and Hemoglobin.

Variables	Urea	Creatinine	Sodium	Potassium	Chloride	Hemoglobin
Urea	1.000	0.743	-0.172	0.287	-0.113	-0.253
Creatinine	0.743	1.000	-0.342	0.376	-0.239	-0.388
Sodium	-0.172	-0.342	1.000	—	0.698	0.264
Potassium	0.287	0.376	—	1.000	-0.041	-0.016
Chloride	-0.113	-0.239	0.698	-0.041	1.000	0.188
Hemoglobin	-0.253	-0.388	0.264	-0.016	0.188	1.000

Pearson correlation analysis indicated positive correlations between serum urea and serum creatinine levels (r = 0.743), P < 0.001, respectively [Table]. Creatinine had a modestly positive correlation with potassium (r = 0.376) and a moderate negative correlation with hemoglobin (r = −0.388). Sodium and chloride exhibited a very high correlation (r = 0.698), reflecting the dependence of electrolyte parameters in chronic hemodialysis patients.

3. Correlation Analysis

In correlation analysis, renal biomarkers and electrolyte levels were significantly correlated with one another. Raised creatinine levels with potassium and chloride are both positive correlations since reduced excretory function of the kidney results in electrolyte derangements. In addition, hemoglobin levels were negatively related to serum creatinine and urea in relation with impaired renal function contributed for progression of renal anemia.

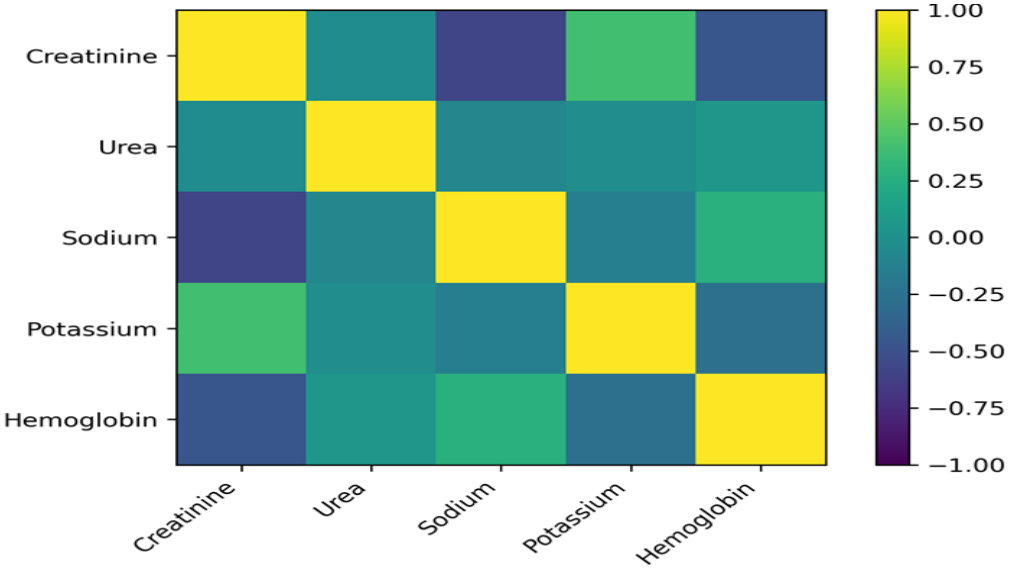

Figure 4: Pearson Correlation Heatmap of Hematological, Biochemical, and Electrolyte Parameters.

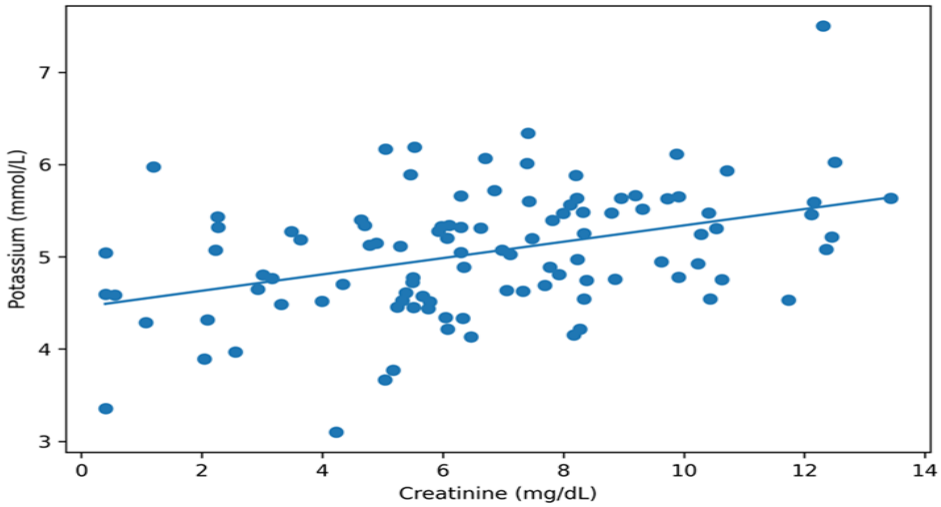

Figure 5: Scatter Plot Showing Relationship between Creatinine and Potassium.

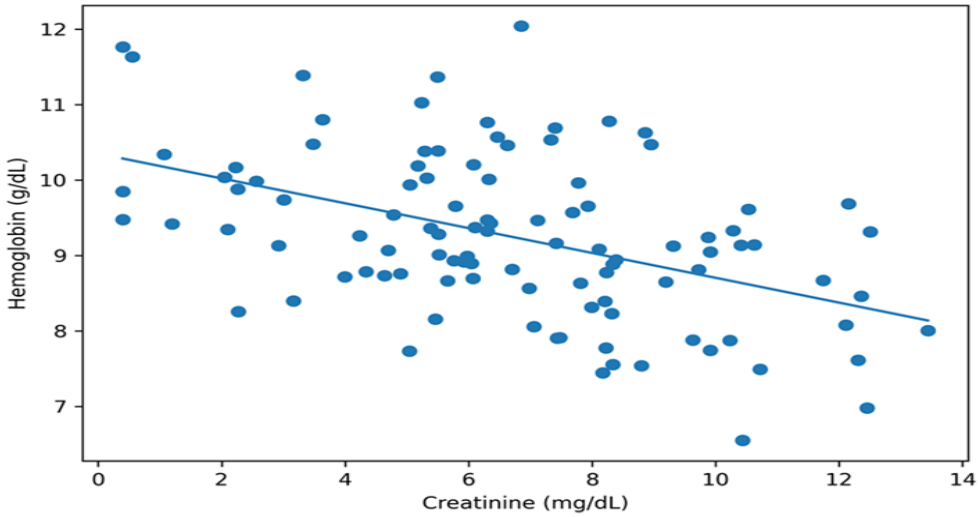

Figure 6: Scatter Plot Showing Inverse Relationship between Hemoglobin and Creatinine.

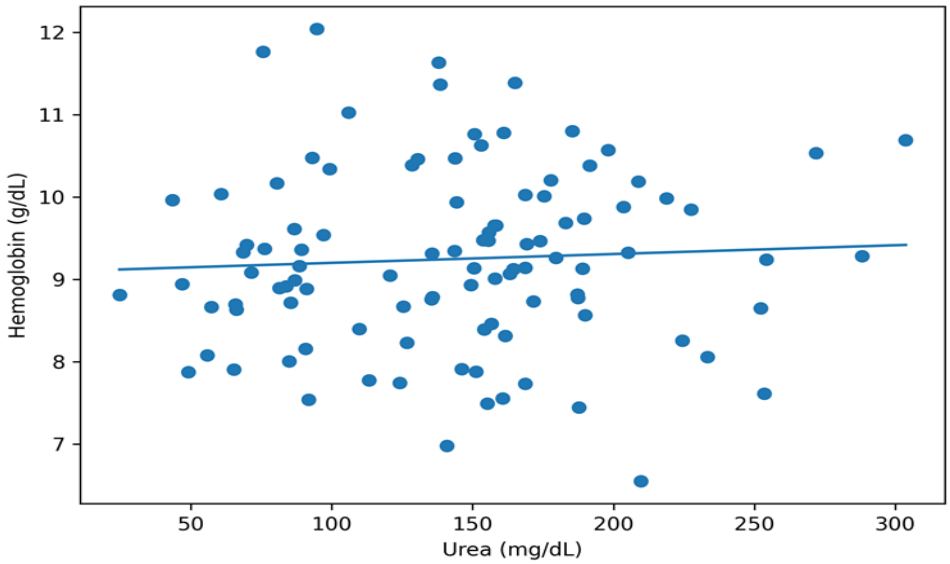

Figure 7: Scatter Plot Showing Inverse Relationship between Hemoglobin and Urea Hematological Findings.

Anemia CKD ami patients were eligible for the study, as they had decreased hemoglobin concentrations compatible with anemia of chronic kidney disease. White blood cell change reflected a chronic activation state, and the type of platelet pathology indicated potential uremic dysfunction, but also hemostatic alteration common in ESRD patients.

Electrolyte Disturbances

Typical biochemical complications among our study group included electrolyte disturbance. Hyperkalemia was prevalent with a correlation to elevated creatine. Sodium flux concorded with extrarenal fluid overload in excess and adequate sodium retention, while chloride imbalance was inversely associated with overall systemic derangement of lactate as well as acid–base balance.

Gender-Based Comparison

Inter- and intra-gender comparisons between male and female hemodialysis patients were carried out to assess possible differences in laboratory parameters. The results are shown in Table 3.

Table 3 Comparison of Laboratory Parameters According to Sex.

Parameters	Male (Mean ± SD)	Female (Mean ± SD)	p-value
Hemoglobin (g/dL)	9.89 ± 2.42	10.14 ± 2.04	0.505
WBC (×10³/µL)	7.91 ± 3.01	8.48 ± 4.11	0.338
Platelets (×10³/µL)	233.40 ± 99.66	260.00 ± 101.58	0.107
Urea (mg/dL)	135.53 ± 65.96	113.69 ± 65.66	0.048*
Creatinine (mg/dL)	6.57 ± 3.35	5.31 ± 3.44	0.032*
Sodium (mmol/L)	137.29 ± 5.66	138.60 ± 7.00	0.301
Potassium (mmol/L)	4.91 ± 0.83	5.08 ± 1.07	0.388
Chloride (mmol/L)	99.29 ± 4.97	100.93 ± 5.69	0.122

Unlike female patients, male patients had higher serum urea and creatinine concentrations ($p = 0.048$ and $p = 0.032$, respectively). There were no important variations on sex-related differences for electrolyte concentrations or hematological parameters.

DISCUSSION

This study was designed to investigate the associations between renal function markers, hematological parameters, and electrolyte disturbances in patients on chronic hemodialysis. The results revealed that long-term renal dysfunction was accompanied by major, complex metabolic and hematological alterations, confirming the belief that CKD and ESRD are potent modifiers of homeostasis. The elevated serum urea and creatinine concentrations provided confirmation of very severe impairment of glomerular filtration as well as significantly decreased renal clearance in the group studied. This coincides with previous studies highlighting serum creatinine and urea as principal parameters of decreasing kidney function and dialysis adequacy in

individuals receiving hemodialysis for end-stage renal disease (ESRD), Levey & Coresh, 2012; Yakupova et al., 2023. The last decade has provided additional evidence that serum creatinine represents a consistent and, in fact, one of the best biomarkers of renal function decline and risk stratification in dialysis patients. Thus, the findings are consistent with current concepts surrounding gradual nephron reduction and nitrogenous waste accumulation in chronic renal failure.

This also confirms the high prevalence of electrolyte derangements, particularly hyperkalemia and hyponatremia, in patients on chronic hemodialysis. Potassium levels were found to be positively correlated with serum creatinine concentrations and a manifestation of direct decrease in potassium excretion in the presence of progressive renal impairment, leading to hyperkalemia consistently. These findings are consistent with previous reports documenting hyperkalemia as one of the most clinically relevant complications of CKD due to its association with cardiac arrhythmias and sudden death (Costa et al., 2023). Likewise, the varied sodium balance may reflect either a volume overload as a result of deranged tubular regulation or osmotic shifts secondary to dialysis. Sodium dysregulation is a major contributor to cardiovascular destabilization and is associated with hypertension in the dialysis population (Lew et al., 2023). In addition, disordered serum potassium levels have been associated with cardiovascular adverse events in patients with advanced CKD or ESRD (Clase et al., 2024). Thus, current findings appear plausible and well supported by laboratory evidence and prior studies.

In this study, hematological findings indicated that all but 3 patients had low hemoglobin concentration, which confirms renal anemia is a common complication of ESRD patients undergoing maintenance hemodialysis. The hemoglobin level is inversely correlated with serum creatinine and urea, emphasising the causal nature of declining renal function in generating anemia. This finding is consistent with older studies showing that anemia of CKD is a complex syndrome due to impaired erythropoietin production, chronic inflammation, disordered iron metabolism, and shortened red blood cell lifespan, all acting synergistically (Babitt and Lin, 2012). In addition, recent real-world evidence indicates anemia is a resurgent problem in patients with Advanced CKD &ESRD, with new treatment options not resolving this issue (Macdougall, 2024). As also suggested in KDIGO 2025 guidelines, non-anemia is seen as an almost inalienable complication of CKD due to its clear correlation with CKD progression and adverse effects on QoL and cardiovascular mortality rate (Matsushita et al. 2010). Hence, the results described here are consistent with prior theories about the pathophysiology of renal anemia and its relationship to disease progression.

In addition to the patients enrolled, you are also trained on other alterations in counts for white blood cells, platelets, and anemia. The change of peripheral white blood cell dysfunction suggested the possibility that inflammatory activation was literally persistent and often accompanied by chronic hemodialysis as well as uremic toxins. The various platelet abnormalities may also reflect potential dysfunction of platelets and hemostatic disturbances secondary to uremia. These data are consistent with earlier published studies of the role that both chronic inflammation and uremic toxins had on immunity dysregulation as well as platelet dysfunction in populations with ESRD (Vanholder et al., 2003). Moreover, most knowledge about chronic inflammation has recognised for many years its significance as an integral feature of established kidney disease that was contributing to adverse clinical outcomes (Stenvinkel 2010).

Subsequent trials again found chronic systemic inflammation to be a central process causing cardiovascular complications and malnutrition as well as leading to increased mortality in hemodialysis patients (Dekker et al., 2024). Therefore, the present study builds on previously existing data by demonstrating the simultaneous association between haematological derangements and kidney impairment among these patients.

Gender differences comparisons showed slightly higher serum creatinine concentrations in male patients and slightly lower hemoglobin levels among female patients. That male patients had significantly higher serum creatinine and urea levels compared with females, whereas differences in hematological and electrolyte parameters were not statistically significant, but they can be justified due to physiological variations in muscle mass as well as hormonal influences on erythropoiesis. Earlier studies also suggested that ultimately, male patients have higher baseline creatinine levels because of larger muscle mass and therefore are more likely to have complications related to anemia (Perrone et al., 1992) compared to female patients. All of the above are plausible and consistent with basic physiology.

The major advantage and novel feature of this study is the assessment of biochemical, hematological, and electrolyte parameters within one analytical framework. While most earlier studies investigated single biomarker(s) or certain electrolyte derangement in isolation, we took a comprehensive view of the interaction between renal biomarkers, hematological parameters, and electrolyte abnormalities in advanced chronic hemodialysis patients. The integrated data presented here illustrate the global profile of AMR-associated metabolic and hematological derangements in ESRD with associated kidney replacement therapies. Thus, the findings may enhance clinical monitoring and allow for evaluations of dialysis adequacy as well as early detection of complications in hemodialysis populations. Many of the more recent recommendations strongly emphasize the need for continuous patient surveillance as a key component in individualizing dialysis management and optimizing outcomes through alignment with broader metabolic parameters, hematological considerations, and electrolyte balance (National Kidney Foundation 2024).

Although these findings speak strongly about the study, its limitations must be considered. A cross-sectional study can be criticized in its ability to infer any causal link between renal impairment and the laboratory abnormalities documented here. Moreover, the observational nature makes it susceptible to confounding and bias, and limited study size and single-centered design, which raises the question of the generalizability of this study for larger populations. Multicenter longitudinal studies with larger sample sizes in the future should be conducted to further evaluate the time response of hematological and biochemical perturbations, as well as their relationship with patient outcomes and dialysis adequacy.

In conclusion, our study confirms the previous theories and results concerning renal impairment associated with electrolyte disturbance and hematological disorder in patients with end-stage renal disease (ESRD) during long-term hemodialysis. Laboratory data support these claims and replicate earlier scientific literature (Levey & Coresh, 2012; Costa et. al., 2023; Babitt & Lin, 2012; Dekker et. al., 2024). Extending earlier work, this research also offers a combined analysis of multiple laboratory parameters across the same patient population with informative clinical implications for better managed care, improved dialysis follow-up, and optimization of risk stratification among chronic hemodialysis patients.

CONCLUSION

The current study showed that patients with chronic hemodialysis have multiple hematological, biochemical, and electrolyte abnormalities related to increasing renal dysfunction. Severe impairment of renal excretory function was confirmed with elevated serum creatinine and urea concentrations, while electrolyte disturbances, especially metabolic instability from dialysis, were highly reflective of defects in electrolyte regulation. Furthermore, decreased levels of hemoglobin and changes in leukocyte and platelet numbers indicate the presence of renal anemia, chronic inflammatory activation, and possible uremic platelet dysfunction in ESRD patients.

Our results confirm previous evidence that diseases of chronic kidney disease (CKD) involve diverse physiological systems in addition to filtration by the kidneys themselves. The correlations found between renal biomarkers and hematological or electrolyte parameters indicate that to obtain valuable actions toward integrated laboratory monitoring that bring relevant information on disease severity or dialysis adequacy, as well as risk of complications. Thus, the combined assessment of biochemical, hematological, and electrolyte markers could facilitate clinical decision-making and contribute to a more efficient management strategy in chronic hemodialysis patients.

The present study made an important contribution through its comprehensive analytical framework that assessed the association between renal biomarkers, hematological indices, and electrolyte imbalances in a single cohort of patients. It expands previous knowledge by offering additional details concerning the systemic complications of ESRD and maintenance hemodialysis.

Nevertheless, these findings should be interpreted in the context of certain limitations. A cross-sectional design was used for this study, which limited the capacity to identify any causal relationships between variables. We acknowledge the potential limitations of a relatively small sample, from only one center, and thus may not be generalizable to larger groups. Additionally, some clinically relevant variables, including dialysis duration, nutritional status, inflammatory markers, and comorbid conditions, were not analyzed in detail.

RECOMMENDATIONS

In conclusion, the current results indicate that long-term hemodialysis patients should be monitored periodically regarding hematologic, biochemical, and electrolyte parameters to achieve an early diagnosis of complications as well as to control dialysis management. Because of the close relation to cardiovascular morbidity and adverse patient outcomes, clinicians should be particularly aware of potassium balance and renal anemia as potential contributors.

Larger multicenter populations with longitudinal follow-up designs should be included in future studies to assess the evolution of hematological and biochemical abnormalities over time. Evaluation of inflammatory markers, oxidative stress, nutritional status, and dialysis adequacy indices may provide additional insight into the intricate pathophysiological mechanisms involved in CKD and its complications and ESRD. Additionally, future studies may assist in establishing individualized therapy and monitoring regimens to ameliorate morbidity and mortality as well as improve health-related quality of life in HD patients.

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