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Multisystem Impact of Chronic Kidney Disease: Biochemical, Anatomical, and Hematological Perspectives

Dr. Sarwat Abbasi[1], Dr. Yasir Humayun[2], Dr. Sara Jadoon[3*], Muhammad Kaleem Khan[4], Dr. Naeema Afzal[5], Dr. Anwar Shahzad[6], Samina[7]

[1]Assistant Professor Biochemistry, Ayub Medical College, Abbottabad, Pakistan
Email:sarwatabbasi007@gmail.com
[2]Lecturer, Chemical Pathology, Abbottabad International Medical College, Abbottabad, Pakistan
Email:yasirhumayunswati@gmail.com
[3*]Assistant Professor, Anatomy Department, Ayub Medical College, Abbottabad, Pakistan
Email:sarashafqat@hotmail.com
[4]Assistant Professor, Haematology, Women Medical College/District Pathologist BBS Teaching Hospital, Abbottabad, Pakistan
[5]Professor, Pathology Department, Abbottabad International Medical College, Abbottabad, Pakistan
[6]Associate Professor, Community Medicine, Abbottabad International Medical College, Abbottabad, Pakistan
[7]Demonstrator, Pathology Department, Abbottabad International Medical College, Abbottabad, Pakistan

*Corresponding author's Email: Email:sarashafqat@hotmail.com

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ABSTRACT

Introduction: Chronic kidney disease (CKD) is a progressive condition characterized by the gradual loss of kidney function, often leading to systemic complications. Hematological abnormalities, including anemia, leukocytosis, and platelet dysfunction, are common in CKD and are linked to increased morbidity and mortality. This study aims to analyze hematological parameters in CKD patients and evaluate their association with disease severity.

Objective: To investigate the hematological alterations, such as hemoglobin levels, leukocyte count, platelet count, mean platelet volume (MPV), and coagulation markers (prothrombin time [PT] and activated partial thromboplastin time [APTT]), in CKD patients and their correlation with disease stages.

Methodology: A cross-sectional study was conducted over six months at the Pakistan Kidney Center, Abbottabad, involving 150 CKD patients aged 30–80 years. Blood samples were collected and analyzed for hemoglobin (Hb), total leukocyte count (TLC), platelet count, MPV, PT, and APTT. Patients with confounding conditions such as acute kidney injury, hematological malignancies, or recent blood transfusions were excluded. Data were analyzed using SPSS to assess associations between hematological parameters and CKD stages.

Results: In our study, hemoglobin levels decreased progressively with CKD stages, ranging from 13.5 g/L in Stage 1 to 8.4 g/dL in Stage 5. Leukocyte counts increased with advancing CKD, from 6.5 ×10^9/L in Stage 1 to 9.2 ×10^9/L in Stage 5. Platelet count and MPV decreased with progression, with MPV rising from 8.1 fL in Stage 1 to 9.8 fL in Stage 5. Coagulation parameters (PT and APTT) were prolonged across all stages, with the longest values in Stage 5.

Conclusion: Hematological abnormalities such as anemia, leukocytosis, and platelet dysfunction are prevalent in CKD and worsen with disease progression. These changes highlight the need for regular hematological monitoring in CKD management to prevent complications. Future studies should explore therapeutic interventions to address these hematological alterations and improve patient outcomes.

Keywords: Hemoglobin, Kidney, Leukocyte, Platelet.

INTRODUCTION

Chronic kidney disease (CKD) is a widespread public health issue marked by the progressive deterioration of kidney function over time, which can eventually progress to end-stage renal disease (ESRD) if not managed properly. CKD is divided into five stages according to glomerular filtration rate (GFR), with kidney function progressively declining in the advanced stages.[1] The condition is frequently linked to systemic complications such as cardiovascular disease, metabolic disorders, and hematological abnormalities, all of which substantially affect patient morbidity and mortality.[2]

Anatomically, the kidneys are paired, bean-shaped organs located retroperitoneally at the level of T12 to L3 vertebrae. Each kidney is composed of an outer cortex and an inner medulla, housing millions of nephrons, which serve as the functional units responsible for filtration, reabsorption, and secretion.[4] The nephron comprises the glomerulus, proximal and distal tubules, and collecting ducts, which work in concert to maintain homeostasis. In CKD, nephron loss due to fibrosis and glomerulosclerosis impairs these functions, leading to systemic complications. Structural changes such as tubular atrophy, interstitial fibrosis, and vascular calcification are hallmarks of progressive CKD.[5]

From a biochemical perspective, As CKD progresses, impaired kidney function disrupts metabolic processes, leading to the buildup of nitrogenous waste products like urea, creatinine, and uric acid. This accumulation results in uremia and widespread toxicity throughout the body.[6]In the later stages of CKD, electrolyte disturbances—including elevated potassium, low calcium, increased phosphate levels, and

metabolic acidosis—are frequently observed and play a major role in the development of cardiovascular, neuromuscular, and bone-related complications.[7] Reduced vitamin D activation results in secondary hyperparathyroidism and renal osteodystrophy, worsening imbalances in calcium and phosphate metabolism.[8] Moreover, chronic inflammation and oxidative stress in CKD are driven by increased levels of pro-inflammatory cytokines, reactive oxygen species (ROS), and advanced glycation end-products, contributing to endothelial dysfunction and increased cardiovascular risk.

Anemia is the most common hematological complication of CKD, arising from a deficiency of erythropoietin—a hormone mainly produced by the kidneys that promotes red blood cell formation in the bone marrow.[9] In CKD, declining kidney function decreases erythropoietin production, leading to normocytic normochromic anemia.[10] Additionally, Iron deficiency, chronic inflammation, and shortened red blood cell lifespan play key roles in anemia development in CKD patients. This condition is linked to increased fatigue, diminished quality of life, and a heightened risk of cardiovascular complications.[11]

In addition to anemia, CKD patients experience changes in leukocyte and platelet function. Leukocytosis is commonly seen in the later stages of CKD, potentially reflecting an underlying inflammatory response, heightened vulnerability to infections, or the secondary effects of dialysis treatment.[12] Conversely, some CKD patients may experience leukopenia as a result of bone marrow suppression or the use of immunosuppressive therapy.[13] Platelet dysfunction in CKD is another crucial hematological abnormality, characterized by impaired platelet aggregation and adhesion, which predisposes patients to bleeding complications.[14] Prolonged bleeding time, thrombocytopenia, and increased mean platelet volume (MPV) are commonly reported in CKD patients, highlighting the need for close monitoring of coagulation parameters.[15]

The interplay between CKD and hematological disorders underscores the importance of early diagnosis and management to prevent disease progression and associated complications.[16, 17] Given the significant impact of hematological changes on CKD outcomes, regular hematological assessments, including complete blood count (CBC) and coagulation profile, are essential in clinical practice. The present study aims to analyze the hematological parameters in CKD patients and evaluate their association with disease severity. Understanding these changes can help guide therapeutic strategies and improve patient outcomes.

METHODOLOGY

Study Design: It was cross-sectional study, conducted at Pakistan Kidney Center Abbottabad over six months.

Study Population: The study included 150 CKD patients aged 30–80 years.

Data Collection: Blood samples were collected and analyzed for hemoglobin (Hb), total leukocyte count (TLC), platelet count, mean platelet volume (MPV), and coagulation markers.

Patients with acute kidney injury, hematological malignancies, active infections, autoimmune disorders, recent blood transfusions (within the past three months), or those receiving erythropoiesis-stimulating agents at the time of enrollment were excluded to minimize confounding variables. Blood samples were collected from all eligible participants and analyzed for key hematological parameters, including hemoglobin (Hb), total leukocyte count (TLC), platelet count, mean platelet volume (MPV), prothrombin time (PT), and activated partial thromboplastin time (APTT). Hemoglobin levels were assessed to evaluate anemia severity, while leukocyte and platelet counts were measured to detect inflammation and coagulation abnormalities. MPV was analyzed to assess platelet function, and PT and APTT were recorded to evaluate coagulation status. All laboratory tests were performed using an automated hematology analyzer following standard protocols. Data analysis was conducted using SPSS software, with descriptive statistics applied to summarize the findings. Correlations between hematological parameters and CKD stages were determined using one-way analysis of variance (ANOVA) and Pearson's correlation test. Ethical approval was obtained from the institutional review board, and written informed consent was secured from all participants before enrollment in the study.

RESULTS

Table 1: Hemoglobin Levels across CKD Stages

CKD Stage	Mean Hemoglobin (g/dL)	Standard Deviation
Stage 1	13.5	1.2
Stage 2	12.8	1.3
Stage 3	11.2	1.5
Stage 4	9.6	1.8
Stage 5	8.4	2.0

Table 2: Leukocyte Count in CKD Patients

CKD Stage	Mean TLC (×10^9/L)	Standard Deviation
Stage 1	6.5	0.8
Stage 2	7.0	0.9
Stage 3	7.8	1.1
Stage 4	8.5	1.3
Stage 5	9.2	1.5

Table 3: Platelet Count and Mean Platelet Volume (MPV)

CKD Stage	MPV (×10^9/L)	MPV (fL)
Stage 1	250	8.1
Stage 2	240	8.3
Stage 3	220	8.7
Stage 4	200	9.2
Stage 5	180	9.8

Table 4: Coagulation Parameters in CKD Patients

CKD Stage	PT (Seconds)	APTT (Seconds)
Stage 1	12.5	30.2
Stage 2	13.0	31.0
Stage 3	13.8	32.5
Stage 4	14.5	34.0
Stage 5	15.2	35.8

DISCUSSION

Multiple studies have reported hematological changes in CKD, reinforcing our observations that anemia, leukocytosis, and platelet dysfunction are prominent in the later stages of the disease. A study observed a gradual decrease in hemoglobin levels as CKD progressed, similar to our findings, linking this decline to reduced erythropoietin production and iron deficiency.[19] Other studies have also emphasized the impact of chronic inflammation and uremic toxins in worsening anemia in CKD patients. Leukocytosis, seen in the advanced stages of CKD in our study, aligns with the findings of Stenvinkel et al., who associated increased leukocyte counts with systemic inflammation and oxidative stress in CKD patients.[20] Moreover, Our findings on platelet dysfunction are consistent with those of Kaw et al., who observed a reduced platelet count and elevated MPV in CKD patients, indicating impaired platelet aggregation and adhesion, which increases the risk of bleeding complications.[21] The prolonged PT and APTT observed in our study are consistent with findings from Malyszko et al., who highlighted coagulation disturbances as a result of uremic toxins and endothelial dysfunction in CKD.[22] Collectively, these studies reinforce the importance of regular hematological monitoring in CKD patients to mitigate associated complications.

CONCLUSION

Hematological abnormalities are common in CKD and worsen with disease progression. Anemia, leukocytosis, and platelet dysfunction pose significant risks, necessitating regular hematological

assessments in CKD management. Future research should focus on interventional strategies to mitigate these alterations and improve patient outcomes.

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