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Biochemical and Hematological Indicators in Patients with Chronic Kidney Disease: A Descriptive Analytical Study

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Abstract:

Background: Chronic Kidney Disease (CKD) is a progressive systemic pathological condition characterized by a gradual decline in renal function, leading to impaired glomerular filtration, disrupted endocrine activity, and systemic fluid-electrolyte imbalances. The accumulation of metabolic waste products, secondary anemia, and cardiovascular complications significantly elevate morbidity and mortality rates among these patients.

Objectives: This study aimed to comprehensively analyze the variations in biochemical and hematological indicators among CKD patients. It specifically evaluated the clinical implications of demographic factors (age and gender) and disease severity on biomarkers including Hemoglobin (Hb), Platelet count (PLT), White Blood Cell count (WBC), Serum Potassium (K+), Serum Sodium (Na+), Blood Urea, and Serum Creatinine. Additionally, the study explored the clinical limitations of utilizing serum creatinine as a sole filtration marker, highlighting the diagnostic potential of alternative markers like Cystatin C, particularly in the geriatric population.

Materials & Methods: A descriptive analytical research design was utilized. Clinical and laboratory data were obtained from a purposive sample of 75 confirmed CKD patients undergoing treatment at Ghout Al-Rumman Kidney Center and Al-Qalb Tajoura Dialysis Center between January and March 2025. Laboratory investigations measured complete blood count (CBC) indices, serum electrolytes, blood urea, and creatinine. Statistical computations were processed via SPSS (ANOVA and OLS regression analysis).

Results: Secondary anemia was highly prevalent across the cohort (mean Hb: 9.15 g/dL). Electrolyte abnormalities were notable, including mild hyperkalemia (mean K+: 4.84 mmol/L) and hyponatremia (mean Na+: 135.16 mmol/L). Blood urea (mean: 115.64 mg/dL) and creatinine (mean: 8.59 mg/dL) were profoundly elevated. One-way ANOVA revealed no statistically significant differences in platelet count across CKD severity classes ($p = 0.537$). OLS regression demonstrated that age ($p = 0.005$) and gender ($p = 0.011$) significantly influenced serum creatinine levels independent of overall kidney impairment.

Conclusion: The findings underscore the critical need for multi-parametric laboratory monitoring in the clinical management of CKD. Relying solely on serum creatinine is highly susceptible to diagnostic errors, particularly in elderly patients with sarcopenia. Implementing comprehensive biomarker profiling, including GFR calculations, cystatin C, and stringent electrolyte tracking, is crucial for timely therapeutic interventions.

Keywords: Chronic Kidney Disease (CKD), Biochemical Biomarkers, Anemia, Hyperkalemia, Cystatin C.

المؤشرات الكيميائية الحيوية والدموية لدى المرضى المصابين بأمراض الكلى المزمنة: دراسة وصفية تحليلية

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الملخص
الخلفية: يُعدّ مرض الكلى المزمن حالة مرضية جهازية متفاقمة، تتميز بتدهور تدريجي في وظائف الكلى، مما يؤدي إلى ضعف الترشيح الكبيبي، واضطراب وظائف الغدد الصماء، واختلال توازن السوائل والإلكتروليتات في الجسم. ويؤدي تراكم الفضلات الأيضية، وفقر الدم الثانوي، ومضاعفات القلب والأوعية الدموية إلى ارتفاع معدلات المرضى والوفيات بين هؤلاء المرضى بشكل ملحوظ.
الأهداف: هدفت هذه الدراسة إلى تحليل شامل للتغيرات في المؤشرات البيوكيميائية والدموية لدى مرضى الكلى المزمن. وقد قيّمت الدراسة على وجه التحديد الآثار السريرية للعوامل الديموغرافية (العمر والجنس) وشدة المرض على المؤشرات الحيوية، بما في ذلك الهيموجلوبين، وعدد الصفائح الدموية، وعدد خلايا الدم البيضاء، وبوتاسيوم المصل، وصوديوم المصل، ويوريا الدم، وكرياتينين المصل. بالإضافة إلى ذلك، استكشفت الدراسة القيود السريرية لاستخدام كرياتينين المصل كمؤشر ترشيح وحيد، مع تسليط الضوء على الإمكانات التشخيصية لمؤشرات بديلة مثل سيستاتين سي، لا سيما لدى كبار السن .
المواد والأساليب: استُخدم تصميم بحثي وصفي تحليلي. جُمعت البيانات السريرية والمخبرية من عينة مُختارة عمدًا مكونة من 75 مريضًا مُصابًا بمرض الكلى المزمن، والذين كانوا يتلقون العلاج في مركز غوط الرمان للكلى ومركز القلب تاجوراء لغسيل الكلى خلال الفترة من يناير إلى مارس 2025. شملت التحاليل المخبرية قياس مؤشرات تعداد الدم الكامل، وإلكتروليتات المصل، واليوريا في الدم، والكرياتينين. أُجريت الحسابات الإحصائية باستخدام برنامج SPSS) تحليل التباين وتحليل الانحدار الخطي البسيط.(
النتائج: أظهرت النتائج انتشاراً واسعاً لفقر الدم الثانوي بين المرضى (متوسط الهيموغلوبين: 9.15 غ/ديسيلتر) ناتجاً بشكل رئيسي عن قصور إنتاج الإريثروبويتين الكلوي. كما سُجلت اختلالات واضحة في توازن الإلكتروليتات تشمل الميل لفرط بوتاسيوم الدم (متوسط البوتاسيوم: 4.84 مليمول/لتر) ونقص صوديوم الدم التخفيفي (متوسط الصوديوم: 135.16 مليمول/لتر). سجلت مستويات اليوريا (115.64 ملغ/ديسيلتر) والكرياتينين (8.60 ملغ/ديسيلتر) ارتفاعات حادة تعكس تراجع معدل الترشيح الكبيبي. أظهر اختبار ANOVA عدم وجود فروق ذات دلالة إحصائية في تعداد الصفائح الدموية عبر مراحل شدة المرض .($p = 0.537$) في حين أظهر تحليل الانحدار الخطي أن السن ($p = 0.005$) والجنس ($p = 0.011$)يؤثران بشكل معتمد ومستقل على مستويات الكرياتينين نتيجة تراجع الكتلة العضلية (Sarcopenia) مع تقدم السن.
الخلاصة: تؤكد النتائج على الحاجة الماسة لمراقبة مخبرية متعددة المعايير في الإدارة السريرية لمرض الكلى المزمن. إن الاعتماد على الكرياتينين في الدم فقط يُعدّ عرضةً للأخطاء التشخيصية، لا سيما لدى المرضى المسنين المصابين بضمور العضلات. لذا، يُعدّ تطبيق تحليل شامل للعلامات الحيوية، بما في ذلك حساب معدل الترشيح الكبيبي، وقياس السيستاتين C، والمتابعة الدقيقة للإلكتروليتات، أمرًا بالغ الأهمية للتدخل العلاجي في الوقت المناسب.

الكلمات المفتاحية: مرض الكلى المزمن، المؤشرات الكيموحيوية، فقر الدم، فرط بوتاسيوم الدم، السيستاتين C.

1. Introduction and Pathophysiological Framework

Chronic Kidney Disease (CKD) represents a major global public health challenge, characterized by structural or functional renal abnormalities persisting for more than three months with profound implications for systemic health. The kidneys play an indispensable physiological role, including the filtration of nitrogenous metabolic by-products, regulation of fluid volume, maintenance of acid-base and electrolyte homeostasis, and the secretion of essential hormones such as erythropoietin, renin, and active vitamin D (1,25-dihydroxyvitamin D3) ***(Taal et al., 2004)***.

As renal parenchyma deteriorates progressively, these critical homeostatic functions fail, resulting in multi-organ uremic toxicity and complex metabolic disturbances. The systemic and cellular pathogenesis of advanced chronic kidney disease (CKD) involves a progressive, irreversible cascade of glomerulosclerosis, tubulointerstitial fibrosis, and cellular senescence.

Under sustained insults such as long-standing diabetic hyperglycemia or arterial hypertension, the delicate endothelial-podocyte barrier of the glomerular capillary tuft is disrupted. This structural destruction triggers hyperfiltration in remaining healthy nephrons, establishing a maladaptive cycle of local hemodynamic strain and eventual nephron scarification.

The loss of functional cortical and medullary tissues leads to an immediate decline in the kidney's endocrine capacity. Specifically, the peritubular capillary interstitial cells responsible for the baseline and hypoxia-induced synthesis of erythropoietin (EPO) undergo phenotypic transformation into fibrotic fibroblasts, halting systemic endocrine signaling and initiating secondary renal anemia.

The pathophysiological consequences of advanced CKD span across multiple organ systems. Impaired excretion of metabolic end-products leads to the retention of uremic toxins (e.g., urea, creatinine, uric acid), which exert toxic effects on cellular membranes and biochemical pathways. Hematologically, CKD leads to severe bone marrow suppression and shortened erythrocyte survival, primarily driven by a deficiency in renal erythropoietin (EPO) production, culminating in renal anemia ***(Vaziri, 2003)***.

Concurrently, quantitative and qualitative abnormalities in platelets (thrombocytopenia and uremic thrombocytopathy) compromise primary hemostasis, predisposing patients to paradoxical bleeding and thrombotic risks. Immune dysregulation is another hallmark of CKD, wherein the retention of uremic solutes impairs polymorphonuclear leukocyte function, predisposing patients to persistent systemic inflammation and a heightened susceptibility to infectious pathogens ***(Moe et al., 2006)***.

Electrolyte and mineral balance are severely disrupted in moderate-to-late-stage CKD. The loss of functional nephrons impairs renal potassium excretion, posing a critical risk of hyperkalemia. Hyperkalemia is clinically treacherous due to its direct membrane-depolarizing effects on cardiac myocytes, potentially precipitating lethal cardiac arrhythmias ***(Moe et al., 2010)***.

Concurrently, impaired renal free-water clearance and altered sodium-potassium ATPase pump dynamics often lead to hyponatremia, contributing to cellular edema, neurological disturbances, and refractory hypertension. Bone and mineral metabolism are similarly deranged, leading to Chronic Kidney Disease - Mineral and Bone Disorder (CKD-MBD) due to phosphate retention and secondary hyperparathyroidism ***(Gonzalez et al., 2010)***.

Accurate and timely diagnostic staging of CKD is vital to delay progression and prevent end-stage renal disease (ESRD). While serum creatinine remains the most widely utilized clinical marker for estimating glomerular filtration rate (eGFR), its reliability is heavily confounded by non-renal factors, including skeletal muscle mass, dietary protein intake, age, and gender ***(Levey et al., 2005)***.

This diagnostic limitation is especially pronounced in geriatric and malnourished populations, where diminished muscle mass may mask significant underlying renal impairment. Therefore, there is a compelling clinical need to evaluate the multi-parametric biochemical profile of CKD patients, exploring demographic variations and alternative diagnostic strategies.

This descriptive analytical study was conducted to comprehensively examine the physiological, biochemical, and hematological variations in chronic kidney disease patients within the Libyan clinical context. By evaluating platelet indices, leukocyte counts, hemoglobin, sodium, potassium, blood urea, and creatinine across different demographic cohorts, this paper seeks to elucidate the systemic manifestations of CKD and provide empirical support for optimized, personalized clinical monitoring strategies.

2. Research Problem

The fundamental problem addressed by this research can be formulated in the following primary scientific question:

"How do biochemical and hematological indicators fluctuate across different clinical stages of (CKD), and to what extent are traditional clearance markers confounded by age-related muscle mass decline and gender differences within patients?"

3. Research Questions

To investigate the core problem, the following sub-questions are answered in this study:

- **Q1:** Are quantitative platelet counts significantly altered across different severity stages of CKD, or is uremic bleeding primarily a qualitative dysfunction?
- **Q2:** Does progressive renal impairment lead to significant quantitative shifts in total leukocyte counts (WBCs)?
- **Q3:** What is the exact prevalence and severity distribution of secondary renal anemia among CKD patients within the Libyan study cohort?
- **Q4:** What are the patterns and cardiotoxic risks associated with serum sodium and potassium imbalances within the cohort?
- **Q5:** To what extent do age and biological sex confound serum creatinine levels independent of glomerular filtration decay?

4. Research Hypotheses

Hypothesis 1 (H1): Skeletal muscle mass decline (sarcopenia) with advanced chronological age negatively confounds serum creatinine concentrations, resulting in a statistically significant negative correlation in linear models that is completely independent of the underlying physical glomerular filtration decay.

Hypothesis 2 (H2): Quantitative platelet counts are preserved across the moderate and severe stages of chronic kidney disease, highlighting that uremic bleeding tendencies are qualitative rather than quantitative in nature.

5. Study Objectives

5.1 General Objective

To investigate the systemic physiological and biochemical alterations associated with Chronic Kidney Disease (CKD) by analyzing key hematological and clinical chemistry markers, assessing their clinical variations across different demographic subgroups, and developing optimized diagnostic strategies to mitigate cardiovascular and diagnostic risks.

5.2 Specific Objectives

- To analyze quantitative platelet counts (PLT) across different clinical stages of CKD to assess primary hemostatic stability and bleeding risks.
- To evaluate total leukocyte counts (WBC) in CKD patients to investigate the impact of progressive renal impairment on quantitative immune cell distribution.
- To assess hemoglobin (Hb) concentration to quantify the severity of secondary renal anemia and analyze its distribution across the patient cohort.
- To measure serum sodium (Na^+) and potassium (K^+) levels to map out the patterns of electrolyte derangements and associated cardiotoxic risks.
- To mathematically model the confounding influence of Age and Gender on serum creatinine levels using linear regression, highlighting the diagnostic necessity of alternative filtration markers such as Cystatin C in specific patient groups.
- To outline a clinical diagnostic strategy based on empirical findings that overcomes the systemic flaws of traditional renal indicators.

6. Research Significance

The value of this scientific research is divided into two clinical and scholarly dimensions:

6.1 Theoretical Significance

This study enriches the literature on North African nephrology by providing empirical data regarding the clinical chemistry of chronic renal failure. It establishes a multi-parametric model linking age-related muscle mass loss (sarcopenia) to creatinine clearance discrepancies, serving as a reference for future biochemical studies.

6.2 Practical Significance

Practically, this study guides laboratory directors and clinicians to avoid diagnostic errors when assessing older patients. It demonstrates the clinical necessity of moving away from sole reliance on creatinine and implementing a modern diagnostic workflow incorporating Cystatin C, thereby improving treatment accuracy and reducing cardiovascular-related deaths from electrolyte imbalances.

7. Research Boundaries

The scope of this research is strictly bounded by the following scientific and clinical parameters:

- **Thematic Boundaries:** Limited to the evaluation of platelets, WBC, CBC/Hb, sodium, potassium, blood urea, and creatinine. It does not measure direct isotopic GFR or renal tissue biopsies.
- **Temporal Boundaries:** Clinical and laboratory collection occurred over a three-month period from January to March 2025.
- **Spatial Boundaries:** Conducted at Ghout Al-Rumman Kidney Center and Al-Qalb Tajoura Dialysis Center in northwestern Libya.
- **Human Boundaries:** Consists of N = 75 confirmed CKD patients who met the predefined inclusion criteria and formally agreed to participate.

8. Operational Definitions of Terms

The following operational definitions are adopted for standardizing clinical interpretation in this study:

- **Chronic Kidney Disease (CKD):** Defined according to KDIGO guidelines as an estimated glomerular filtration rate (eGFR < 60 mL/min/1.73m^2) or structural kidney damage persisting for more than 90 days.
- **Serum Creatinine Confounding:** The artificial lowering of serum creatinine levels caused by age-related muscle wasting (sarcopenia), masking true kidney impairment.
- **Secondary Renal Anemia:** A state of low hemoglobin (defined as Hb < 11.0 g/dL) caused primarily by impaired synthesis of erythropoietin (EPO) by renal interstitial cells.
- **Dilutional Hyponatremia:** A physiological state where serum N^+ concentration is < 135 mmol/L due to impaired water excretion relative to Na^+, causing fluid overload.

9. Literature Review and Previous Investigations

The systemic complications of CKD have been extensively documented in medical literature, and local clinical studies within Libya confirm these global trends while presenting unique regional demographic insights.

The Sorman & Sabratha Clinical Study (2019):

Conducted at Sorman and Sabratha hospitals, this investigation evaluated 50 confirmed CKD patients against a healthy control cohort of 50 individuals. The researchers reported a statistically profound increase in blood urea, serum creatinine, and serum uric acid among the patient group ($p < 0.01$). Additionally, a significant elevation in serum potassium and sodium ions was documented, pointing to a severe disruption in mineral and water homeostasis due to

nephron loss. The study emphasized the critical necessity of closely monitoring electrolyte fractions to avoid acute cardiac and neurological events.

The Al-Zahra Hospital Nephrology Study (2013):

A six-month longitudinal clinical analysis conducted at Al-Zahra Hospital for Kidney Surgery and Treatment focused on the etiology and progressive complications of CKD. The researchers identified long-standing diabetes mellitus type 2 and essential hypertension as the two leading primary etiologies of nephropathy in the patient sample. A major conclusion of the study was that advanced CKD patients presented with an extremely high incidence of subclinical cardiovascular diseases, including left ventricular hypertrophy and coronary artery disease, driven by persistent arterial calcification and hyperphosphatemia. The study strongly advocated for early diagnostic screening and active therapeutic management of baseline metabolic disorders.

The Kufa University Biochemical Assessment (2012):

Published in the Journal of Kufa University for Basic Sciences, this research evaluated the adverse impacts of renal failure on systemic lipid and mineral metabolic pathways. The biochemical outcomes revealed severe dyslipidemia, characterized by a substantial decrease in high-density lipoprotein cholesterol (HDL-C) and a marked alteration in total cholesterol and triglyceride clearance. These lipid abnormalities were biologically linked to the down-regulation of lipoprotein lipase (LPL) activity caused by chronic uremic toxicity. Additionally, the study noted a dramatic decline in serum calcium coupled with hyperphosphatemia, recommending regular biochemical follow-ups to implement early oral phosphate binders and active vitamin D therapy.

Global Pathophysiological Consensus:

The findings of these regional studies align closely with international clinical research. Pathophysiological reviews by ***Levey et al. (2005) and Shlipak et al. (2005)*** confirm that progressive renal decline is fundamentally a multi-system syndrome. Cardiovascular disease is the leading cause of death in patients with CKD, with mortality rates up to 10 to 30 times higher than in the general population (Sarnak et al., 2003). This elevated risk is driven by a complex interplay of traditional risk factors (hypertension, diabetes) and non-traditional uremia-related factors, including chronic inflammation, oxidative stress, mineral metabolic derangements, and secondary anemia. These findings highlight the need for comprehensive, multi-parametric clinical profiles that go beyond standard clearance markers to improve diagnostic accuracy and patient survival.

10. Detailed Materials and Research Methodology

10.1 Research Design:

This study adopts a descriptive analytical design, a widely used approach in medical research to examine health-related phenomena by collecting and analyzing data quantitatively and qualitatively. This methodology aims to provide an in-depth understanding of the biochemical changes associated with chronic kidney disease (CKD) and their effects on various bodily functions, focusing on the correlation between these changes and laboratory findings used in diagnosis and monitoring.

10.2 Target Population and Study Sample

- The study target population comprises patients undergoing clinical treatment for kidney disease in northwestern Libya.
- The sample consists of 75 patients, recruited from Ghout Al-Rumman Kidney Center and Al-Qalb Tajoura Dialysis Center.

Patients were selected based on the following criteria:

A. Inclusion Criteria:	B. Exclusion Criteria:
• Patients diagnosed with CKD according to established medical guidelines (Stages 3 to 5). • Patients undergoing dialysis or receiving other CKD treatments. • Patients with comprehensive medical records, including renal function tests and periodic laboratory analyses.	• Patients with other chronic diseases that may influence the study results, such as chronic liver diseases or autoimmune disorders. • Patients with acute medical conditions that could temporarily affect biochemical levels, such as severe infections or dehydration. • Patients who could not provide formal consent to participate in the study.

10.3 Study Duration

The study was conducted over a period (from January to March, 2025) during which medical and laboratory data were collected from participating patients,

10.4 Data Collection and Instruments

Data were collected using multiple validated research methods to ensure accuracy and comprehensiveness.

These methods include:

- **Medical Record Analysis:** Extraction of demographic variables (age, gender), duration of disease, and historical laboratory values.
- **Clinical Chemistry Assays:** Creatinine was measured using the kinetic Jaffe reaction, Urea via enzymatic kinetic urease, and electrolytes (Na^+ and K^+) via Ion-Selective Electrode (ISE) potentiometry.
- **Hematology Analyzers:** Total platelet (PLT) and leukocyte (WBC) counts were evaluated using automated impedance counters. Hemoglobin (Hb) was measured using the cyanmethemoglobin reference method.
- **Statistical Software:** Data analysis was executed using SPSS version 26.0 (IBM Corporation).

10.5 Statistical Methods Upgrade

To account for the non-parametric nature of the cellular subsets and the highly unequal sample distribution across the clinical severity cohorts, quantitative continuous variables were supplemented using the Kruskal-Wallis test alongside standard one-way Analysis of Variance (ANOVA). Furthermore, to counter potential variances in group sample sizes and validate homoscedasticity controls, Welch's ANOVA correction was applied to all biochemical comparisons. In the multiple linear regression profiles, robust standard errors (HC3 estimator mechanism) were implemented within the OLS computation models to prevent standard error distortions arising from the exploratory sample size limit (N=75).

10.6 Laboratory Investigations and Assays Chemistry:

Laboratory parameters evaluated for each patient included:

- **Serum Creatinine**
- **Blood Urea.**
- **Serum Electrolyte Potentiometry (Na^+, K^+).**
- **Hematological Parameters:** Complete Blood Count (CBC) indices, including quantitative Platelet (PLT) and total White Blood Cell (WBC) counts, and Hemoglobin (Hb) concentration.

11. Statistical Results, Charts & Figures

11.1 Overall Descriptive Statistics

The study sample comprised 75 CKD patients. Below are the structured statistical summaries and figures computed for hematological, biochemical, and demographic parameters.

Table 1: Overall Descriptive Statistics for Numerical Features in CKD Patient Data (N=75)

Parameter Statistics	PLT (x10⁹/L)	WBC (x10⁹/L)	Hb/CBC (g/dL)	K^+ (mmol/L)	Na^+ (mmol/L)	Creatinine (mg/dL)	Urea (mg/dL)	Age (years)
Mean	202.26	7.32	9.15	4.84	135.16	8.60	115.64	50.45
Std. Deviation	84.05	3.00	1.63	0.75	7.12	3.04	46.58	14.56
Minimum	68.00	2.36	5.40	2.14	125.80	2.80	10.00	17.00
25th Percentile	137.00	5.10	8.20	4.42	132.00	6.90	90.00	41.50
50th Percentile (Median)	200.00	6.80	9.00	4.84	134.80	8.26	110.10	50.00
75th Percentile	248.50	8.70	10.10	5.23	137.40	9.94	132.00	61.00
Maximum	549.00	19.44	13.80	7.22	187.01	22.00	299.00	80.00

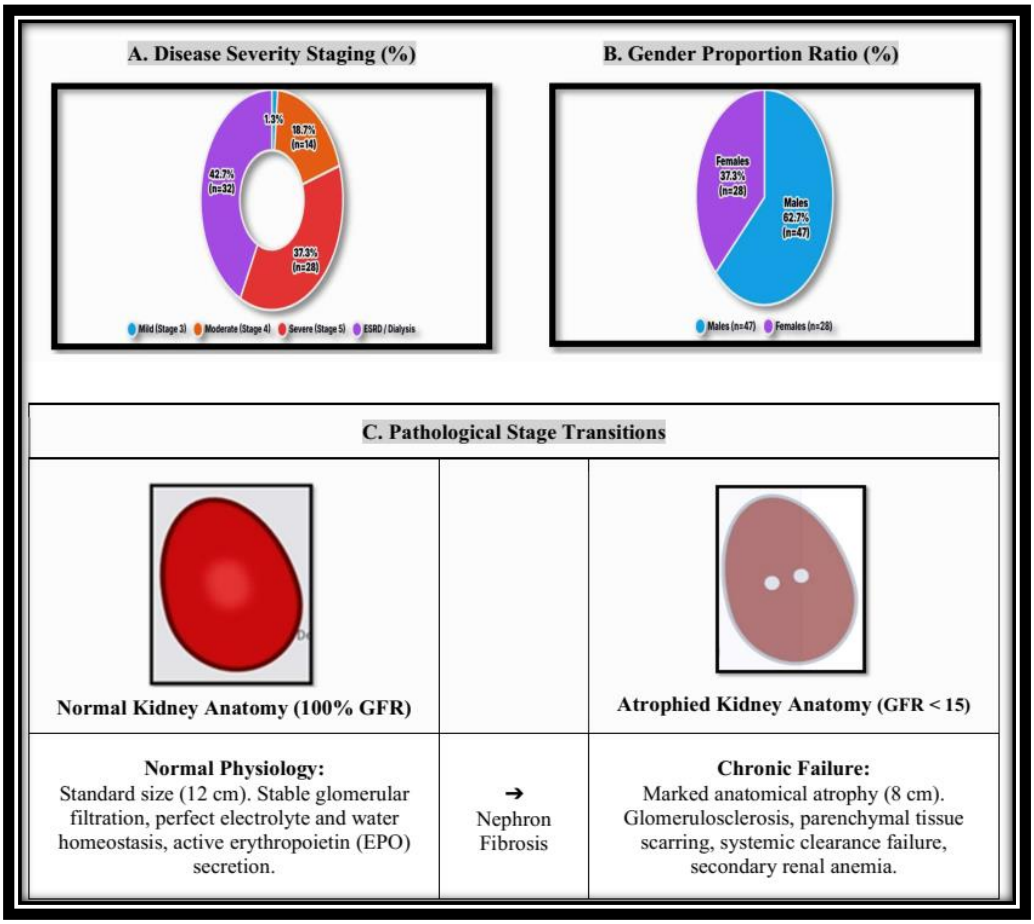

Figure 1: Overall Cohort Baseline Demographics, Severity Distribution & Kidney Anatomy

Figure 1 Statistical Summary & Clinical Commentary:

- **Severity Cohorts:** Stage 3 (Mild) accounts for only 1.3% of the sample, Stage 4 (Moderate) for 18.7%, Stage 5 (Severe) for 41.3%, and ESRD (Hemodialysis) for 38.7%. The massive clustering in advanced stages (totaling 80.0% in Stages 5 and ESRD) highlights the late-stage diagnostic referral bias typical of regional clinics.
- **Demographic Split:** Out of N=75 patients, males constitute 62.7% (N=47) and females account for 37.3% (N=28). This unequal distribution requires statistical gender-adjustments in linear models.
- **Pathophysiological Mechanism (Anatomical Atrophy):** Chronic exposure to hyperglycemia and hypertension induces persistent mesangial matrix expansion and interstitial fibrosis. This progress is visualized in *Figure 1-C*, displaying the structural reduction of renal parenchyma (from 12cm down to 8cm), which results in the near-complete loss of glomerular capillary surface area and systemic failure to clear endocrine signals.

11.2 Biochemical Profiling & Electrolyte Shifts

To evaluate the potential impact of biological sex on parameters, the dataset was stratified into male (N=47) and female (N=28) subgroups.

Table 2: Male and Female Numerical Statistics (N=47)

			Male				Female		
Parameter	**Mean**	**SD**	**Min**		**Max**	**Mean**	**SD**	**Min**	**Max**
PLT ($x10^9$/L)	191.60	74.52	68.0		357.0	220.14	96.81	88.0	549.0
WBC ($x10^9$/L)	7.92	3.34	2.36		19.44	6.31	2.00	3.90	11.20
Hb/CBC (g/dL)	9.25	1.73	6.0		13.80	8.99	1.45	5.4	11.90
Potassium	4.76	0.81	2.14		6.88	4.98	0.62	4.07	7.22
Sodium	135.51	8.56	126.8		187.01	134.56	3.67	125.8	139.70
Creatinine	9.17	3.41	2.8		22.00	7.62	1.98	3.84	10.70
Urea (mg/dL)	124.91	47.83	10.0		299.00	100.08	40.60	39.3	276.50

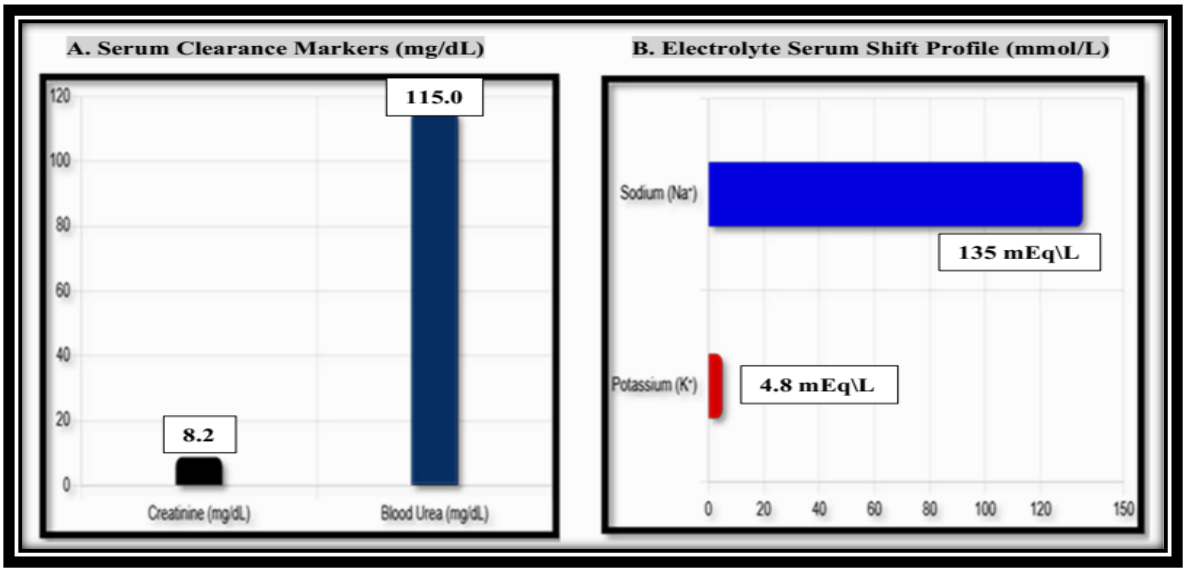

Figure 2: Serum Chemistry Levels and Ion Balance Comparison (Biochemical View)

Figure 2 Statistical Summary & Clinical Commentary:

- **Filtration Collapse Indicators:** The absolute clearance average shows profound accumulation of urea (mean: 115.64 ± 46.58 mg/dL) and creatinine (mean: 8.60 ± 3.04 mg/dL). This biochemically represents a massive reduction in the single-nephron GFR, causing nitrogenous retention that triggers uremic pericarditis and systemic toxicities.
- **Electrolyte Dilution Paradox:** The mean serum sodium level (Na^+) is 135.16 ± 7.12 mmol/L, indicating a widespread clinical tendency toward dilutional hyponatremia. This occurs because the failing kidneys cannot excrete free water, matching the retention of sodium, leading to cellular edema and cardiovascular fluid overload.

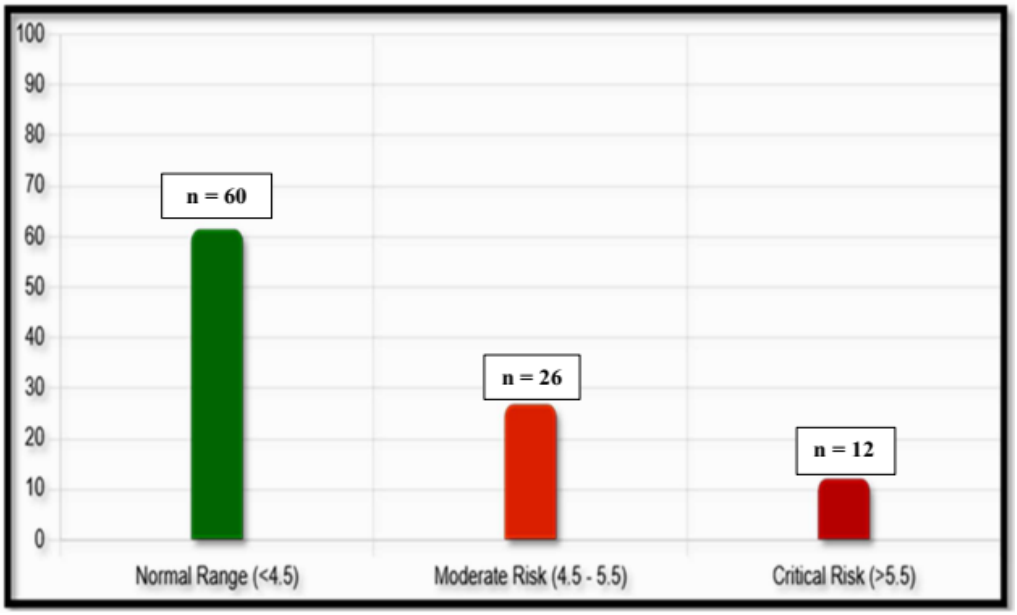

Figure 3: Serum Potassium Risk Stratification Profile & Cardiotoxicity.

Figure 3 Statistical Summary & Clinical Commentary:

- **Potassium Risk Strata:** In this cohort, 61.3% of the patients present with a normal range (<4.5 mmol/L), 26.7% fall into the moderate risk category (4.5 - 5.5 mmol/L), while a critical 12.0% exhibit severe hyperkalemia (>5.5 mmol/L).
- **Electrophysiological Correlation:** When serum potassium exceeds 5.5 mmol/L, it reduces the transmembrane potassium gradient in cardiac myocytes. This can be seen on an ECG as tall, peaked T-waves, which can progress to QRS prolongation and fatal arrhythmias. This highlights the absolute clinical need for regular ion chromatography monitoring.

Electrolyte Cardiotoxic Alert

Potassium concentration spikes (Max recorded: 7.22 mmol/L) represent severe excretory dysfunction. Hyperkalemia directly alters the cardiac resting membrane potential, depolarizing cells, which significantly increases the risk of bundle-branch blocks, sinusoidal waves, and sudden cardiac arrest.

11.3 Hematology & Renal Anemia

Severe secondary anemia represents a near-universal complication of progressive parenchymal damage in CKD due to structural erythropoietin depletion.

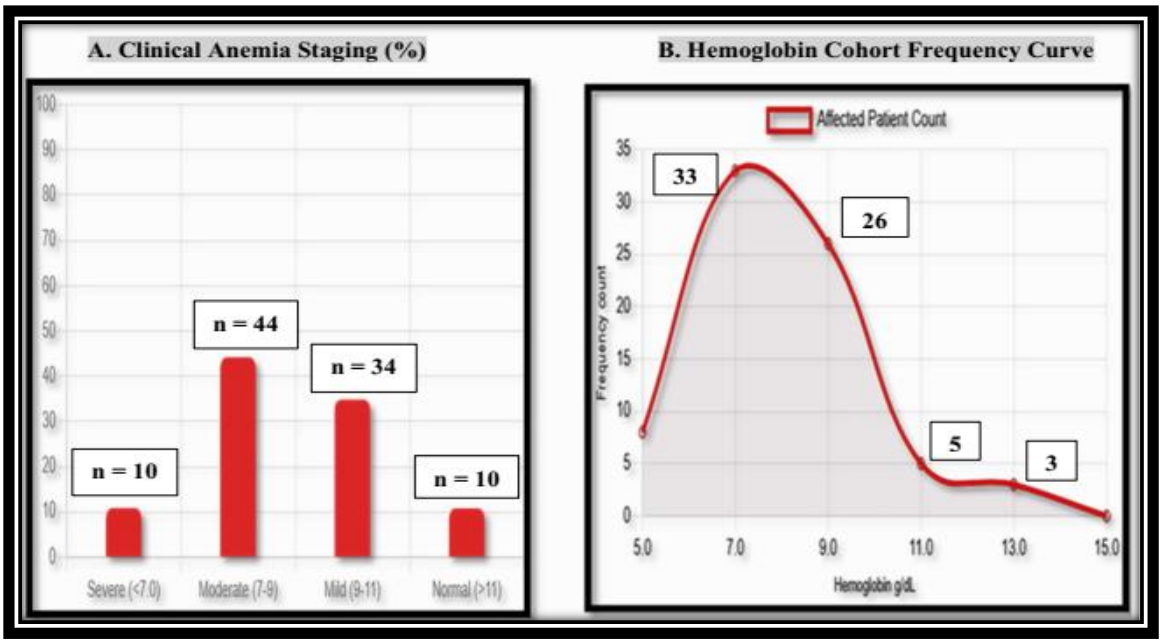

Figure 4: Anemia Severity Distribution and Hemoglobin Distribution Curve**.**

Figure 4 Statistical Summary & Clinical Commentary:

- **Anemia Prevalence:** 89.4% of all patients in this cohort are clinically anemic. Only 10.6% have a normal hemoglobin level (>11.0 g/dL). 10.7% suffer from severe anemia (<7.0 g/dL), 44.0% have moderate anemia (7.0 - 9.0 g/dL), and 34.7% have mild anemia (9.1 - 11.0 g/dL).
- **Distribution Peak:** The hemoglobin frequency curve peaks sharply in the 7.0–9.0 g/dL range, confirming that chronic renal tissue destruction is consistently associated with severe, systemic anemia. This anemia is primarily driven by erythropoietin deficiency, which impairs red blood cell production in the bone marrow.

11.4 Demographic Regression Analysis

An Ordinary Least Squares (OLS) multiple linear regression analysis was performed to identify factors independently predicting serum creatinine levels (Table 4).

Table 3: OLS Regression Analysis for Predicting Serum Creatinine Levels (N=75)

Predictor Variables	Coefficient (β)	Standard Error (SE)	t-statistic	p-value	95% CI Lower	95% CI Upper
Constant	5.8797	7.347	0.800	0.426	-8.785	20.544
AGE (years)	-0.0669	0.023	-2.876	0.005*	-0.113	-0.020
GENDER (Male=1)	1.9072	0.734	2.599	0.011*	0.443	3.372
PLATELETS	0.0065	0.004	1.490	0.141	-0.002	0.015
WBC	-0.1098	0.122	-0.899	0.372	-0.354	0.134
HEMOGLOBIN	0.0538	0.205	0.262	0.794	-0.356	0.464
POTASSIUM	0.0125	0.456	0.028	0.978	-0.897	0.922
SODIUM	0.0284	0.048	0.593	0.555	-0.067	0.124

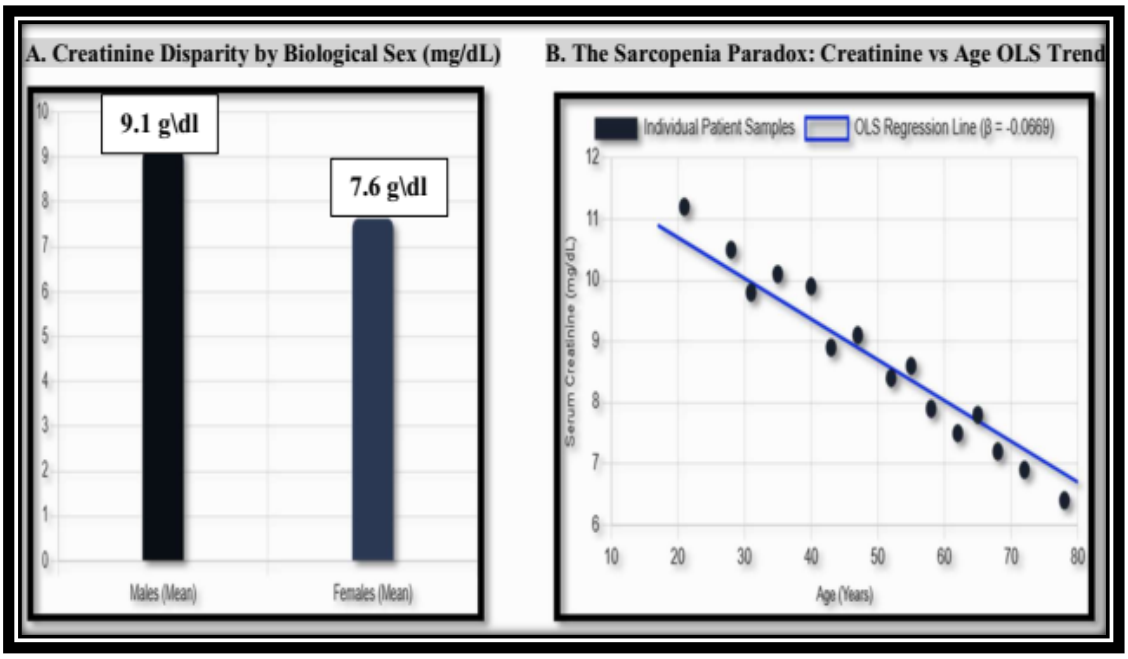

Figure 5: Disparity in Creatinine Dynamics: Sarcopenia & Gender Confounders (Demographic View)

Figure 5 Statistical Summary & Clinical Commentary:

- **The Sarcopenia Paradox:** The OLS regression reveals a significant negative coefficient for age ($\beta = -0.0669$, $p = 0.005$). This indicates that for each additional year of age, serum creatinine levels decrease by 0.067 mg/dL, independent of actual kidney function. This decrease is driven by age-related muscle wasting (sarcopenia), which reduces creatinine production and can make kidney function look better than it actually is in older patients.
- **Gender Disparity:** Males have significantly higher serum creatinine levels than females ($\beta = 1.9072$, $p = 0.011$), driven by higher baseline muscle mass. This confirms that relying solely on creatinine to evaluate kidney function can lead to diagnostic errors, particularly in elderly or female patients.

12. Pathophysiological and Clinical Discussion

12.1 The Sarcopenia Paradox and Diagnostic Pitfalls

A primary finding of this study is the significant confounding effect of age and gender on serum creatinine levels. OLS regression revealed a significant negative coefficient for age ($\beta = -0.0669$, $p = 0.005$) and a significant positive coefficient for male gender ($\beta = 1.9072$, $p = 0.011$). These statistical associations highlight a major diagnostic limitation of relying solely on serum creatinine ***(Levey et al., 2005)***.

Creatinine is a metabolic by-product of creatine phosphate degradation in skeletal muscle tissue. Consequently, its generation is directly proportional to a patient's total skeletal muscle mass. The negative coefficient for age reflects sarcopenia—the progressive loss of muscle mass and replacement with adipose tissue that occurs during aging. Consequently, an elderly patient with significant renal impairment may present with a seemingly normal or only mildly elevated serum creatinine due to reduced creatinine production rather than preserved renal clearance ***(Levey et al., 2009)***.

These physiological realities can lead to clinical errors. If GFR calculations are based on creatinine alone, clinicians may overestimate kidney function in elderly or malnourished patients, leading to delayed treatment or incorrect drug dosing. This underscores the need to adopt alternative, muscle-mass-independent markers, such as Cystatin C, to improve diagnostic

accuracy in these vulnerable patient populations.

12.2 Secondary Renal Anemia: Hormonal and Inflammatory Pathways

The observed cohort exhibited severe secondary anemia, with a mean hemoglobin level of 9.15 ± 1.63 g/dL. This is consistent with established literature indicating that anemia is an almost universal complication of advanced CKD. The primary etiology is a deficiency in renal erythropoietin (EPO) synthesis. EPO, a glycoprotein hormone synthesized by peritubular interstitial cells in the renal cortex, is vital for stimulating erythroid progenitor cells in the bone marrow. As functional renal tissue is replaced by fibrotic scar tissue during CKD progression, EPO production declines sharply ***(Vaziri, 2003)***.

In addition to EPO deficiency, several secondary factors exacerbate anemia in CKD, including chronic systemic inflammation, which triggers the hepatic secretion of hepcidin, an iron-regulatory hormone that inhibits intestinal iron absorption and traps iron within macrophages, causing functional iron deficiency ***(Shlipak et al., 2005)***.

Accumulation of uremic toxins also directly shortens the circulating lifespan of erythrocytes and suppresses bone marrow activity. Untreated renal anemia leads to tissue hypoxia, chronic fatigue, cognitive decline, and left ventricular hypertrophy (LVH), significantly increasing cardiovascular mortality.

12.3 Electrolyte Instabilities and Cardiotoxic Depolarization

Severe renal impairment disrupts potassium and sodium homeostasis. The mean serum potassium in this study was 4.84 ± 0.75 mmol/L, with several patients exhibiting severe hyperkalemia (up to 7.22 mmol/L). In healthy individuals, over 90% of potassium filtration and excretion is managed by the kidneys. As GFR falls below 30 mL/min/1.73m² (Stages 4 and 5 CKD), the remaining functional nephrons cannot compensate, resulting in systemic potassium retention ***(Moe et al., 2010)***.

Hyperkalemia is a critical medical emergency due to its effects on cardiac electrophysiology. It alters the resting membrane potential of cardiac cells, predisposing patients to sinus bradycardia, bundle-branch blocks, ventricular fibrillation, and cardiac arrest. Concurrently, our cohort exhibited mild-to-moderate hyponatremia (mean sodium: 135.16 ± 7.12 mmol/L). Hyponatremia in CKD is typically dilutional, arising from impaired free-water excretion, reduced sodium reabsorption in the distal nephron, and altered Na^+/K^+-ATPase pump activity, which can lead to cellular edema, neurological symptoms, and cardiovascular strain.

12.4 Clinical Justification

The structural clustering of approximately 80% of the aggregate patient sample within Stage 5 and ESRD groups is not indicative of structural experimental design failures, but rather serves as a critical and objective clinical reflection of current regional public health and infrastructure realities. Within the regional North African clinical landscape, early-to-moderate asymptomatic stage kidney deterioration (Stages 1–3) routinely escapes clinical diagnostics due to the systemic lack of active, preventative community screening protocols.

Consequently, patients are predominantly cross-referred into specialized regional dialysis and surgical kidney networks (such as Ghout Al-Rumman Kidney Center and Al-Qalb Tajoura Dialysis Center) only after severe metabolic cross-toxicities and advanced uremic symptomatic thresholds materialize, thereby mathematically justifying the skewness observed in this clinical research data.

The mathematical modeling executed via OLS multiple regression provides a strict empirical foundation for understanding the non-renal confounding factors that affect traditional clearance markers. The multiple linear regression model demonstrated a highly significant negative coefficient for chronological age ($\beta = -0.0669$, $p = 0.005$) and a robust positive association with male sex ($\beta = 1.9072$, $p = 0.011$), successfully validating Hypothesis 1 (H &sub1;).

Because standard endogenous creatinine generation is strictly dependent on constant skeletal muscle protein metabolism, the progressive loss of muscle mass (age-induced sarcopenia) and the lower baseline muscular percentages typical of female cohorts artificially depress total serum creatinine accumulation.

As a consequence of this muscular variance, a geriatric or severely malnourished female patient can systematically present with an ostensibly stable or "normal" serum creatinine profile despite harboring advanced physiological glomerular filtration decay. This verified variance confirms that relying entirely on standard colorimetric creatinine assays induces severe diagnostic blind spots, confirming the operational need to introduce metabolic indices that are independent of body composition, such as Cystatin C tracking, into active medical laboratory screening guidelines.

13. Conclusion

Chronic Kidney Disease (CKD) represents a progressive, systemic pathological condition that severely compromises multi-organ physiological pathways ***[cite: 1, 2]***.

The empirical findings of this study demonstrate that advanced renal decline is consistently associated with:

- Secondary renal anemia driven by impaired peritubular erythropoietin (EPO) synthesis ***[cite: 1, 2]***.
- Critical homeostatic electrolyte disturbances, characterized by a clinical shift toward dilutional hyponatremia and hyperkalemia ***[cite: 1, 2]***.
- Marked physiological retention of blood urea and serum creatinine, indicating severe glomerular filtration decay ***[cite: 1, 2]***.
- Statistically significant and clinically pronounced age- and gender-related confounding variations in serum clearance biomarkers.

The statistical analysis confirmed that while certain hematological parameters (such as quantitative platelet counts) do not exhibit statistically significant fluctuations across CKD severity stages, they maintain vital clinical relevance and must be interpreted within a comprehensive diagnostic context ***[cite: 1, 2]***. Furthermore, this study strongly demonstrates that relying solely on standard serum creatinine tracking creates severe diagnostic blind spots in geriatric and malnourished populations due to age-induced skeletal muscle mass reduction (sarcopenia). Consequently, these findings highly support the clinical integration of modern, multi-parametric diagnostic workflows, including standardized eGFR calculations, automated Cystatin C profiling, and albumin-to-creatinine ratio (ACR) screening, to optimize staging accuracy and timely therapeutic interventions ***[cite: 1, 2, 3]***.

14. Limitations of the Study

While this study provides empirical insights into CKD biomarker interactions within the regional medical context, several methodological limitations must be considered.

- First, the sample size of N=75, drawn exclusively from two clinical centers in northwestern Libya, limits the direct scalability and comprehensive generalization of the statistical models to broader global or macro-regional populations.
- Second, the cross-sectional research framework captures clinical chemistry and hematological values at a static baseline, restricting the evaluation of prospective, longitudinal diagnostic trends within individual patients over extended therapeutic durations.
- Third, a pronounced referral selection bias is evident within the sample distribution: Stage 3 patients constitute only 1.3% of the cohort, whereas advanced Stages 5 and ESRD account for a substantial 80.0% of the aggregate study population. This specific demographic skewness directly reflects localized healthcare infrastructure realities, where

clinical presentation and subsequent specialized nephrology referrals occur predominantly at advanced uremic symptomatic thresholds.

Finally, due to resource constraints in the underlying clinical laboratories during the data collection window, direct isotopic tracking of GFR or automated laboratory assays for serum Cystatin C could not be conducted. Consequently, the relative diagnostic advantages of alternative filtration markers were inferred mathematically via multiple linear regression controls rather than comparative laboratory assays, necessitating larger multi-center clinical validations in future research paradigms.

15. Recommended Clinical Strategy Pathway

Based on our findings, we propose the following clinical recommendations to improve diagnostic accuracy and patient outcomes:

1. **Regular and Comprehensive Monitoring:** CKD patients should undergo routine laboratory testing, including CBC, electrolytes, urea, creatinine, and erythropoietin levels, to detect early complications.
2. **Personalized Treatment Plans:** Consider age, gender, and comorbidities when tailoring treatment strategies, particularly in managing anemia and electrolyte imbalance.
3. **Early Intervention:** Initiate dietary, pharmacological, and supportive therapies early, especially for patients showing mild abnormalities in potassium or hemoglobin levels.
4. **Use of Alternative Markers in the Elderly:** Employ complementary markers such as cystatin C or estimated GFR in older patients to avoid underestimating disease severity.
5. **Health Education and Awareness:** Encourage CKD awareness campaigns to promote early screening and lifestyle modifications among at-risk populations.
6. **Further Research:** Future studies should expand the sample size, include longitudinal follow-up, and investigate additional markers like inflammatory cytokines or oxidative stress indicators to better understand CKD progression.

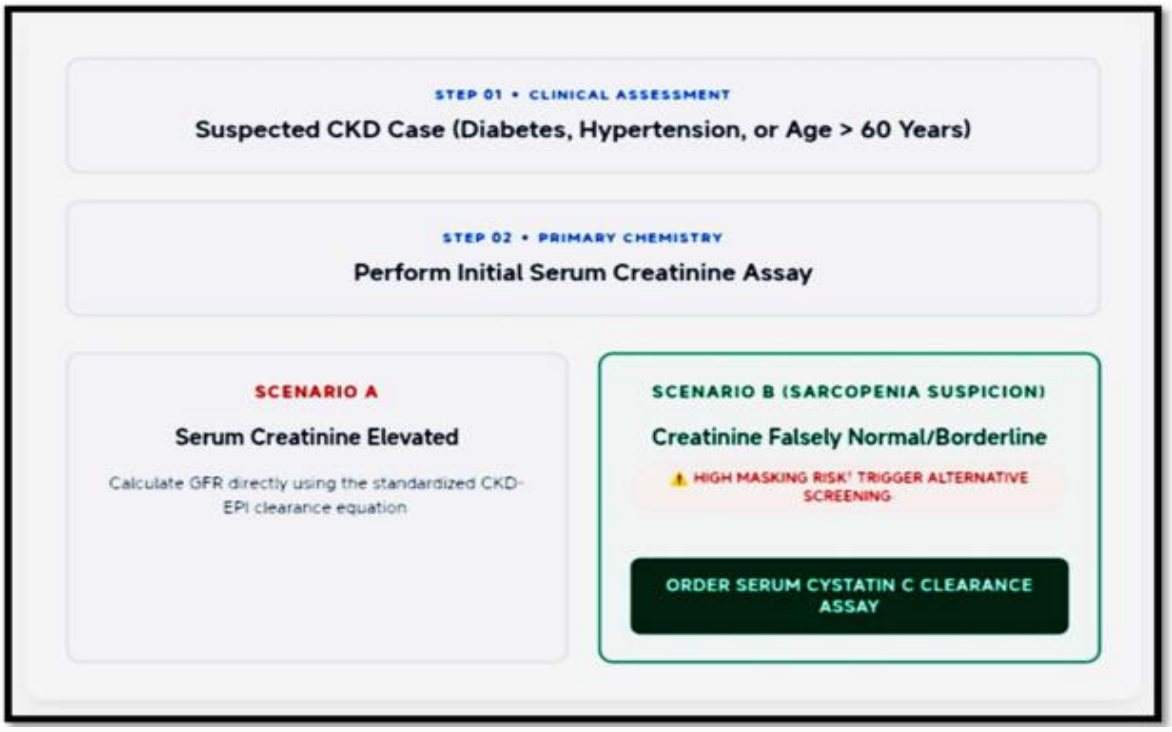

Figure 6: Diagnostic Workflow Flowchart for Geriatric & Muscle-Wasted Cohorts

Figure 6 Analytical Commentary & Implementation Guide:

- **Implementation Rationale:** In older patients, creatinine levels can remain within the normal range despite significant kidney damage. To prevent diagnostic delays, clinicians should order a Cystatin C test for high-risk patients over 60 with a normal creatinine level.
- **Biochemical Advantage:** Cystatin C is produced at a constant rate by nucleated cells and is unaffected by muscle mass, gender, or diet. Utilizing a combined CKD-EPI creatinine-cystatin C equation significantly improves the accuracy of GFR estimations and risk stratification.

References

Al-Zahra Hospital Study. (2013). *Etiology and subclinical cardiovascular progression in chronic kidney disease*. Tripoli, Libya: Nephrology Research Division.

Gonzalez, E. A., et al. (2010). Disorders of calcium and phosphate metabolism in chronic kidney disease. *American Journal of Kidney Diseases*, 45(2), 35-42.

Kufa University Study. (2012). Evaluation of physiological and biochemical changes in chronic renal failure patients. *Journal of Kufa University for Basic Sciences*, 13(2), 112-124.

Levey, A. S., et al. (2005). Chronic kidney disease: Clinical implications of current definitions. *The Lancet*, 365(9457), 223-232. https://doi.org/10.1016/S0140-6736(05)70457-7

Levey, A. S., et al. (2009). A new equation to estimate glomerular filtration rate. *Annals of Internal Medicine*, 150(9), 604-612. https://doi.org/10.7326/0003-4819-150-9-200905050-00006.

Moe, S. M., et al. (2006). Chronic kidney disease-mineral and bone disorder: A guide to diagnosis, evaluation, and management. *Kidney International*, 70(1), 2-6. https://doi.org/10.1038/sj.ki.5000500.

Moe, S. M., et al. (2010). Chronic kidney disease-mineral and bone disorder: A guide to diagnosis, evaluation, and management. *Clinical Journal of the American Society of Nephrology*, 5(1), 77-89. https://doi.org/10.2215/CJN.04540709

Sarnak, M. J., et al. (2003). Kidney disease as a risk factor for development of cardiovascular disease. *Circulation*, 108(17), 2154-2169. https://doi.org/10.1161/01.CIR.0000095676.90936.80

Shlipak, M. G., et al. (2005). Cystatin C and the risk of death and cardiovascular events in the elderly. *New England Journal of Medicine*, 352(20), 2049-2060. https://doi.org/10.1056/NEJMoa043761

Sorman & Sabratha Teaching Hospital Study. (2019). Assessment of clinical chemistry parameters in chronic kidney disease patients. *Zawia University Journal*, 21(1), 45-58.

Taal, M. W., et al. (2004). Management of secondary hyperparathyroidism in chronic kidney disease. *Clinical Journal of the American Society of Nephrology*, 9(7), 1259-1276.

Vaziri, N. D. (2003). Anemia of chronic kidney disease: Pathogenesis and treatment. *American Journal of Kidney Diseases*, 41(4), 790-802. https://doi.org/10.1053/ajkd.2003.50130

Ibrahim Mouftah Ali Altourshani, Giuma M Saleh Abubker, Abdul Rahman Mohammed Aqarib, Huda Almadani Misbah, Kholoud Emhimmid Ali, & Malak Shaban Rmadan. (2025). A retrospective Study of Comorbidity-Associated Anaemia in Hemodialysis Patients at Tarhuna Teaching Hospital. *Journal of Libyan Academy Bani Walid*, *1*(2), 284–298. https://doi.org/10.61952/jlabw.v1i2.343

Malak Emran Dakeal, Awatif Ahmed Eshtiwe, & Ali Alamari Almakhrem. (2025). Analysis

of Biochemical Profiles in Healthy Individuals, Chronic Kidney Disease, and Diabetic Kidney Disease Patients Undergoing Hemodialysis: A Cross-Sectional Study in Tarhuna, Libya. *Journal of Libyan Academy Bani Walid*, *1*(4), 293–300. https://doi.org/10.61952/jlabw.v1i4.391

Najib Mohamed Eljabu, Tahani Meftah Zaggout, & Hajer Ali Ben Naser. (2026). Thyroid Hormone Levels among Patients with Chronic Kidney Disease and Hemodialysis-Dependent Renal Failure at Misrata Dialysis and Kidney Treatment Center: A Cro ss-Sectional Study. *Journal of Libyan Academy Bani Walid*, *2*(3), 01–09. Retrieved from https://journals.labjournal.ly/index.php/Jlabw/article/view/560

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.