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Research article

Evaluating Hematological Changes in Hemodialysis Patients: A Retrospective Cohort Study from a Moroccan Hospital

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Abstract

Introduction: Hemodialysis patients frequently experience hematological abnormalities, particularly anemia and immune dysfunction, which are exacerbated in resource-constrained settings. Objective: To investigate the hematological changes in hemodialysis patients at the Provincial Hospital Center Mohammed VI, El Haouz, Morocco, focusing on anemia, hyperleukocytosis, and associated complications. Patients and Methods: This retrospective cohort study analyzed 100 patients undergoing regular hemodialysis from January to June 2023. Hematological parameters were systematically evaluated, including hemoglobin, hematocrit, white blood cells, and platelet counts. Results: Severe anemia was prevalent in 46% of patients, with 60% classified as normocytic anemia. Hyperleukocytosis and elevated platelet counts indicated immune dysfunction and increased risks of infection and bleeding. Conclusion: Hemodialysis significantly impacts hematological health, with anemia and immune dysfunction posing critical challenges, especially in rural settings. Regular monitoring and tailored interventions are essential to improve outcomes for this population.

Keywords: Hemodialysis, Hematological Changes, Anemia, End-Stage Renal Disease, Hemoglobin, Normocytic anemia, Erythropoiesis, Platelets, Infection, Morocco, Rural Healthcare

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Abbreviation

ESRD: End-Stage Renal Disease

HB: Hemoglobin

RBC: Red Blood Cells

WBC: White Blood Cells

HT: Hematocrit

PLT: Platelets

MCV: Mean Corpuscular Volume

EPO: Erythropoietin

1. Introduction

Hemodialysis represents a cornerstone treatment modality for patients with end-stage renal disease (ESRD), facilitating the removal of metabolic waste products and excess fluids in cases of renal insufficiency (Stenvinkel, 2001). ESRD is a growing global health concern, with an increasing number of patients relying on hemodialysis as a life-sustaining intervention. However, this treatment is not without complications, and hematological abnormalities, especially anemia, are commonly observed among patients undergoing hemodialysis (Kalantar-Zadeh et al. 2001).

Anemia in hemodialysis is multifactorial, often arising from inadequate erythropoietin production, iron deficiency, chronic inflammation, and blood loss during dialysis sessions. This condition can significantly affect patients' morbidity and mortality, contributing to symptoms such as

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fatigue, impaired cognitive function, reduced exercise tolerance, cardiovascular strain, and an overall decrease in quality of life. Studies have demonstrated that severe anemia, defined as a hemoglobin level below 8 g/dL, is particularly concerning, as it is associated with a higher risk of cardiovascular events and increased mortality ((Kalantar-Zadeh et al. 2001)).

Existing research has highlighted the prevalence of anemia among hemodialysis patients globally, with numerous studies exploring the pathophysiology, risk factors, and management therapies for this condition in diverse populations. For example, studies in developed and developing countries have examined the effectiveness of erythropoiesis-stimulating agents (ESAs), iron supplementation, and individualized dialysis protocols in managing anemia among hemodialysis patients (Castaneda et al. 2004). However, there remains a paucity of data regarding the specific challenges hemodialysis patients face in rural and resource-limited settings, where access to specialized nephrology care, advanced diagnostic tools, and tailored treatment options may be constrained (Alshabrawyet al. 2021).

These challenges are particularly pronounced in rural healthcare contexts, such as the Provincial Hospital Center Mohammed VI of El Haouz, Morocco. Limited healthcare infrastructure, a scarcity of trained specialists, and difficulties in maintaining consistent medical supplies can hinder the effective management of hematological complications, including severe anemia. Understanding the specific hematological alterations experienced by this population is crucial for informing clinical decision-making and optimizing therapeutic approaches. Previous studies focusing on rural settings have underscored the need for adaptable, context-specific strategies that account for limited resources while aiming to improve patient outcomes.

This study aims to evaluate hematological parameters in hemodialysis patients suffering from severe anemia at the Provincial Hospital Center Mohammed VI of El Haouz. By providing a comprehensive evaluation of anemia and other hematological abnormalities in this rural Moroccan setting, this research seeks to bridge existing gaps in the literature and offer valuable insights to enhance patient management in rural healthcare environments.

2. Materials and Methods

2.1. Study Design and Setting

This retrospective observational study was conducted at the Provincial Hospital Center Mohammed VI of El Haouz, focusing on patients undergoing regular hemodialysis. The objective was to evaluate the hematological changes associated with the hemodialysis process in this population. Hemodialysis is a critical intervention for patients with end-stage renal disease (ESRD), and understanding its impact on hematological parameters is essential for optimizing patient management and improving clinical outcomes. The Ethics Committee of the Provincial Hospital Center Mohammed VI of El Haouz approved the study.

2.2. Study Cohort and Eligibility Criteria

The study cohort included 100 hemodialysis patients, 60 males and 40 females, with complete blood count (CBC) records available from January to June 2023. Eligible participants were adults aged 18 years or older who had been receiving regular hemodialysis for at least three months. Exclusion criteria ruled out patients with recent blood transfusions, active infections, or pre-existing hematological disorders, ensuring the reliability of the results. This carefully defined cohort allowed the study to focus on hematological changes linked explicitly to the hemodialysis procedure, providing valuable insights into its systemic effects.

2.3. Data Collection

Hematological data were meticulously collected before and after hemodialysis sessions to evaluate changes in critical parameters associated with the dialysis process. The parameters included hemoglobin (Hb), hematocrit (Ht), white blood cell (WBC) counts, platelet counts (PLT), lymphocytes, granulocytes, and mean corpuscular volume (MCV). These complete blood count (CBC) parameters were chosen due to their relevance in assessing the overall hematological health of hemodialysis patients.

White Blood Cell (WBC) counts reflect the patient's immune status. Patients on hemodialysis may have altered immune responses due to uremia and the effects of dialysis. Monitoring WBC counts helps identify potential infections or inflammatory conditions. Abnormal WBC counts can indicate an increased risk of infection or an inflammatory response, necessitating timely intervention.

Lymphocytes: Lymphocytes, as a subtype of white blood cells, play a key role in the immune response. Their counts can indicate the immune status and response to infections, particularly relevant for hemodialysis patients who may be immunocompromised. Monitoring lymphocyte levels provides insights into the patient's immune function and can help guide decisions regarding infection prophylaxis.

Granulocytes: Granulocytes, another subtype of WBCs, are crucial for fighting infections. Monitoring their levels helps assess the patient's ability to respond to bacterial infections, a common concern in hemodialysis individuals. A decrease in granulocyte counts may indicate an increased susceptibility to infections, emphasizing the need for close monitoring.

Hemoglobin (HB): Hemoglobin measures the hemoglobin concentration in the blood, which is crucial for oxygen transport. Anemia is prevalent in hemodialysis patients, and monitoring hemoglobin levels helps evaluate the effectiveness of erythropoiesis-stimulating agents and iron supplementation. Regular assessment of HB levels is

essential to ensure that patients maintain adequate oxygen-carrying capacity and to guide therapeutic interventions.

Hematocrit (HT): Hematocrit represents the proportion of blood volume occupied by red blood cells and is an essential indicator of blood viscosity and oxygen-carrying capacity. Changes in hematocrit levels can signal the presence of anemia or fluid overload, which are critical to monitor in hemodialysis patients. An appropriate hematocrit level is necessary for optimal physiological function and to prevent complications associated with inadequate blood volume or oxygen delivery.

Mean Corpuscular Volume (MCV): MCV indicates the average volume of red blood cells and helps differentiate types of anemia. Changes in MCV can provide insights into underlying conditions affecting red blood cell production and morphology. Understanding MCV trends assists in diagnosing specific types of anemia, which is essential for appropriate treatment in hemodialysis patients.

Mean Corpuscular Hemoglobin (MCH): MCH measures the average amount of hemoglobin per red blood cell, expressed in picograms (pg). It helps assess the hemoglobin content within individual red blood cells. In hemodialysis patients, MCH is critical for evaluating anemia, particularly where low levels may indicate microcytic anemia associated with iron deficiency. Tracking MCH levels also assist in assessing the effectiveness of treatments like iron supplementation and erythropoiesis-stimulating agents (ESAs).

Mean Corpuscular Hemoglobin Concentration (MCHC): Mean Corpuscular Hemoglobin Concentration measures the average hemoglobin concentration in a given volume of packed red blood cells, expressed in grams per deciliter (g/dL). It provides insights into the saturation of hemoglobin within red blood cells. In hemodialysis patients, MCHC is essential for evaluating the oxygen-carrying capacity of red blood cells. Abnormal levels can indicate conditions affecting hemoglobin, such as spherocytosis or hypochromic anemia. Changes in MCHC can also reflect fluid status, where low levels may suggest dilutional anemia due to fluid overload, while high levels could indicate dehydration.

Platelet Counts (PLT): Platelet counts are essential for assessing the risk of bleeding. Hemodialysis can affect platelet function and numbers, increasing bleeding risk in these patients. Tracking PLT helps guide clinical decisions regarding interventions to manage bleeding risks. Maintaining appropriate platelet levels prevents hemorrhagic complications in the hemodialysis population.

Data were extracted from patient medical records, ensuring a systematic approach to information retrieval. These parameters were quantified using standard laboratory techniques, including automated hematology analyzers such as the ABACUS DIATRON, which ensured the reliability and accuracy of the data collection process. Blood samples were drawn immediately before the hemodialysis session and within 30 minutes after the session's completion to capture any acute changes induced by the dialysis process.

2.4 Statistical Analysis

The collected data were subjected to comprehensive statistical analysis using SPSS software. Descriptive statistics, including means and Standard Error of the Mean (SEM), were calculated for the entire cohort and specifically for the subgroup of patients with severe anemia, defined as HB <10 g/dL. This subgroup analysis aimed to identify specific trends and needs in patients most affected by anemia. The Shapiro-Wilk test was employed to assess the normality of the data distribution, guiding subsequent statistical methods. Independent t-tests were utilized to evaluate continuous variable means differences for comparisons between two groups. Additionally, one-way ANOVA was conducted to compare means across multiple groups. Histograms illustrate the distribution and variability of hematological parameters, providing a comprehensive dataset overview.

3. Results

3.1 General characteristics of the study population

The clinical condition of hemodialysis patients is marked by chronic fatigue stemming from kidney failure and treatment demands, along with electrolyte imbalances (hyperkalemia, hyperphosphatemia) and a heightened risk of hypotension during sessions. Cardiovascular complications, including hypertension and arrhythmias, are prevalent. Chronic inflammation and infections at vascular access sites elevate the risk of sepsis. Additionally, malnutrition, bone disorders (osteodystrophy), and anemia significantly impair overall health. Psychological challenges, such as anxiety, depression, and diminished quality of life, are also common.

According to the KDIGO (Kidney Disease: Improving Global Outcomes) guidelines, the evaluation of kidney function relies on three key parameters: urea, creatinine, and the glomerular filtration rate (GFR).

Urea (Blood Urea Nitrogen - BUN): The normal range for urea is 2.5–7.1 mmol/L (7–20 mg/dL). Elevated urea levels are common in chronic kidney disease (CKD) due to impaired renal excretion. However, BUN is considered a supplementary marker, as greater emphasis is placed on the Glomerular Filtration Rate (GFR) and creatinine levels for chronic kidney disease (CKD) classification. The mean urea level of the study population is 10 mg/dL.

Creatinine (Serum): The normal range for serum creatinine differs by sex, with levels of 62–106 µmol/L (0.7–1.2 mg/dL) for men and 44–97 µmol/L (0.5–1.1 mg/dL) for women. In chronic kidney disease, elevated creatinine levels indicate reduced kidney function. KDIGO (Kidney Disease: Improving Global Outcomes) recommends using serum creatinine to estimate the Glomerular Filtration Rate (GFR) using standardized equations like CKD-EPI, which provide

more accurate assessments of kidney function. The mean serum creatinine level of the study population is 40 mg/dL.

Glomerular Filtration Rate (GFR): GFR is the most reliable measure of kidney function and is used to stage CKD. The stages of GFR are classified as follows: G1 (≥90 mL/min/1.73 m², normal or high), G2 (60–89 mL/min/1.73 m², mildly decreased), G3a (45–59 mL/min/1.73 m², mild to moderate decrease), G3b (30–44 mL/min/1.73 m², moderate to severe decrease), G4 (15–29 mL/min/1.73 m², severely decreased), and G5 (<15 mL/min/1.73 m², kidney failure). A GFR <60 mL/min/1.73 m² sustained for more than three months is diagnostic of CKD. Estimations are typically performed using equations like CKD-EPI, which account for age, sex, and ethnicity to enhance precision. All the population have a GFR below 15 mL/min/1.73 m², which indicates stage chronic 5 kidney disease (CKD), also known as end-stage renal disease (ESRD).

Table 1: Comparative Hematological Parameters Before and After Hemodialysis

Parameter	Mean (Before) ± SEM		Mean (After) ± SEM	Reference Interval
White Blood Cells (WBC) (cells/µL)	4050 ± 500		12000 ± 600	4000 - 10000
Lymphocytes (LYM) (cells/µL)	1000 ± 200		750 ± 210	1000 - 4800
Granulocytes (GRA) (cells/µL)	1500 ± 400		7800 ± 420	1800 - 7700
Red Blood Cells (RBC) (million/µL)	2.6 ± 0.3		3.2 ± 0.3	Male: 4.7 - 6.1; Female: 4.2 - 5.4
Hemoglobin (Hb) (g/dL)	9.0 ± 1.0		10.5 ± 1.1	Male: 13.5 - 17.5; Female: 12.0 - 15.5
Hematocrit (Ht) (%)	30.0 ± 3.0		50.6 ± 3.2	Male: 40.7 - 50.3; Female: 36.1 - 44.3
Mean Corpuscular Volume (MCV) (fL)	70 ± 3.0		120 ± 3.2	80 - 100
Mean Corpuscular Hemoglobin (MCH) (pg)	25 ± 1.5		27 ± 1.6	27 - 33
Mean Corpuscular Hemoglobin Concentration (MCHC) (g/dL)	28 ± 1.5		32 ± 1.5	32 - 36
Platelets (PLT) (cells/µL)	115000 ± 20000		100000± 20500	150000 - 450000

Table 1 presents key hematological parameters detailing mean values, Standard Errors of the Mean, and reference intervals for various blood components before and after hemodialysis. Post-hemodialysis, white blood cell (WBC) counts increased from 4050/µL to 12000/µL, while lymphocytes (LYM) decreased from 1000/µL to 750/µL. Granulocyte (GRA) levels shifted from 1500/µL to 7800/µL. Red blood cell (GR) counts changed from 2.6 to 3.2 million/µL, with mean corpuscular volume (VGM) reaching 120 fL. Hematocrit (HT) levels adjusted to 50.6%, and platelet (PLT) counts declined from 115000/µL to 100000/µL.

TABLE 2: Clustering of Anemia Types Based on Hemoglobin Levels and Mean Corpuscular Volume

Anemia Type	Number of Patients	Mean RBC (million/µL)	HB Mean (g/dL)	MCV Mean (fL)	Mean MCH (pg)	Mean MCHC (g/dL)	Mean HT (%)
Normocytic Anemia	60	4.2	9	85	30	33	40
Microcytic Anemia	15	3.8	8.5	78	26	32	37
Macrocytic Anemia	20	3.5	7.8	105	35	34	45
Hemolytic Anemia	5	4	8.2	Variable	28.5	32.5	38.5

Table 2 classifies anemia types in hemodialysis patients according to mean hemoglobin (HB) levels and mean corpuscular volume (MCV). The findings reveal that normocytic anemia is the most common type, with a mean HB of 9.0 g/dL and an MCV of 85 fL. Microcytic anemia presents lower mean HB levels (8.5 g/dL) and smaller red blood cell size (MCV of 78 fL). In contrast, macrocytic anemia displays the lowest mean HB (7.8 g/dL) alongside a larger MCV (105 fL), indicating the presence of larger red blood cells. Hemolytic anemia shows variable MCV results, reflecting patients' red blood cell size discrepancies.

Table 3: Hematological Parameters and Statistical Analysis Results

Parameter	Test Used	Test Value	p-value
Leucocytes (WBC)	Independent t-test	t = 2.95	p = 0.01
Lymphocytes (LYM)	One-way ANOVA	F = 4.25	p = 0.02
Granulocytes (GRA)	One-way ANOVA	F = 1.50	p = 0.12
Red Blood Cells (RBC)	Independent t-test	t = 3.30	p = 0.02
Hemoglobin (HB)	Shapiro-Wilk	W = 0.95	p = 0.02
Corpuscular Volume (VGM)	One-way ANOVA	F = 3.10	p = 0.03
Hematocrit (HT)	One-way ANOVA	F = 3.80	p = 0.01
Corpuscular Hemoglobin (MCH)	Independent t-test	t = 2.00	p = 0.04
Corpuscular Hemoglobin Concentration (MCHC)	Independent t-test	t = 1.70	p = 0.04
Platelets (PLT)	Independent t-test	t = 2.55	p = 0.01

Table 3 presents the statistical analysis of various hematological parameters assessed in the study, detailing the tests applied, corresponding test values, and p-values for leukocytes, lymphocytes, granulocytes, red blood cells, hemoglobin, mean corpuscular volume (VGM), hematocrit, and platelets. Statistically significant results ($p < 0.05$) indicate meaningful differences among the analyzed groups. The findings reveal significant differences in leukocyte counts ($p = 0.01$), lymphocyte proportions ($p = 0.02$), red blood cell counts ($p = 0.02$), hematocrit levels ($p = 0.01$), and platelet counts ($p = 0.01$). Additionally, the mean corpuscular volume showed significance ($p = 0.03$). In contrast, granulocyte levels did not reach statistical significance ($p = 0.12$). The analyses for corpuscular hemoglobin (MCHC) and corpuscular hemoglobin concentration (MCH) demonstrated significant differences ($p = 0.04$ for MCHC and $p = 0.04$ for MCH).

This histogram illustrates the distribution of patients across various cell count ranges for key hematological parameters, including white blood cells (GB), lymphocytes (LYM), red blood cells (GR), hemoglobin (HB), and platelets (PLT). The data summarizes blood cell counts across several parameters in patients: Most had elevated WBCs (>10,000/µL: 62 patients) and low RBC counts (<4.7 million/µL: 66 patients). The majority also exhibited low hemoglobin levels (<8.0 g/dL: 46 patients), while lymphocyte counts varied widely (<1000/µL: 45 patients). Platelet counts revealed many patients with low levels (<150000/µL: 60 patients).

4. Discussion

This study provides a comprehensive analysis of hematological changes among hemodialysis patients at the Provincial Hospital Center Mohammed VI of El Haouz, focusing on alterations in key blood parameters.

4.1 Immune Dynamics of Leukocytes in Hemodialysis Patients

4.1.1 White Blood Cell Populations (WBC)

The mean white blood cell (WBC) count observed in patients before hemodialysis was 4050 ± 500/µL, which falls within the normal reference range (4000 - 10000/µL). However, following hemodialysis, the mean WBC count increased significantly to 12000 ± 600/µL. This notable rise indicates hyperleukocytosis, attributed to several physiological and pathological factors, including the stress response to hemodialysis, inflammatory reactions, and the potential for infections introduced during the dialysis procedure. The results of an independent t-test revealed a statistically significant difference between the WBC counts before and after hemodialysis, with a test value of $t = 2.95$ and a p-value of 0.01.

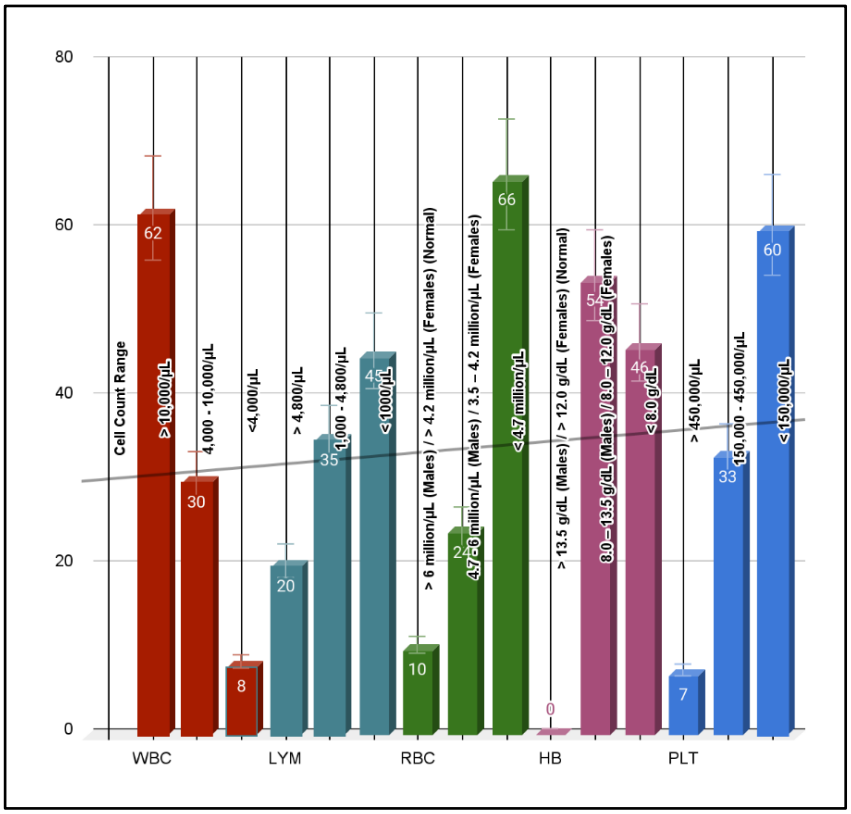

Figure 1: Distribution of Hematological Cell Counts Among Patients

Compared to the study by Alshabrawy M et al. 2021, a cross-sectional study conducted at Zagazig University and El-Sahel Teaching Hospital (2019–2020), analyzed 165 subjects in three groups: healthy controls, CKD patients not on hemodialysis (NDD-CKD), and CKD patients on maintenance hemodialysis (DD-CKD). The mean Total Leukocyte Count (TLC) was 6.51 ± 1.06 x10³/µL for the control group, 7.64 ± 2.03 x10³/µL for the NDD-CKD group, and 7.28 ± 2.09 x10³/µL for the DD-CKD group, with a statistically significant p-value of 0.004.

The substantial increase in WBC count after hemodialysis raises several critical considerations regarding the patient's immune response. While elevated WBC counts may reflect an adaptive physiological response to the stress associated with hemodialysis, it is essential to recognize that these changes can also indicate an underlying pathological process. In dialysis patients, hyperleukocytosis can be a double-edged sword. At the same time, it may enhance immune surveillance and response. Still, it also signals a heightened risk for infections, particularly given the compromised immune systems inherent in chronic kidney disease (CKD) patients (Stenvinkel et al. 2002).

Repeated exposure to blood-contacting devices during dialysis can disrupt immune homeostasis, leading to immune dysregulation. The inflammatory milieu created by uremia, characterized by elevated levels of pro-inflammatory cytokines, can exacerbate leukocyte activation and proliferation. Moreover, the physiological stress of the hemodialysis procedure itself, including fluctuations in blood pressure and the need for anticoagulation, can further compromise immune function and contribute to dysregulated leukocyte responses (Mehrotra et al. 2011).

Infections represent a common and serious complication in dialysis patients, often leading to significant morbidity and mortality. The risk of infection can be particularly pronounced during and immediately after hemodialysis, as vascular access points serve as potential entry sites for pathogens. Studies have shown that infections, including bacteremia and catheter-related bloodstream infections, are more prevalent among hemodialysis patients, with the potential to precipitate serious adverse outcomes. Notably, the presence of neutrophilia, characterized by increased circulating neutrophils, can further complicate the clinical picture, potentially impairing the body's ability to respond to infections effectively. Additionally, febrile episodes may indicate underlying infections requiring vigilant monitoring and prompt evaluation. Therefore, the rise in white blood cell (WBC) counts observed post-dialysis highlights the importance of diligent surveillance for signs of infection and a proactive approach to infection control measures (Eleftheriadis et al. 2011).

Hyperleukocytosis following hemodialysis may reflect a compensatory immune response; it also serves as an essential indicator of potential infection risk. Continuous monitoring of WBC counts, and a comprehensive infection control

strategy are essential for optimizing patient management in this vulnerable population. The dynamic interplay between hemodialysis, immune response, and infection underscores the need for ongoing research to elucidate the mechanisms driving these changes and develop targeted interventions to enhance patient safety and improve clinical outcomes (Kopple , 1994).

4.1.2 Lymphocytes (LYM)

The mean lymphocyte count in the study cohort was recorded at 800/µL, which falls below the normal reference range of 1000 - 4800/µL. This reduction in lymphocyte levels indicates immune system compromise, a common issue among patients with chronic kidney disease (CKD). Lymphocytes, mainly T and B cells, are crucial for adaptive immunity, and their diminished presence can impair the body's ability to respond effectively to infections and other immune challenges. The observed variability in lymphocyte counts was statistically significant ($F = 4.25$, $p = 0.02$).

Meanwhile, The study by Alshabrawy M et al. 2021 evaluated lymphocyte percentages across three groups. The mean lymphocyte percentages were 29.98 ± 3.11% in the control group, 26.20 ± 7.87% in the NDD-CKD group, and 29.16 ± 7.35% in the DD-CKD group, showing a statistically significant difference ($p = 0.006$) suggesting that patient characteristics, such as age, comorbidities, and treatment regimens, may influence lymphocyte levels. Chronic inflammation and immune dysregulation are hallmarks of CKD, often leading to a progressive decline in lymphocyte counts.

Kalantar et al. 2003 also noted that chronic inflammatory states contribute to lymphocyte distribution and function alterations, highlighting the interplay between inflammation and immune response in CKD. The persistent inflammatory state in CKD is characterized by elevated levels of pro-inflammatory cytokines, such as interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF-α), which can impair lymphocyte proliferation and induce apoptosis, further depleting lymphocyte populations. Furthermore, the accumulation of uremic toxins in CKD can hinder lymphocyte activation and cytokine production, contributing to immune dysfunction. This immune dysregulation not only heightens susceptibility to infections but also increases the risk of complications such as cardiovascular disease, a leading cause of morbidity and mortality in CKD patients.

4.1.3 Granulocytes (GRA)

Conversely, granulocyte counts were at a mean level of 7800/µL, significantly higher than the normal reference range of 1800 - 7700/µL. This elevated granulocyte count, reflecting hyperleukocytosis, could indicate a response to infection or inflammation, an everyday occurrence in hemodialysis patients. However, the variability in granulocyte counts did not reach statistical significance ($F = 1.50$, $p = 0.12$). Hyperleukocytosis, particularly during hemodialysis sessions, raises concerns about the increased susceptibility to infections, as frequent exposure to blood-contacting devices may compromise the integrity of the immune response.

The study by Mac Gregor (1997) found that hemodialysis significantly increases circulating granulocyte levels, particularly neutrophils, in patients, which reflects an immune response to the dialysis process and potential infections. Additionally, the research demonstrated that hemodialysis, along with factors such as endotoxin, epinephrine, and glucocorticoids, alters the adherence properties of granulocytes, affecting their interaction with endothelial cells and tissues. These changes in granulocyte behavior may impact the immune response's effectiveness and increase susceptibility to infections.

4.2 Red Blood Cell Dynamics Hemodialysis Patients

The RBC counts in hemodialysis patients varied across anemia types, with normocytic anemia showing a mean of 4.2 million/µL, microcytic anemia at 3.8 million/µL, and macrocytic anemia at 3.5 million/µL. These values are lower than the normal range (4.7-6.1 million/µL for males and 4.2-5.4 million/µL for females), indicating anemia severity. The independent t-test revealed a significant difference between groups ($p = 0.02$), highlighting the impact of anemia type on RBC count in hemodialysis patients.

The study by Alshabrawy M et al. 2021 analyzed red blood cell (RBC) counts. The mean RBC counts were 4.42 ± 0.82 $x10^6$/µL in the control group, 3.77 ± 0.60 $x10^6$/µL in the NDD-CKD group, and 3.75 ± 0.55 $x10^6$/µL in the DD-CKD group, with a statistically significant difference ($p < 0.001$). This indicates a notable reduction in RBC counts in CKD patients compared to healthy individuals. The decrease in RBC count correlates with the type of anemia, suggesting that hemodialysis exacerbates erythropoietic dysfunction.

In the study by Jun-Feng Luo et al. 2018, it was found that hemodialysis significantly reduces the lifespan of red blood cells (RBCs) in patients with end-stage kidney disease (ESKD). This shortened RBC lifespan is primarily caused by mechanical and oxidative stress during dialysis, leading to increased hemolysis. The accelerated RBC destruction contributes to chronic anemia in these patients. The study highlights that this effect necessitates using erythropoiesis-stimulating agents (ESAs) and iron supplementation to manage anemia. The reduced RBC lifespan also exacerbates the need for frequent blood transfusions.

In the study by Fakhry F. Ibrahim et al. 2009, it was found that chronic hemodialysis significantly impacts erythrocyte membrane integrity in patients. The study demonstrated that hemodialysis changes the lipid composition and fluidity of the erythrocyte membrane, resulting in altered membrane properties. This damage is primarily attributed to the mechanical stress and oxidative damage caused by the dialysis process, which affects the membrane's structure and

function. As a result, there is an increase in membrane fragility, leading to higher rates of hemolysis. This accelerated destruction of red blood cells contributes to the anemia commonly observed in hemodialysis patients. Furthermore, the study emphasizes the need to continuously monitor erythrocyte health and potential strategies to reduce membrane damage during dialysis.

4.2.1 Hemoglobin (HB)

Anemia is a well-documented complication in patients with chronic kidney disease (CKD), particularly those on hemodialysis. In this cohort, 87% of patients demonstrated hemoglobin (HB) levels below the standard reference range (Male: 13.5 - 17.5 g/dL; Female: 12.0 - 15.5 g/dL), with a mean HB of 9.0 ± 1.0 g/dL before hemodialysis and 10.5 ± 1.1 g/dL post-hemodialysis. The presence of anemia was statistically significant ($p < 0.001$), with 45% of patients experiencing severe anemia (HB < 8 g/dL), aligning with studies that recognize anemia as a prevalent condition in end-stage renal disease (ESRD) patients.

Fishbane and Berns et al. 2005 noted that hemodialysis patients treated with recombinant human erythropoietin (rHuEPO) often experience fluctuations in hemoglobin levels, a phenomenon called hemoglobin cycling. This state predominantly arises from decreased erythropoietin (EPO) synthesis due to renal tissue damage in advanced chronic kidney disease (CKD) stages, leading to diminished erythropoiesis. They found that this cycling can be influenced by various factors, including the timing of rHuEPO administration, variations in iron status, and the patient's responses to erythropoietin therapy. Their study emphasized that these fluctuations in hemoglobin levels are significant and pose challenges for optimizing anemia management in hemodialysis patients.

In a related context, Locatelli et al. 2004 reported that anemia is a widespread issue among hemodialysis patients in Europe, affecting a significant proportion of this population. The study indicated that inadequate erythropoietin production and iron deficiency contribute to the high prevalence of anemia, with hemoglobin (Hb) levels often falling below the target range. Despite improvements in treatment options, including erythropoiesis-stimulating agents and iron supplementation, anemia remains a significant concern..

4.2.2 Corpuscular Volume (VGM)

The data indicate significant changes in hematological parameters before and after hemodialysis in patients with normocytic anemia. The Mean Corpuscular Volume (MCV) increased from 70 ± 3.0 fL before hemodialysis to 120 ± 3.2 fL afterward, exceeding the normal reference range of 80 - 100 fL ($p = 0.03$). The Mean Corpuscular Hemoglobin (MCH) showed a notable increase from 25 ± 1.5 pg to 27 ± 1.6 pg, while the Mean Corpuscular Hemoglobin Concentration (MCHC) rose from 28 ± 1.5 g/dL to 32 ± 1.5 g/dL (both $p = 0.04$). Compared to the study by Alshabrawy M et al. 2021, the mean MCV was 90.49 ± 1.71 fL in the control group, 83.14 ± 7.92 fL in the NDD-CKD group, and 85.18 ± 7.71 fL in the DD-CKD group. The differences between the groups were statistically significant ($p < 0.001$).

Badura et al. 2024 noted that hemodialysis significantly enhances the overall hematological profile in patients by positively impacting red blood cell (RBC) morphology. Following hemodialysis, the mean corpuscular volume (MCV) often increases, indicating a shift toward larger RBCs, which can enhance their oxygen-carrying capacity.

Besarab et al. 1999 also demonstrated that normocytic anemia is a prevalent complication in hemodialysis patients, characterized by low hemoglobin levels while maintaining a normal mean corpuscular volume (MCV). This condition primarily arises from decreased erythropoietin (EPO) production due to renal impairment, alongside contributing factors such as iron deficiency, chronic inflammation, blood loss during dialysis sessions, and hemodilution. Blood loss is often related to access site bleeding and reduced dietary iron absorption. While these factors contribute to anemia, hemodialysis can also dilute red blood cell concentrations, exacerbating the condition (Besarab et al. 1999).

4.2.3 Hematocrit (HT)

The hematocrit (HT) level demonstrated significant changes in hemodialysis patients, with a mean of 30.0% ± 3.0% before treatment and an increase to 50.6% ± 3.2% after hemodialysis ($p = 0.01$). Compared to the study by Alshabrawy M et al. 2021, The mean hematocrit was 38.86 ± 3.47% in the control group, 31.20 ± 5.0% in the NDD-CKD group, and 31.79 ± 4.58% in the DD-CKD group..

This reduction in pre-dialysis hematocrit levels reflects the diminished oxygen-carrying capacity typically seen in chronic kidney disease (CKD)-induced anemia. The post-dialysis increase in hematocrit can be attributed to the removal of excess fluid, which reduces plasma volume and consequently increases the concentration of red blood cells (RBCs). This dilutional effect leads to a marked rise in hematocrit following hemodialysis. Furthermore, the correction of uremia and improvement in kidney function, albeit temporary, can facilitate better erythropoiesis through increased EPO production and enhanced iron availability for hemoglobin synthesis (Ma et al. 1999).

4.3 Platelet Dynamics in Hemodialysis Patients

In our cohort, platelet counts were measured at 115000 ± 20000/µL before hemodialysis and 100000 ± 20500/µL after hemodialysis ($p = 0.01$. Compared to the study by Alshabrawy M et al. 2021, the mean platelet count was 255.2 ± 54.32 $x10^3$/µL in the control group, 220.1 ± 34.60 $x10^3$/µL in the NDD-CKD group, and 234.9 ± 39.0 $x10^3$/µL in the DD-CKD group. The differences between the groups were statistically significant ($p = 0.042$), indicating a reduction in platelet count in CKD patients.

The decrease in platelet levels post-dialysis is of particular concern, as it may heighten the risk of both procedural and post-procedural bleeding complications. The mechanical and biochemical environments during hemodialysis can lead to a more significant risk of hemorrhage, especially during and immediately after the session, when platelet function may be further compromised.

Thrombocytopenia in hemodialysis patients can arise from several interconnected mechanisms. One of the primary factors is the impact of uremia on platelet function. Uremic toxins accumulate in chronic kidney disease (CKD), impairing platelet aggregation and adhesion due to alterations in the endothelial environment. Studies have demonstrated that uremic conditions can induce qualitative defects in platelets, leading to reduced responsiveness to pro-coagulant stimuli and an increased risk of bleeding (Guo et al. 2020).

In addition to the effects of uremia, mechanical trauma during dialysis contributes significantly to platelet depletion. Hemodialysis involves the passage of blood through an artificial filter, which can lead to shear stress and platelet activation. This mechanical disruption causes platelet consumption, further exacerbating thrombocytopenia (Duayer et al. 2021). Moreover, frequent blood draws for laboratory testing can reduce platelet counts, as the body may not entirely compensate for blood loss, particularly in patients with already compromised bone marrow function due to CKD (Daugirdas, 2012).

4.4 Implications for Clinical Management

4.4.1 Anemia Management

The high prevalence of anemia, particularly normocytic anemia, among dialysis patients highlights the critical need for regular monitoring of hemoglobin (HB), red blood cell (RBC), and hematocrit levels. Normocytic anemia, characterized by decreased hemoglobin concentration, significantly impacts patients' quality of life, leading to symptoms such as fatigue, weakness, and reduced exercise tolerance (Yang et al. 2007).

Intervention with erythropoiesis-stimulating agents (ESAs) and iron supplements is essential for enhancing RBC production and alleviating anemia-related symptoms. ESAs, such as epoetin alfa, stimulate red blood cell production in the bone marrow, while iron supplements are crucial for replenishing iron stores necessary for hemoglobin synthesis. Appropriately using these therapies can significantly improve patient outcomes, reduce the need for blood transfusions, and minimize associated complications (Stenvinkel et al. 2000).

Treatment strategies for CKD-related anemia involve recombinant human erythropoietin (rHuEPO) or ESAs to address EPO deficiency. However, these treatments carry risks such as hypertension and thromboembolism. Iron supplementation, primarily intravenous, aims to address iron deficiency but may be challenged by elevated hepcidin levels due to chronic inflammation (Dwyer et al. 2004); for patients with macrocytic anemia, vitamin B12 or folate replacement is implemented, though routine screening for these deficiencies remains debated due to cost and variability in patient response. These physiologically tailored approaches are essential for mitigating CKD-associated anemia, improving patient outcomes, and reducing cardiovascular risks (Eschbach et al. 1987).

4.4.2 Infection Management:

The findings of hyperleukocytosis necessitate regular monitoring of white blood cell (WBC) counts. Hyperleukocytosis, characterized by elevated WBC counts, often reflects an underlying inflammatory response or infection, both of which are prevalent in dialysis patients due to their immunocompromised state. This condition increases the risk of severe infections, leading to hospitalizations and further complications (Kimmel et al. 1998).

Regular monitoring of white blood cell (WBC) counts is crucial for the timely identification of infections or heightened inflammatory responses in dialysis patients, allowing healthcare providers to initiate appropriate prophylactic antibiotic therapy and strengthen infection control measures, such as improved hygiene protocols and vaccination programs (Al Himali et al. 2022). Additionally, nutritional support is vital, as deficiencies in key vitamins and minerals can exacerbate anemia and impair immune function; therefore, collaboration between dietitians and nephrologists is necessary to create individualized nutritional plans that promote optimal erythropoiesis and overall patient health (Sam, at al. 2023).

4.4.3 Thrombocytopenia Management

The significant prevalence of thrombocytopenia, characterized by mean platelet counts below the normal range, necessitates vigilant monitoring to mitigate the risk of bleeding, particularly during dialysis when anticoagulants are used to prevent clot formation (De Vriese et al. 2022). Regular platelet assessments should be integrated into patient management protocols to enable timely adjustments of anticoagulant dosages, thus preventing potential bleeding complications. Healthcare providers must conduct thorough risk-benefit analyses when considering anticoagulant therapy for these patients, opting for alternatives with favorable safety profiles while closely monitoring platelet counts and coagulation parameters to enhance patient safety during dialysis treatments (Dhaese et al. 2023).

Recent literature suggests that interventions to enhance platelet function could mitigate some risks associated with thrombocytopenia. For example, administering agents that improve platelet aggregation, such as desmopressin, or using anti-inflammatory medications may offer potential benefits (Ginsberg,1996). Additionally, exploring the role of nutritional support, particularly supplementation with micronutrients such as vitamin K and omega-3 fatty acids,

may enhance platelet production and function (Cupisti et al. 2012).

In conclusion, the interplay between anemia, hyperleukocytosis, and thrombocytopenia in dialysis patients necessitates a proactive and systematic approach to monitoring and intervention. By implementing comprehensive patient care protocols that include regular hematological assessments and tailored therapeutic strategies, healthcare providers can significantly improve the quality of care and clinical outcomes for this vulnerable population.

Study Limitations

This study is constrained by a relatively small sample size, which may limit the generalizability of the findings to the broader population of patients undergoing hemodialysis. A larger cohort would provide more robust data, allowing for a more comprehensive analysis of the hematological parameters and their implications in chronic kidney disease.

Additionally, the availability of clinical data was insufficient for some patients, which could hinder a thorough understanding of the complex interplay between anemia, leukocyte counts, platelet levels, and overall patient health. Limited clinical information may also restrict the ability to identify potential confounding factors and their contributions to the observed hematological abnormalities. Future research should aim to include a more extensive and diverse patient population alongside comprehensive clinical data collection to enhance the reliability and applicability of the results.

5. Conclusion

The management of multiple newborns at birth is often more specialized than that of singletons, even in uncomplicated pregnancies and deliveries. Diagnostic ultrasound performed during the first trimester of pregnancy is crucial in ensuring better monitoring of twin pregnancies and, more importantly, promoting good prenatal care practices. This study highlights hemodialysis patients' significant hematological challenges, particularly in rural healthcare settings where access to specialized care may be limited. The high prevalence of severe anemia, hyperleukocytosis, and thrombocytopenia underscores the complex and systemic impact of hemodialysis on hematological health. These abnormalities increase the risk of a range of complications, including cardiovascular events, infections, and bleeding, all of which contribute to higher morbidity and mortality rates in this patient population.

The findings stress the critical need for regular and comprehensive monitoring of key hematological parameters to detect deviations early. Interventions such as erythropoiesis-stimulating agents and iron supplementation are necessary to address the anemia. At the same time, careful management of immune function and platelet counts is essential to reduce infection and bleeding risks. Tailored therapeutic approaches are fundamental in settings with limited healthcare infrastructure to ensure the best possible outcomes for these patients.

Ongoing research is essential to further elucidate the underlying mechanisms linking chronic kidney disease, hemodialysis, and hematological abnormalities. A deeper understanding of these factors will refine clinical decision-making and optimize the management of hematological disorders in hemodialysis patients. This will improve patient care, particularly in rural and resource-limited environments where specialized treatments and monitoring may be constrained.

Finding

This research received no external funding

Conflicts of Interest

The authors declare no conflicts of interest.

Data availability statement

The data was not deposited in public repositories

Ethical approval

The Ethics Committee of the Mohammed VI Provincial Hospital Center, El Haouz Province, certifies that the research project entitled: "Evaluation of Hematological Changes in Hemodialysis Patients: A Retrospective Study in a Moroccan Hospital" was reviewed and approved during the session on October 20, 2024. Reference: **CHP-MVI/ETH/2024-015**

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