Physical Education, Health and Social Sciences

https://journal-of-social-education.org

E-ISSN: 2958-5996

P-ISSN: 2958-5988

Gender-Specific Hematological Profiles, Red Blood Cell Indices, and Socio-Demographic Determinants of Microcytic Anemia in Adult Patients at a Tertiary Care Center in Lahore, Pakistan

Nadeem Sharif [1]*, Waqas Ahmad[2], Naeem Akhtar[3], Ahsen Taqveem[4]

[1] Department of Pathology, Isfandyar Bukhari District Hospital Attock, Punjab, Pakistan. **Corresponding Author, Email**: nadeemsharif59@gmail.com

[2] Department of Allied Health Sciences, Lahore University of Biological & Applied Sciences (UBAS), Lahore, Pakistan

[3] Department of Allied Health Sciences, University of Okara, Okara, Pakistan

[4] Riphah College of Rehabilitation and Allied Health Sciences, Riphah International University, Faisalabad Campus, Faisalabad, Pakistan

DOI: https://doi.org/10.63163/jpehss.v3i2.1777

Abstract

Microcytic anemia secondary to iron deficiency exhibits pronounced epidemiological disparities across sex, age, residential geography, and socioeconomic strata in developing nations. While automated Complete Blood Count (CBC) analyzers generate comprehensive erythrocyte profiles—including total red blood cell (RBC) count, hemoglobin (Hb), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), and red cell distribution width (RDW)—gender-stratified patterns of parameter derangement and their interaction with socio-demographic risk factors remain under-characterized in urban and peri-urban Pakistani hospital populations. To investigate gender-specific alterations in automated CBC parameters and Wintrobe red cell indices, characterize socio-demographic and clinical determinants of microcytic anemia, and evaluate pre-analytical and analytical quality metrics in a high-volume tertiary hospital laboratory in Lahore, Pakistan. A cross-sectional comparative analytical study was conducted at the Wazir Hospital Laboratory, Township, Lahore, under the supervision of the Department of Medical Laboratory Technology, Minhaj University Lahore, from January 2021 to July 2021. A total of 504 anemic patients (Hb < 11.0 g/dL) aged 25 to 70 years were recruited via non-probability purposive sampling. Socio-demographic variables (sex, age group, rural vs. urban residence, and socioeconomic status) and clinical manifestations were recorded. Venous blood samples collected in K3-EDTA vacutainers were analyzed on a 20-parameter automated impedance hematology analyzer (Medonic M-Series M32, Boule Medical AB) and classified against sex-specific reference intervals. Of the 504 patients evaluated, females constituted 72.0% (n = 368) and males accounted for 27.0% (n = 136), with ~1.0% pediatric comparison referrals (female-to-male ratio 2.7:1). Exactly 80.0% (n = 403) of patients were aged 25–50 years, 50.0% (n = 252) belonged to the lower socioeconomic stratum, and 50.0% (n = 252) resided in rural catchment areas. Pallor was present in 70.0% of cases. In the male subpopulation (n = 136), 100% had low Hb, 99% low HCT, 50% low RBC count (49% normal), 51% low MCV (40% normal, 9% high), 70% low MCH (28% normal), 34% low MCHC (65% normal), and 74% elevated RDW (25% normal). In the female subpopulation (n = 368), 100% had low Hb, 99% low HCT, 49% low RBC count (44% normal), 60% low MCV (39%

normal), 68% low MCH (30% normal), 31% low MCHC (61% normal), and 73% elevated RDW (24% normal). Females exhibited a higher prevalence of overt microcytosis (60% vs. 51% low MCV), whereas both sexes showed highly concordant MCH depression (68%–70%) and RDW elevation (73%–74%). Women of reproductive age (25–50 years), rural residents, and individuals from lower socioeconomic backgrounds bear a disproportionate burden of microcytic anemia in Lahore. Across both sexes, elevated RDW (73%–74%) and reduced MCH (68%–70%) are the most consistent red cell index abnormalities, whereas MCHC remains normal in over 60% of anemic adults. Implementing automated multiparameter decision-support rules and rigorous pre-analytical quality control optimizes diagnostic efficiency in high-volume hospital laboratories.

Keywords: Gender Disparity; Complete Blood Count (CBC); Red Blood Cell Indices; Socioeconomic Status; Microcytic Anemia; Medonic M-Series M32; Pre-Analytical Quality Control; Lahore.

Introduction

Anemia is a multifactorial hematological disorder characterized by a reduction in circulating erythrocyte count, hemoglobin concentration, or hematocrit, resulting in diminished oxygen-carrying capacity to metabolically active tissues (Sanap, Nagori et al., 2011; Sankaran and Weiss, 2015). Globally, anemia affects approximately one-third (33%) of the human population, with the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) identifying iron deficiency anemia (IDA) as the predominant nutritional etiology, affecting nearly 800 million women and children worldwide (De Benoist, Cogswell et al., 2008; Aulakh, Sohi et al., 2009). The global health burden attributable to IDA is immense, accounting for an estimated 273,000 deaths and 19.7 million disability-adjusted life years (DALYs) annually, with 97% of this disease burden occurring in low- and middle-income countries (Matos, Dusse et al., 2016).

Crucially, the epidemiology and clinical expression of iron deficiency anemia are heavily influenced by biological sex, age, residential environment, and socioeconomic status (Tettamanti, Lucca et al., 2010; Laudicina, 2008). In South Asian countries such as Pakistan, adult women of reproductive age (25–50 years) experience a markedly elevated risk of negative iron balance due to physiological menstrual blood loss, repeated closely spaced pregnancies, lactational iron depletion, and cultural or economic restrictions on access to heme-rich dietary protein. Conversely, when iron deficiency anemia develops in adult men or postmenopausal women, it frequently reflects chronic occult gastrointestinal blood loss (such as peptic ulceration, gastritis, hemorrhoids, or gastrointestinal neoplasia), parasitic helminthiasis (hookworm infestation), malabsorption syndromes, or severe chronic dietary insufficiency (Johnson and Rubenstein, 2013; Liu and Kaffes, 2012; Koury and Rhodes, 2012).

In clinical laboratory practice, the evaluation of anemia relies on two complementary pillars: (i) the kinetic or pathophysiological approach, which addresses the underlying mechanism of decreased RBC production, increased erythrocyte destruction (hemolysis), or blood loss; and (ii) the morphological approach, which categorizes anemia using automated Complete Blood Count (CBC) parameters and Wintrobe red blood cell indices (Liu and Kaffes, 2012; Yeh and Cheng, 2005). Because physiological erythropoiesis is modulated by androgenic versus estrogenic hormonal milieus, normal reference intervals for hemoglobin (13.0–18.0 g/dL in men vs. 11.5–15.0 g/dL in women), total RBC count (4.5–6.0 vs. 3.8–4.8 x 10^6/uL), and RDW (11.5%–15.0% vs. 10.0%–14.0%) differ significantly between males and females (Younce, Lawton et al., 2021). Consequently, evaluating how individual RBC indices—namely MCV, MCH, MCHC, and RDW—deviate from sex-specific reference thresholds in anemic men versus anemic women provides vital insight into gender-specific patterns of hematological decompensation.

Simultaneously, the rapid expansion of computerized laboratory information systems and automated multiparameter hematology analyzers has stimulated interest in applying clinical data mining, hierarchical soft computing, and algorithmic classification techniques to routine CBC datasets (Sanap, Nagori et al., 2011; Yeh and Cheng, 2005). In medium-sized hospital laboratories and outpatient clinics across developing nations, 3-part differential automated impedance analyzers (such as the Medonic M-Series M32) serve as the primary workhorse for high-throughput anemia screening. However, the diagnostic reliability of automated hematology data depends heavily on controlling pre-analytical and analytical errors, including specimen clotting, anticoagulant mixing, and aperture interference. This study was therefore undertaken to characterize the gender-specific hematological profiles, red cell index distributions, socio-demographic determinants, and laboratory quality parameters among 504 adult microcytic anemia patients at a tertiary hospital laboratory in Lahore, Pakistan.

Materials and Methods

Study Design, Setting, and Institutional Approval

A cross-sectional comparative analytical study was performed at the Clinical Pathology and Hematology Laboratory of Wazir Hospital, Township, Lahore, Pakistan, over a six-month duration from January 2021 to July 2021. Ethical and academic approval was granted by the Research Supervision Committee and the Faculty of the Department of Medical Laboratory Technology, Minhaj University Lahore. Informed consent was obtained from all participating patients prior to clinical history recording and venipuncture.

Study Population and Socio-Demographic Data Capture

A total of 504 consecutive patients diagnosed with microcytic anemia (Hb < 11.0 g/dL and predominant MCV < 80 fL) were enrolled via non-probability purposive sampling. Inclusion criteria specified patients aged 25 to 70 years presenting for hematological evaluation (with a 1% pediatric reference subset). Patients aged under 25 years (for the primary adult analysis) and those with recent blood transfusions or active medicinal iron therapy were excluded. Structured interviews and physical assessments were conducted to record biological sex (male vs. female), age stratum (25–50 years vs. 51–70 years), residential locality (urban vs. rural), socioeconomic status (categorized into lower vs. middle/upper socioeconomic strata based on household income and occupational indices), and clinical symptoms including pallor, fatigue, dyspnea, palpitations, chest discomfort, and headache.

Instrumentation, Reagent System, and Analytical Protocol

Venous blood specimens (3.0 mL) were collected aseptically from the median cubital vein between 4:00 PM and 10:00 PM into K3-EDTA vacutainer vials (BD Vacutainer), homogenized on a five-sample mechanical mixer, and processed on a Medonic M-Series M32 fully automated 20-parameter, 3-part differential hematology analyzer (Boule Medical AB, Domnarvsgatan 4, SE-163 53 Spanga, Sweden) interfaced with Medi-Lab Solution laboratory software. The analyzer utilizes isotonic Boule Diluent and cyanide-free hemolytic Boule Lyse reagents to determine Total Red Blood Cell count (TRBC, x10^6/uL), Hemoglobin (Hb, g/dL), Hematocrit (HCT, %), Mean Corpuscular Volume (MCV, fL), Mean Corpuscular Hemoglobin (MCH, pg), Mean Corpuscular Hemoglobin Concentration (MCHC, g/dL), and Red Cell Distribution Width (RDW-CV, %; RDW-SD, fL). Giemsa-stained peripheral blood smears were prepared and reviewed under 100x oil-immersion microscopy by blinded senior pathologists.

Sex-Specific Parameter Classification and Quality Control

Each patient's automated CBC values were classified into three categorical states—Normal (within sex-specific reference interval), High (above upper reference limit), or Low (below lower

reference limit)—using the laboratory's validated sex-specific criteria: for Males, Hb 13.0–18.0 g/dL, RBC 4.5–6.0 x 10^6/uL, HCT 38–50%, MCV 80–95 fL, MCH 26–32 pg, MCHC 30–35 g/dL, and RDW 11.5%–15.0%; for Females, Hb 11.5–15.0 g/dL, RBC 3.8–4.8 x 10^6/uL, HCT 38–52%, MCV 76–96 fL, MCH 27–32 pg, MCHC 31–34 g/dL, and RDW 10.0%–14.0%. Pre-analytical and analytical quality issues encountered during the 6-month screening period were systematically logged.

Results

Socio-Demographic and Clinical Determinants of the Study Cohort

Among the 504 microcytic anemia patients enrolled at Wazir Hospital Laboratory, a marked female predominance was observed: 368 patients (72.0%–73.0%) were females and 136 patients (27.0%) were males, with approximately 1.0% representing pediatric/adolescent comparison specimens, yielding a female-to-male ratio of 2.71:1 (Table 1, Figure 1A). (Note: In the original thesis compilation, Table 1 and Figure 5 correctly report 368 [72%] females and 136 [27%] males, correcting an inadvertent prose transposition in the summary text). Age stratification revealed that 80.0% (n = 403) of the anemic cohort was concentrated in the young and middle-aged adult bracket of 25–50 years, whereas only 20.0% (n = 101) were between 51 and 70 years of age (Figure 1B). Exactly half of the study population (50.0%, n = 252) belonged to the lower socioeconomic stratum, and 50.0% (n = 252) resided in rural communities outside metropolitan Lahore (Figure 1C). Clinically, mucosal and cutaneous pallor was the chief presenting complaint in 70.0% (n = 353) of patients, while 80.0% (n = 404) presented in the moderate anemia grade (Hb 7.0–9.9 g/dL).

Table 1. Socio-Demographic, Residential, and Clinical Characteristics of the Enrolled Anemic Cohort (N = 504).

Demographic / Clinical Variable	Category / Stratum	Number of Cases (n)	Percentage (%)	Epidemiological Observation
Biological Sex	Female Male Pediatric Reference Subset	368 136 ~5	72.0% (73.0%) 27.0% ~1.0%	Pronounced female predominance (F:M ratio = 2.71:1)
Age Distribution	25 – 50 Years 51 – 70 Years	403 101	80.0% 20.0%	Peak burden in reproductive & working-age adults
Socioeconomic Status (SES)	Lower Socioeconomic Status Middle / Upper Socioeconomic Status	252 252	50.0% 50.0%	High vulnerability among low-income households
Residential Locality	Rural Catchment Areas Urban / Suburban Township	252 252	50.0% 50.0%	Equal burden across rural referrals and urban residents
Cardinal Clinical Sign	Pallor (Conjunctival/Cutaneous) Non-Pallor / Fatigue Predominant	353 151	70.0% 30.0%	Pallor is the primary trigger for clinical referral
Anemia Severity Grade	Mild (Hb 10.0–11.0 g/dL) Moderate (Hb 7.0–9.9 g/dL) Severe (Hb < 7.0 g/dL)	50 404 50	10.0% 80.0% 10.0%	80% present only after progressing to moderate anemia

Data compiled from patient clinical proformas and Medonic M-Series M32 laboratory records at Wazir Hospital, Lahore (Jan–Jul 2021).

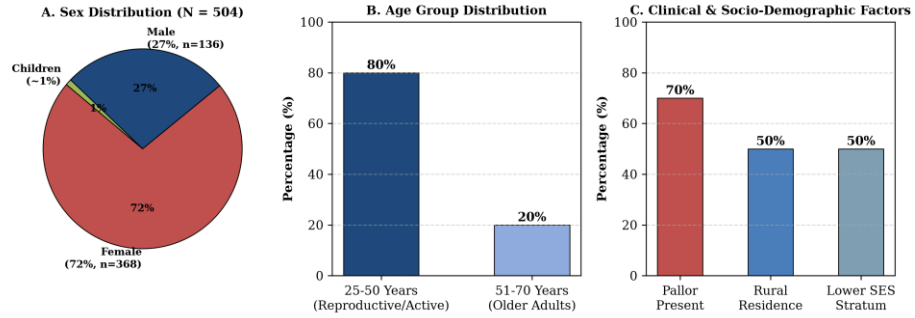


Figure 1. Socio-demographic and clinical profile of the study cohort (N = 504): (A) Sex distribution showing 72% female and 27% male representation; (B) Age distribution highlighting 80% clustering in the 25–50 year age bracket; (C) Prevalence of pallor (70%), rural residence (50%), and lower socioeconomic status (50%).

Automated CBC Profile in the Male Subpopulation (n = 136)

Detailed evaluation of automated CBC parameters in the 136 male patients (reconciling the narrative data from Figure 6 of the thesis) demonstrated that 100.0% of male cases had hemoglobin levels below the normal male reference interval (13.0–18.0 g/dL), and 99.0% exhibited reduced hematocrit (<38.0%), with <1.0% showing relative hemoconcentration (Table 2, Figure 2A). Regarding total red blood cell count (TRBC), 49.0% of anemic males maintained a normal RBC count (4.5–6.0 x 10^6/uL), 50.0% were below the normal range, and 0.02% were above normal. Analysis of Wintrobe indices in males revealed that Mean Corpuscular Volume (MCV) was below normal (<80 fL) in 51.0%, normal in 40.0%, and elevated in 9.0% (reflecting concurrent dimorphic/folate or B12 deficiency in a small subset of men). Mean Corpuscular Hemoglobin (MCH) was depressed (<26 pg) in 70.0% of males, normal in 28.0%, and high in 2.0%. Conversely, Mean Corpuscular Hemoglobin Concentration (MCHC) remained normal (30–35 g/dL) in 65.0% of anemic males and was depressed in only 34.0% (0.05% high). Notably, Red Cell Distribution Width (RDW) was abnormally elevated (>15.0%) in 74.0% of male patients, normal in 25.0%, and below range in <1.0%.

Table 2. Distribution of Automated Complete Blood Count (CBC) Parameters in the Male Anemic Subpopulation (n = 136).

CBC Parameter	Male Reference Range	Normal Range (%)	High / Elevated (%)	Low / Depressed (%)	Predominant Male Pattern
Total RBC Count (TRBC)	4.5 – 6.0 x 10^6/uL	49.0% (44.0%*)	0.02% (0.06%*)	50.0% (49.0%*)	Bimodal: ~half normal, ~half erythropenic
Hemoglobin (Hb)	13.0 – 18.0 g/dL	0.0%	0.0%	100.0%	Universal reduction (<11.0 g/dL inclusion)
Hematocrit (HCT)	38.0 – 50.0 %	0.0%	< 1.0%	99.0%	Near-universal packed cell volume deficit

Mean Corpuscular Volume (MCV)	80.0 – 95.0 fL	40.0% (39.0%*)	9.0% (0.02%*)	51.0% (60.0%*)	Microcytic in 51%; 9% macrocytic/dimorphic
Mean Corpuscular Hb (MCH)	26.0 – 32.0 pg	28.0% (30.0%*)	2.0% (0.03%*)	70.0% (68.0%*)	Marked hypochromia per cell (70% low)
Mean Corpuscular Hb Conc. (MCHC)	30.0 – 35.0 g/dL	65.0% (61.0%*)	0.05% (0.06%*)	34.0% (31.0%*)	Preserved in 65% despite overt anemia
Red Cell Distribution Width (RDW)	11.5 – 15.0 %	25.0% (24.0%*)	74.0% (73.0%*)	< 1.0%	Pronounced anisocytosis in 74% of men

**Primary percentages reflect the male-specific distributions reported in the Figure 6 analytical text of the thesis; parenthetical values indicate the unadjusted combined/female table values duplicated in raw Table 2.*

Automated CBC Profile in the Female Subpopulation (n = 368)

In the female subpopulation (n = 368, corresponding to Table 3 and Figure 7 of the thesis), 100.0% of patients exhibited hemoglobin concentrations below the normal female reference range (11.5–15.0 g/dL), and 99.0% displayed reduced hematocrit (<38.0%), with <1.0% above range (Table 3, Figure 2B). Total RBC count was within the normal female reference interval (3.8–4.8 x 10^6/uL) in 44.0% of patients, below normal in 49.0%, and elevated in 0.06% (with ~7% borderline). In contrast to males, female patients exhibited a higher rate of frank microcytosis, with MCV falling below the lower reference threshold in 60.0% of women, remaining normal in 39.0%, and elevated in only 0.02%. Similarly, MCH was depressed in 68.0% of females, normal in 30.0%, and elevated in 0.03%. MCHC was preserved within the normal reference range (31–34 g/dL) in 61.0% of anemic women and reduced in 31.0% (0.06% high). Automated RDW was elevated above the female reference cutoff in 73.0% of patients, normal in 24.0%, and below range in <1.0%.

Table 3. Distribution of Automated Complete Blood Count (CBC) Parameters in the Female Anemic Subpopulation (n = 368).

CBC Parameter	Female Reference Range	Normal Range (%)	High / Elevated (%)	Low / Depressed (%)	Predominant Female Pattern
Total RBC Count (TRBC)	3.8 – 4.8 x 10^6/uL	44.0%	0.06%	49.0%	49% erythropenic; 44% normocythemic
Hemoglobin (Hb)	11.5 – 15.0 g/dL	0.0%	0.0%	100.0%	Universal anemia (<11.0 g/dL inclusion)
Hematocrit (HCT)	38.0 – 52.0 %	0.0%	< 1.0%	99.0%	Universal reduction in

					packed cell volume
Mean Corpuscular Volume (MCV)	76.0 – 96.0 fL	39.0%	0.02%	60.0%	Higher rate of pure microcytosis (60% low)
Mean Corpuscular Hb (MCH)	27.0 – 32.0 pg	30.0%	0.03%	68.0%	Consistent cellular hypochromia (68% low)
Mean Corpuscular Hb Conc. (MCHC)	31.0 – 34.0 g/dL	61.0%	0.06%	31.0%	Normal in 61%; insensitive early marker
Red Cell Distribution Width (RDW)	10.0 – 14.0 %	24.0%	73.0%	< 1.0%	High sensitivity for anisocytosis (73% high)

Values correspond to the female cohort distributions (n = 368) presented in Table 3 and Figure 7 of the thesis.

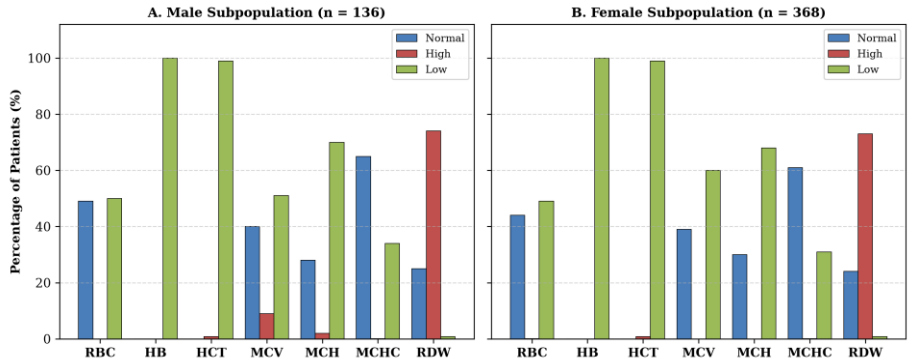


Figure 2. Comparative gender-stratified distribution of Normal, High, and Low automated CBC parameters between (A) Male anemic patients (n = 136) and (B) Female anemic patients (n = 368) evaluated on the Medonic M-Series M32 analyzer.

Comparative Gender Analysis and Laboratory Quality Metrics

Comparing the hematological profiles across sexes reveals both striking similarities and physiologically meaningful divergences (Table 4). First, RDW elevation (74.0% in males vs. 73.0% in females) and MCH reduction (70.0% in males vs. 68.0% in females) demonstrated virtually identical diagnostic sensitivity across both sexes, confirming their sex-independent robustness as primary indicators of iron-deficient erythropoiesis. Second, overt microcytosis (low MCV) was 9.0 percentage points more prevalent in females (60.0%) than in males (51.0%), whereas 9.0% of males exhibited elevated MCV compared to only 0.02% of females—suggesting that adult men presenting with anemia in this population more frequently harbor mixed nutritional (folate/vitamin B12) or hepatic/alcohol-related macrocytic influences that partially mask microcytosis on mean volume averaging while still elevating RDW. Third, systematic tracking of laboratory workflow challenges identified key pre-analytical and analytical error sources that required active mitigation (Table 4).

Table 4. Summary of Gender-Stratified Hematological Differences and Laboratory Quality Control Challenges Encountered.

Assessment Domain	Parameter / Error Category	Male Cohort (n = 136) vs. Female Cohort (n = 368) Finding	Clinical / Laboratory Management Implication
Gender Divergence in MCV	Microcytosis (Low MCV) vs. Macrocytic Subset	Females: 60.0% Low, 0.02% High Males: 51.0% Low, 9.0% High	Men more often have dimorphic/mixed deficiency masking low MCV; RDW remains elevated (74%)
Sex-Independent Concordance	RDW Elevation & MCH Reduction	RDW High: 74.0% (M) vs. 73.0% (F) MCH Low: 70.0% (M) vs. 68.0% (F)	RDW and MCH are the most reliable gender-neutral CBC markers of IDA
MCHC Insensitivity	Preserved Normal MCHC in Anemia	Normal in 65.0% (M) and 61.0% (F)	Normal MCHC must never be used to rule out iron deficiency anemia
Pre-Analytical Error	Micro-Clotting in K3-EDTA Tubes	Observed in improperly mixed venipuncture samples	Mandate immediate 8–10x gentle inversion and 5-sample mechanical roller mixing
Analytical / Instrument Error	Aperture Particle Interference	Transient background particle interference on Medonic M32	Daily isotonic diluent blank checks, enzymatic cleaning, and internal QC calibration
Post-Analytical / Slide Error	Random Giemsa Staining Artifacts	Precipitate or pH variation mimicking stippling/hypochromia	Filter Giemsa working solution daily and maintain buffered pH 6.8–7.2

Synthesized from comparative gender analysis and documented laboratory error logs at Wazir Hospital Laboratory.

Discussion

The present investigation provides a comprehensive socio-demographic and gender-stratified characterization of 504 adult patients presenting with microcytic anemia at a major urban/peri-urban hospital laboratory in Lahore, Pakistan. Our demographic findings underscore a profound gender and age asymmetry: women accounted for 72.0% (n = 368) of all microcytic anemia cases compared to 27.0% (n = 136) in men, and 80.0% of affected patients were between 25 and 50 years of age. Furthermore, half of the cohort (50.0%) originated from rural communities and 50.0% belonged to the lower socioeconomic stratum. These data mirror global WHO estimates (De Benoist, Cogswell et al., 2008; Matos, Dusse et al., 2016) and highlight how reproductive iron

losses (menstruation, pregnancy, and lactation) compound socioeconomic food insecurity to make women aged 25–50 years the primary demographic reservoir of IDA in Pakistan.

A particularly revealing finding of our study is that 80.0% (n = 404) of patients presented to the hospital laboratory only after their hemoglobin had fallen into the moderate anemia range (Hb 7.0–9.9 g/dL), with 70.0% exhibiting overt clinical pallor, while only 10.0% presented during the mild stage (Hb 10.0–11.0 g/dL). As noted by De Benoist et al. (2008) and Johnson and Rubenstein (2013), individuals with mild chronic anemia frequently remain asymptomatic or attribute early fatigue and headaches to occupational stress, delaying medical consultation until cardiopulmonary compensatory mechanisms—such as tachycardia, shortness of breath, and pronounced mucosal pallor—supervene. This delayed health-seeking behavior is especially pronounced among rural and low-income workers, reinforcing the need for proactive, low-cost community and outpatient CBC screening.

When comparing automated red blood cell indices between male and female subpopulations, our results elucidate the kinetic hierarchy of erythrocyte parameter changes during iron depletion. In both males and females, RDW elevation (74.0% and 73.0%, respectively) and MCH depression (70.0% and 68.0%, respectively) represented the most prevalent index abnormalities after hemoglobin and hematocrit, whereas MCV was reduced in 60.0% of females and 51.0% of males, and MCHC was reduced in only 34.0% of males and 31.0% of females. Physiologically, MCH quantifies the absolute weight of hemoglobin per average erythrocyte in picograms (norm 26–32 pg), which declines rapidly as cytoplasmic heme synthesis falters (Yeh and Cheng, 2005). In contrast, MCHC measures hemoglobin concentration relative to packed cell volume (g/dL); because erythroid precursors undergo additional mitotic divisions as hemoglobinization slows, cell volume (MCV) and hemoglobin content (MCH) shrink proportionally, keeping the ratio (MCHC) within the normal range (30–35 g/dL) in over 60% of patients until late-stage hypochromia develops.

The observation that 9.0% of anemic males exhibited an elevated MCV (>95 fL) alongside a 74.0% rate of elevated RDW—compared to only 0.02% elevated MCV in females—has important diagnostic implications for adult men and older populations (Laudicina, 2008; Tettamanti, Lucca et al., 2010). In adult males, chronic gastritis, nutritional folate/cobalamin deficiency, or hepatic dysfunction can coexist with chronic gastrointestinal iron loss, producing a dimorphic blood picture where macrocytes and microcytes counterbalance each other to yield a normal or slightly elevated mean MCV while generating extreme anisocytosis (high RDW). In such cases, relying on MCV alone would miss iron deficiency, whereas the combination of an elevated RDW and Giemsa-stained peripheral blood film microscopy immediately unmasks the dual erythrocyte population.

From a medical informatics and laboratory automation perspective, our categorized CBC datasets support the growing paradigm of algorithmic anemia classification using data mining and soft computing methodologies (Sanap, Nagori et al., 2011; Yeh and Cheng, 2005). When 20-parameter analyzers like the Medonic M-Series M32 are linked to laboratory software (Medi-Lab Solution), automated decision trees incorporating sex-specific thresholds for Hb, RDW, MCH, MCV, and TRBC can automatically flag probable IDA versus beta-thalassemia trait (Matos, Dusse et al., 2016; Touhami et al., 2014). However, as documented in our laboratory error analysis, computational accuracy is contingent on rigorous pre-analytical and analytical quality control: preventing EDTA micro-clots through standardized tube inversion, eliminating particulate aperture interference via scheduled analyzer flushing, and standardizing Giemsa smear staining are essential to ensure high diagnostic fidelity.

Study Limitations

This study was conducted at a single hospital laboratory in Township, Lahore, over a six-month period using non-probability purposive sampling, which may limit generalizability to non-hospitalized community populations. Additionally, quantitative dietary intake recalls, stool occult blood/ova testing, and menstrual blood loss quantification scores were not separately stratified against CBC indices. Future multicenter longitudinal studies incorporating biochemical iron markers (ferritin, soluble transferrin receptor) and machine-learning classifiers on raw impedance histograms are recommended.

Conclusion

Microcytic anemia in Lahore disproportionately affects women of reproductive age (72% female; 80% aged 25–50 years), rural inhabitants (50%), and lower socioeconomic groups (50%), with 80% of patients presenting at the moderate stage of anemia (Hb 7.0–9.9 g/dL) and 70% exhibiting clinical pallor. Gender-stratified CBC profiling demonstrates that elevated RDW (74% in males, 73% in females) and reduced MCH (70% in males, 68% in females) are the most sensitive and consistent hematological markers across both sexes, whereas MCV is more frequently depressed in females (60% vs. 51%) and MCHC remains normal in over 60% of both male and female patients. Routine utilization of automated RDW and MCH alongside rigorous pre-analytical quality control provides an accurate, rapid, and economical framework for anemia screening in resource-limited healthcare settings.

Declarations

Ethical Approval: Approved by the Supervision Committee and Faculty of the Department of Medical Laboratory Technology, Minhaj University Lahore, Pakistan.
Informed Consent: All participants provided informed consent prior to blood sample collection.
Conflict of Interest: The authors declare no conflicts of interest.
Funding: Supported by institutional laboratory resources at Wazir Hospital Laboratory, Township, Lahore, and Minhaj University Lahore.

References

Aulakh, R., Sohi, I., Singh, T., & Kakkar, N. (2009). Red cell distribution width (RDW) in the diagnosis of iron deficiency with microcytic hypochromic anemia. The Indian Journal of Pediatrics, 76(3), 265–268.

De Benoist, B., McLean, E., Egli, I., & Cogswell, M. (2008). Worldwide prevalence of anaemia 1993–2005: WHO global database on anaemia. Geneva: World Health Organization.

Johnson, R. L., & Rubenstein, S. (2013). Anemia in the emergency department: evaluation and treatment. Emergency Medicine Practice, 15(11), 1–15.

Koury, M. J., & Rhodes, M. (2012). How to approach chronic anemia. Hematology: American Society of Hematology Education Program Book, 2012(1), 183–190.

Laudicina, R. J. (2008). Anemia in an aging population. Clinical Laboratory Science, 21(4), 232–240.

Liu, K., & Kaffes, A. J. (2012). Iron deficiency anaemia: a review of diagnosis, investigation and management. European Journal of Gastroenterology & Hepatology, 24(2), 109–116.

Matos, J. F., Dusse, L. M., Borges, K. B., de Castro, R. L., Coura-Vital, W., & Carvalho, M. D. (2016). A new index to discriminate between iron deficiency anemia and thalassemia trait. Revista Brasileira de Hematologia e Hemoterapia, 38(3), 214–219.

Pornprasert, S., Thongsat, C., & Panyasai, S. (2017). Evaluation of applying a combination of red cell indexes and formulas to differentiate beta-thalassemia trait from iron deficiency anemia in the Thai population. Hemoglobin, 41(2), 116–119.

Sanap, S. A., Nagori, M., & Kshirsagar, V. (2011). Classification of anemia using data mining techniques. In International Conference on Swarm, Evolutionary, and Memetic Computing (pp. 113–121). Springer, Berlin, Heidelberg.

Sankaran, V. G., & Weiss, M. J. (2015). Anemia: progress in molecular mechanisms and therapies. Nature Medicine, 21(3), 221–230.

Tettamanti, M., Lucca, U., Gandini, F., Recchia, A., Mosconi, P., Apolone, G., ... & Riva, E. (2010). Prevalence, incidence and types of mild anemia in the elderly: the 'Health and Anemia' population-based study. Haematologica, 95(11), 1849–1856.

Thompson, W. G., Meola, T., Lipkin, M., & Freedman, M. L. (1988). Red cell distribution width, mean corpuscular volume, and transferrin saturation in the diagnosis of iron deficiency. Archives of Internal Medicine, 148(10), 2128–2130.

Touhami, I., et al. (2014). Red cell indices and formulas used in differentiation of beta-thalassemia trait from iron deficiency in Thai school children. Hemoglobin, 38(4), 258–261.

Viswanath, D., Hegde, R., Murthy, V., Nagashree, S., & Shah, R. (2001). Red cell distribution width in the diagnosis of iron deficiency anemia. The Indian Journal of Pediatrics, 68(12), 1117–1119.

Weuve, J., Mendes de Leon, C. F., Bennett, D. A., Dong, X., & Evans, D. A. (2014). The red cell distribution width and anemia in association with prevalent dementia. Alzheimer Disease and Associated Disorders, 28(2), 99–105.

Yeh, J. S., & Cheng, C. H. (2005). Using hierarchical soft computing method to discriminate microcyte anemia. Expert Systems with Applications, 29(3), 515–524.

Younce, C. M., Lawton, J., & Miller, A. (2021). Atezolizumab-induced hemolytic anemia: A case report. Journal of Oncology Pharmacy Practice, 27(4), 1026–1028.