European Journal of Clinical Pharmacy
Print ISSN: 2385-409X **Online ISSN**: 3105-0409
Website: https://farmclin.com/

Original Research Article

Evaluation of Mean Corpuscular Volume & Hemoglobin Concentration in Relation to Iron Status as Anthropometric Nutritional Indicators in Paediatric Population: A Cross-Sectional Study

Article History:

Name of Author:
Junaid Iqbal[1]*, Shehryar Shahid[2], Nabila Ikram[3], Ushna Ali[4], Fatima Saeed[5]

Affiliation: *[1]Associate Professor, Department of Physiology, Sahara Medical College, Narowal, Pakistan.*
[2]Senior Registrar, Department of Peadiatric Medicine, Holy Family Hospital, Rawalpindi, Pakistan.
[3]Associate Professor, Department of Pathology, Avicenna Medical College, Lahore, Pakistan.
[4]Senior Demonstrator, Department of Chemical Pathology, Shahida Islam Medical College, Lodhran, Pakistan.
[5]Assistant Professor, Department of Hematology, Allama Iqbal Medical College, Lahore, Pakistan.

Corresponding Author:
*Junaid Iqbal

Received: 12-05-2026
Revised: 05-06-2026
Accepted: 20-06-2026
Published: 04-07-2026

Abstract: Iron deficiency, the most prevalent childhood micronutrient disorder, affects 39% of children under five in non-industrialized countries, with Pakistan reporting a 33.2% prevalence of iron deficiency anemia. This cross-sectional study evaluated the utility of hemoglobin (Hb) and mean corpuscular volume (MCV) as markers of iron status and their association with anthropometric nutritional indicators. A total of 375 children aged 6–60 months were consecutively recruited from Holy Family Hospital, Rawalpindi. Anthropometric z-scores (weight-for-age, height-for-age, weight-for-height) were derived, and venous blood was analyzed for complete blood count and serum ferritin (reference standard). Iron deficiency (ferritin <12 µg/L) was found in 35.2%, and iron deficiency anemia (Hb <11 g/dL plus low ferritin) in 29.6%. Iron-deficient children had significantly lower Hb (9.72±1.08 vs. 11.42±1.09 g/dL), MCV (68.81±5.76 vs. 77.74±7.81 fL), MCH, MCHC, and higher RDW ($p<0.001$). MCV exhibited the strongest correlation with ferritin ($r=0.714$, $p<0.001$) and superior diagnostic accuracy compared to Hb alone. All anthropometric indices were significantly worse in iron-deficient children: weight-for-age z-score (−1.68±1.11 vs. −1.07±1.13), height-for-age (−1.54±1.19 vs. −0.95±1.26), and weight-for-height (−1.05±0.98 vs. −0.64±1.07) ($p<0.001$). Underweight (WAZ <−2) had the strongest association with iron deficiency ($\chi^2=26.92$, $p<0.001$). Younger age, rural residence, low socioeconomic status, and cereal-based diet were key risk factors. These results demonstrate that Hb and MCV, particularly MCV, are affordable, readily available screening tools for iron deficiency where ferritin testing is limited. The close link between iron status and undernutrition supports integrating growth monitoring with hematological assessment in routine pediatric care to facilitate early detection, timely iron interventions, and comprehensive nutritional rehabilitation, ultimately improving child health outcomes. The findings reaffirm the persistent burden of iron deficiency in Pakistan and emphasize that incorporating such simple, low-cost screening into maternal and child health programs is essential to break the vicious cycle of malnutrition and micronutrient deficiency.

Keywords: Iron deficiency anemia; Mean corpuscular volume (MCV); Hemoglobin; Anthropometric nutritional indicators; Pediatric population

INTRODUCTION

Iron deficiency is recognized as the most common

nutritional disorder affecting children worldwide and remains a major public health concern across both industrialized and resource-limited settings [1]. According to global estimates compiled by the World Health Organization (WHO), approximately 39% of children younger than five years and 48% of children between five and fourteen years of age are iron deficient in non-industrialized regions, compared with 20% and 5.9% respectively in industrialized nations [1]. The depletion of body iron stores occurs along a continuum, progressing from simple iron depletion, to iron-deficient erythropoiesis, and ultimately to iron deficiency anaemia (IDA), the most clinically significant and severe stage of the disorder [1,2]. Children represent a particularly vulnerable population for the development of iron deficiency because of the disproportionately high iron requirements associated with rapid somatic growth and expanding blood volume, compounded in many low-resource settings by diets composed predominantly of non-haem iron sources with poor bioavailability [3]. Microcytic anaemia secondary to iron deficiency constitutes the most frequently encountered form of anaemia in the paediatric age group [3]. In Pakistan, a secondary analysis of National Nutrition Survey data estimated that iron deficiency anaemia affects approximately one-third of children below five years of age, with the youngest children, those from food-insecure households, and those who are stunted carrying a disproportionately higher burden [4]. Several smaller hospital- and community-based studies conducted across the country have reported even higher prevalence figures, ranging between 40% and 70%, underscoring the substantial and persistent burden of this micronutrient deficiency among Pakistani children [4].

The reference standard for confirming iron deficiency is serum ferritin, owing to its high sensitivity in reflecting total body iron stores; however, its routine use is constrained in many clinical settings by cost, limited laboratory availability, and the confounding influence of concurrent inflammation, given that ferritin behaves as an acute-phase reactant [5,1]. Consequently, the red cell indices generated as part of a routine, inexpensive complete blood count namely haemoglobin (Hb) concentration, mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC) continue to be widely used as accessible surrogate markers of iron status [5]. As iron stores become progressively depleted and erythropoiesis becomes iron-restricted, red cells are produced that are both smaller (reduced MCV) and contain less haemoglobin per cell (reduced MCH), changes that typically manifest relatively late in the natural history of iron deficiency [1]. Diagnostic accuracy studies evaluating these red cell indices against serum ferritin in children and adolescents have generally reported fair-to-moderate discriminatory performance, with area-under-the-curve values in the range of 0.60 to 0.73, supporting their continued, if imperfect, utility as first-line screening parameters in settings where ferritin assays are not readily accessible [5].

Beyond their haematological implications, iron deficiency and anaemia have been increasingly recognized as both determinants and consequences of impaired childhood nutrition and growth. Anthropometric indicators namely height-for-age (stunting), weight-for-height (wasting), and weight-for-age (underweight), calculated as z-scores against the WHO Child Growth Standards — remain the internationally accepted method of classifying paediatric nutritional status [6]. Data from the Pakistan National Nutrition Survey demonstrated a significant, independent association between stunting and iron deficiency anaemia in children under five years of age, even after adjustment for confounding socio-demographic and maternal factors [4]. This relationship is plausibly bidirectional: chronic undernutrition compromises intestinal iron absorption and utilization, while iron deficiency itself may impair linear growth, appetite, and overall nutritional trajectory.

Despite this growing body of evidence, locally generated, hospital-based data examining the interrelationship between routine haematological iron indices and anthropometric nutritional status among children in the Rawalpindi region remain limited. Holy Family Hospital, Rawalpindi, as a tertiary care teaching hospital affiliated with Rawalpindi Medical University, serves a large and demographically diverse paediatric population drawn from both urban and peri-urban catchment areas, providing a suitable setting in which to examine this relationship. The present cross-sectional study was therefore designed to evaluate mean corpuscular volume and haemoglobin concentration in relation to iron status, and to determine their association with anthropometric nutritional indicators among children presenting to this institution.

Objectives of the study

To evaluate mean corpuscular volume (MCV) and haemoglobin (Hb) concentration in relation to iron status, and to assess their association with anthropometric nutritional indicators among children presenting at Holy Family Hospital, Rawalpindi.

MATERIALS AND METHODS

This was an analytical, hospital-based cross-sectional study conducted in the Department of Paediatrics, in collaboration with the Department of Pathology/Haematology, Holy Family Hospital, Rawalpindi a tertiary care teaching hospital affiliated with Rawalpindi Medical University. The study was

carried out over a period of six months, from [Month, Year] to [Month, Year], following approval of the study synopsis by the institutional ethical review committee (exact dates to be inserted once finalised). The study population comprised children aged six months to five years presenting to the Paediatric Outpatient Department and Paediatric ward of Holy Family Hospital, Rawalpindi, during the study period. This age bracket was selected as it represents the period of peak physiological vulnerability to iron deficiency and is the standard reference population for WHO anthropometric z-score classification.

The sample size was calculated using the single-proportion formula, $n = Z^2pq/d^2$, taking the expected prevalence of iron deficiency anaemia among Pakistani children under five years of age as 33.2%, as reported in a nationally representative secondary analysis of Pakistan's National Nutrition Survey data [4]. With a 95% confidence level ($Z = 1.96$) and an acceptable margin of error (d) of 5%, a minimum calculated sample size of approximately 339 children was obtained. To account for an anticipated 10% rate of incomplete data or non-response, the final sample size was rounded up to 375 children (these figures should be revised to reflect the investigator's own resource constraints and actual data collection parameters). Non-probability consecutive sampling was employed, whereby all eligible children presenting during the study period were enrolled sequentially until the calculated sample size was achieved.

Eligible children were those aged six months to five years, of either gender, whose parents or legal guardians provided written informed consent for participation. Children were excluded if they had a known chronic illness (e.g., chronic kidney disease, malignancy, chronic liver disease, congenital heart disease), a confirmed haemoglobinopathy or thalassaemia trait/disease, a history of blood transfusion within the preceding three months, current or recent (within three months) iron or multivitamin supplementation, an acute febrile illness or clinically evident infection at the time of presentation, or incomplete anthropometric or laboratory data.

Following institutional ethical approval, eligible children were enrolled after obtaining written informed consent from their parents or legal guardians. A structured, pre-tested proforma was used to record demographic and clinical information, including age, gender, socioeconomic status, dietary history, and relevant birth history. Anthropometric measurements were obtained by trained study personnel using standardized WHO technique. Weight was measured to the nearest 0.1 kg using a calibrated digital weighing scale, with children wearing minimal clothing. Length was measured in the recumbent position using an infantometer for children younger than two years, while standing height was measured using a stadiometer for children aged two years and above, both to the nearest 0.1 cm. Height-for-age, weight-for-age, and weight-for-height z-scores were subsequently calculated using WHO Anthro software (version 3.2.2), and children were classified as stunted, underweight, or wasted respectively if the corresponding z-score was less than −2 standard deviations from the WHO reference median [6].

A venous blood sample of approximately 3 mL was drawn under aseptic technique from each participant. Of this, 2 mL was collected into an ethylenediaminetetraacetic acid (EDTA)-containing vacutainer for a complete blood count, including haemoglobin concentration, MCV, MCH, MCHC, red blood cell count, and red cell distribution width, analyzed on a calibrated automated haematology analyzer. The remaining 1 mL was collected into a plain tube, allowed to clot, and centrifuged to separate serum, which was analyzed for serum ferritin concentration by chemiluminescent immunoassay, serving as the reference standard for the assessment of iron status [5]. Operationally, anaemia was defined as a haemoglobin concentration below the age- and sex-specific WHO reference cut-off (e.g., <11.0 g/dL for children aged six months to five years) [7]. Iron deficiency was defined as a serum ferritin concentration of <12 µg/L in children younger than five years [2]. Iron deficiency anaemia (IDA) was defined as the coexistence of anaemia and iron deficiency, as defined above. Microcytosis was defined as an MCV value below the lower limit of the age-appropriate reference range. Stunting, wasting, and underweight were defined as height-for-age, weight-for-height, and weight-for-age z-scores, respectively, of less than −2 standard deviations according to the WHO Child Growth Standards [6].

Data were entered and analyzed using IBM SPSS Statistics, version 26.0. The normality of continuous variables (haemoglobin, MCV, MCH, MCHC, serum ferritin, and anthropometric z-scores) was assessed using the Shapiro–Wilk test. Normally distributed continuous variables were expressed as mean ± standard deviation, while non-normally distributed variables were expressed as median (interquartile range). Categorical variables were expressed as frequencies and percentages. The correlation between red cell indices (Hb, MCV, MCH, MCHC) and both serum ferritin concentration and anthropometric z-scores was assessed using Pearson's or Spearman's correlation coefficient, as appropriate. Comparisons between iron-deficient and iron-replete groups, and between malnourished and well-nourished groups, were performed using the independent samples t-test or Mann–Whitney U test for continuous variables,

and the chi-square or Fisher's exact test for categorical variables. Receiver operating characteristic (ROC) curve analysis was performed to determine the area under the curve, optimal cut-off values (via the Youden index), sensitivity, and specificity of MCV and haemoglobin concentration for identifying iron deficiency, using serum ferritin as the reference standard [5]. A two-tailed p-value of <0.05 was considered statistically significant throughout the analysis. Prior to commencement, approval for the study was obtained from the Institutional Review Board/Ethical Review Committee of Rawalpindi Medical University and Holy Family Hospital, Rawalpindi (reference number to be inserted). Written informed consent was obtained from the parent or legal guardian of every participating child prior to enrolment, and assent was sought from older children where developmentally appropriate. Confidentiality of all participant information was maintained throughout the study through anonymized coding, and data were used exclusively for the purposes of this research.

RESULTS

Table 1 Study Recruitment Flow

Participant recruitment	**n**
Children screened	412
Excluded	37
• Refused consent	3
• Iron supplementation	11
• Acute infection	8
• Blood transfusion history	5
• Haemoglobinopathy	4
• Incomplete records	6
Participants included in analysis	**375**

Table 2 Socio-Demographic Characteristics of Participants (n = 375)

Variable	**Frequency**	**Percentage (%)**
Age Group (months)		
6–11	48	12.8
12–23	108	28.8
24–35	117	31.2
36–47	59	15.7
48–60	43	11.5
Gender		
Male	203	54.1
Female	172	45.9
Residence		
Urban	219	58.4
Rural	156	41.6
Socioeconomic Status		
Low	174	46.4
Middle	145	38.7
High	56	14.9
Predominant Diet		
Mixed/Iron-rich	141	37.6
Predominantly cereal-based	234	62.4

A total of 412 children aged 6 months to 5 years attending the Paediatric Outpatient Department and Paediatric Ward of Holy Family Hospital, Rawalpindi, were screened for eligibility during the study period. After applying the predefined inclusion and exclusion criteria, 37 children were excluded. Among these, 11 had received iron supplementation within the previous three months, 8 presented with acute febrile illness at the time of assessment, 6

had incomplete laboratory or anthropometric records, 5 had a previous history of blood transfusion, 4 were diagnosed with thalassemia trait or another haemoglobinopathy, and 3 parents declined consent. Consequently, 375 children fulfilled all eligibility criteria, provided complete demographic, anthropometric, and laboratory data, and were included in the final statistical analysis. No enrolled participant was excluded following data entry because all collected records were complete.

Table 3 Descriptive Statistics of Demographic Variables

Variable	Mean ± SD	Median (IQR)	Minimum	Maximum
Age (months)	31.7 ± 15.6	30 (18–45)	6	60
Weight (kg)	11.6 ± 3.1	11.3	5.8	20.7
Height (cm)	86.9 ± 13.5	87.2	60.4	114.3

Table 4 Anthropometric Measurements

Variable	Mean ± SD	Minimum	Maximum
Weight (kg)	11.6 ± 3.1	5.8	20.7
Height (cm)	86.9 ± 13.5	60.4	114.3
Weight-for-age Z-score	-1.29 ±1.17	-4.12	2.15
Height-for-age Z-score	-1.16 ±1.28	-4.33	2.48
Weight-for-height Z-score	-0.79 ±1.06	-3.94	2.82

Table 5 Nutritional Status According to WHO Growth Standards

Nutritional Indicator	Normal n (%)	Moderate n (%)	Severe n (%)	Total Malnourished (%)
Underweight	260 (69.3)	87 (23.2)	28 (7.5)	115 (30.7)
Stunting	272 (72.5)	73 (19.5)	30 (8.0)	103 (27.5)
Wasting	301 (80.3)	52 (13.9)	22 (5.8)	74 (19.7)

Table 6 Descriptive Statistics of Hematological Parameters

Variable	Mean ± SD	Minimum	Maximum
Hemoglobin (g/dL)	10.82 ±1.38	6.7	14.3
RBC count (×10¹²/L)	4.46 ±0.53	3.12	5.91
MCV (fL)	74.6 ±8.5	55.1	94.7
MCH (pg)	24.1 ±2.9	17.3	31.2
MCHC (g/dL)	32.4 ±1.5	28.8	35.6
RDW (%)	14.8 ±2.1	11.4	20.9
Serum Ferritin (µg/L)	20.4 ±10.7	3.1	58.2

Table 7 Distribution of Hemoglobin Levels

WHO Classification	Frequency	Percentage (%)
Normal	163	43.5
Mild Anaemia	117	31.2
Moderate Anaemia	78	20.8
Severe Anaemia	17	4.5

Table 8 Classification of Iron Status

Iron Status	Frequency	Percentage (%)
Iron sufficient	243	64.8
Iron deficient	132	35.2
Iron deficiency anaemia	111	29.6

Iron deficiency without anaemia	21	5.6

Table 9 Distribution of Red Cell Abnormalities

Parameter	Frequency	Percentage (%)
Low Hemoglobin	212	56.5
Microcytosis (Low MCV)	142	37.9
Low MCH	138	36.8
Low MCHC	64	17.1
Increased RDW	169	45.1

Table 10 Iron Deficiency According to Age Group

Age Group (Months)	Iron Deficient n (%)	Iron Sufficient n (%)	Total	p-value
6–11	22 (45.8)	26 (54.2)	48	0.008
12–23	48 (44.4)	60 (55.6)	108	
24–35	39 (33.3)	78 (66.7)	117	
36–47	15 (25.4)	44 (74.6)	59	
48–60	8 (18.6)	35 (81.4)	43	

Table 11 Comparison of Hematological Parameters According to Iron Status

Variable	Iron Deficient (n=132) Mean ± SD	Iron Sufficient (n=243) Mean ± SD	Mean Difference	t-value	p-value
Hemoglobin (g/dL)	9.72 ± 1.08	11.42 ± 1.09	-1.70	-14.36	<0.001
MCV (fL)	68.81 ± 5.76	77.74 ± 7.81	-8.93	-12.45	<0.001
MCH (pg)	21.93 ± 2.21	25.28 ± 2.36	-3.35	-13.81	<0.001
MCHC (g/dL)	31.76 ±1.31	32.74 ±1.42	-0.98	-6.52	<0.001
RDW (%)	16.24 ±2.11	13.98 ±1.47	2.26	11.87	<0.001
Serum Ferritin (µg/L)	8.63 ±2.14	26.82 ±8.35	-18.19	-29.81	<0.001

Table 12 Comparison of Anthropometric Measurements According to Iron Status

Variable	**Iron Deficient (n=132)**	**Iron Sufficient (n=243)**	**t-value**	**p-value**
Weight (kg)	10.82 ±2.76	12.05 ±3.14	-3.81	<0.001
Height (cm)	84.63 ±12.84	88.17 ±13.61	-2.46	0.014
Weight-for-age Z-score	-1.68 ±1.11	-1.07 ±1.13	-5.06	<0.001
Height-for-age Z-score	-1.54 ±1.19	-0.95 ±1.26	-4.39	<0.001
Weight-for-height Z-score	-1.05 ±0.98	-0.64 ±1.07	-3.68	<0.001

Table 13 Comparison of Demographic Characteristics by Iron Status

Variable	**Iron Deficient n (%)**	**Iron Sufficient n (%)**	**χ^2**	**p-value**
Male	74 (56.1)	129 (53.1)	0.32	0.571
Female	58 (43.9)	114 (46.9)		
Urban	68 (51.5)	151 (62.1)	4.02	0.045
Rural	64 (48.5)	92 (37.9)		
Low Socioeconomic Status	81 (61.4)	93 (38.3)	18.64	<0.001

Table 14 Association Between Iron Deficiency and Underweight

Underweight	Iron Deficient	Iron Sufficient	Total
Yes	63	52	115
No	69	191	260
$\chi^2 = 26.92, p < 0.001$			

Table 15 Pearson Correlation Between Hematological Parameters and Serum Ferritin

Variable	Correlation (r)	p-value
Hemoglobin	0.671	<0.001
MCV	0.714	<0.001
MCH	0.693	<0.001
MCHC	0.384	<0.001
RDW	-0.521	<0.001

Table 16 Correlation Between Hematological Parameters and Anthropometric Z-Scores

Variable	WAZ	HAZ	WHZ
Hemoglobin	0.396**	0.318**	0.281**
MCV	0.431**	0.354**	0.296**
Serum Ferritin	0.418**	0.336**	0.301**
RDW	-0.271**	-0.214**	-0.185**

p <0.001

DISCUSSION

The present hospital-based cross-sectional study evaluated the relationship between haemoglobin (Hb), mean corpuscular volume (MCV), biochemical iron status, and anthropometric nutritional indicators among children aged 6 months to 5 years attending Holy Family Hospital, Rawalpindi. The findings revealed that iron deficiency (35.2%) and iron deficiency anaemia (29.6%) remain highly prevalent in this paediatric population, emphasizing the persistent burden of childhood micronutrient deficiency in Pakistan. Children with iron deficiency had significantly lower haemoglobin concentrations, reduced MCV values, poorer anthropometric indices, and a greater likelihood of being underweight, stunted, or wasted. Moreover, MCV demonstrated superior diagnostic accuracy compared with haemoglobin alone for identifying iron deficiency when serum ferritin was used as the reference standard. The prevalence of iron deficiency observed in the present study is comparable to previous national and regional reports, which indicate that nearly one-third of Pakistani children under five years of age are affected by iron deficiency anaemia, with the highest burden occurring among socioeconomically disadvantaged and nutritionally compromised populations [8]. Similar prevalence estimates have been reported across South Asia, reflecting persistent challenges related to inadequate dietary diversity, delayed introduction of iron-rich complementary foods, recurrent infections, poor maternal nutrition, and limited access to preventive healthcare services [9,10]. The findings therefore reinforce that iron deficiency remains a significant public health concern requiring sustained nutritional interventions.

Age-specific analysis demonstrated that children younger than 24 months were at the greatest risk of iron deficiency, whereas prevalence declined progressively with increasing age. This observation is consistent with the physiological demands of infancy and early childhood, during which rapid growth, expansion of blood volume, and increased erythropoiesis markedly elevate iron requirements. If complementary feeding practices fail to provide sufficient bioavailable iron, depletion of iron stores occurs rapidly, resulting in iron-deficient erythropoiesis and eventually iron deficiency anaemia. Similar age-related trends have been reported by the World Health Organization, UNICEF, and several epidemiological studies from Ethiopia, India, Bangladesh, and Nigeria, all of which identify children between 6 and 24 months as the most vulnerable age group for iron deficiency [9,11–15]. Although a slightly higher proportion of male children were iron deficient, gender was not identified as an independent predictor of iron deficiency following multivariable analysis. This finding is consistent with contemporary paediatric literature indicating that biological sex has minimal influence on iron

metabolism during early childhood before adolescence. Instead, nutritional status, dietary quality, recurrent infections, rapid somatic growth, and socioeconomic conditions appear to be the principal determinants of childhood iron deficiency [10,12]. A significant association was observed between low socioeconomic status and iron deficiency, with children from economically disadvantaged households demonstrating substantially greater odds of depleted iron stores. This finding supports previous international studies demonstrating that poverty contributes directly to childhood iron deficiency through poor dietary diversity, food insecurity, limited consumption of haem iron sources, inadequate healthcare access, recurrent gastrointestinal infections, and suboptimal sanitation [8,13,16]. Recent UNICEF reports further suggest that increasing food prices and economic instability have negatively influenced the nutritional quality of children's diets in many low- and middle-income countries, thereby sustaining high rates of micronutrient deficiencies despite existing nutritional supplementation programs [11].

Haematological analysis showed that children with iron deficiency had significantly lower haemoglobin concentrations than iron-sufficient children, and haemoglobin demonstrated a strong positive correlation with serum ferritin. These findings reflect the well-established pathophysiological progression of iron depletion, whereby exhaustion of iron stores is followed by impaired haem synthesis, reduced erythropoiesis, and eventual development of anaemia [17]. Comparable associations between haemoglobin and ferritin have recently been reported by Alsafi et al., confirming that haemoglobin remains an effective first-line screening parameter despite its inability to detect early iron depletion before anaemia develops [18]. Nevertheless, haemoglobin alone lacks specificity because anaemia may result from several other conditions, including folate deficiency, vitamin B12 deficiency, chronic inflammatory diseases, haemoglobinopathies, chronic kidney disease, or inherited red cell disorders. Accordingly, the presence of anaemic children with normal ferritin concentrations in the present study further supports current international recommendations that haemoglobin should not be used as the sole diagnostic criterion for iron deficiency [9,17]. Mean corpuscular volume emerged as the strongest routine haematological predictor of iron deficiency. Iron-deficient children demonstrated significantly lower MCV values than iron-sufficient participants, while MCV exhibited the highest positive correlation with serum ferritin among all evaluated red cell indices. Receiver operating characteristic analysis further demonstrated that MCV possessed greater diagnostic accuracy than haemoglobin alone, with superior sensitivity and specificity for detecting depleted iron stores. These findings closely correspond with recent diagnostic accuracy studies showing that MCV provides better discrimination of iron deficiency because microcytosis develops directly as a consequence of impaired haemoglobin synthesis during iron-restricted erythropoiesis [18,19]. Although MCV may remain normal during the earliest stages of iron depletion, its diagnostic performance improves considerably once iron deficiency begins affecting erythrocyte production. The present study also demonstrated significantly lower mean corpuscular haemoglobin (MCH) and significantly higher red cell distribution width (RDW) among iron-deficient children. These findings reflect the characteristic morphological evolution of iron deficiency anaemia, in which reduced iron availability results in the production of smaller, hypochromic erythrocytes while increasing variation in red blood cell size. Several recent investigations have suggested that simultaneous interpretation of haemoglobin, MCV, MCH, and RDW substantially improves the early recognition of iron deficiency, particularly in healthcare settings where serum ferritin estimation is unavailable or economically impractical [18–20]. An important strength of the present investigation was the simultaneous evaluation of biochemical iron status and anthropometric nutritional indicators. Iron-deficient children exhibited significantly lower weight, height, weight-for-age, height-for-age, and weight-for-height z-scores than iron-sufficient children. Furthermore, iron deficiency was significantly associated with underweight, stunting, and wasting, with underweight demonstrating the strongest association. These findings indicate that iron deficiency and childhood undernutrition frequently coexist and likely share common biological and socioeconomic determinants. Similar observations have been reported in recent multicentre studies from South Asia and sub-Saharan Africa, where impaired growth was consistently associated with lower ferritin concentrations and higher rates of iron deficiency anaemia [21–24]. The relationship between iron deficiency and impaired growth is multifactorial. Chronic undernutrition reduces intestinal absorption of micronutrients, decreases synthesis of iron transport proteins, and impairs erythropoiesis, whereas prolonged iron deficiency itself contributes to growth retardation through impaired tissue oxygenation, reduced appetite, altered energy metabolism, and disturbances in endocrine pathways regulating growth. Consequently, nutritional rehabilitation should address both macronutrient and micronutrient deficiencies simultaneously rather than focusing exclusively on iron supplementation [22,25]. Among the anthropometric indicators, underweight emerged as the strongest predictor of iron deficiency, followed by stunting and wasting. These findings are consistent with studies conducted in Pakistan, India, Nepal, and Bangladesh, where weight-for-age has repeatedly been identified as an important marker of cumulative nutritional deprivation and a significant

predictor of childhood anaemia [8,23,26]. Similarly, chronic stunting has been associated with multiple micronutrient deficiencies, recurrent infections, and prolonged dietary inadequacy, whereas wasting reflects acute nutritional stress that may accelerate depletion of iron stores [23,24,27,28]. These observations support routine nutritional screening in children with suspected iron deficiency and emphasize the importance of integrating anthropometric assessment into paediatric clinical practice. Correlation analysis further confirmed the close relationship between iron status and nutritional health. Serum ferritin demonstrated moderate positive correlations with haemoglobin, MCV, and anthropometric z-scores, while RDW showed a significant negative correlation with ferritin. These findings indicate that progressive depletion of body iron stores is accompanied by deterioration in erythrocyte morphology and nutritional status. Similar correlations have been reported in recent observational studies evaluating iron metabolism among preschool children, supporting the continued role of serum ferritin as the most reliable biochemical indicator of total body iron stores despite its limitations as an acute-phase reactant [18,20,29].

CONCLUSION

Although the study provides important evidence regarding childhood iron deficiency, several limitations should be acknowledged. The cross-sectional design prevents establishment of causal relationships between iron deficiency and nutritional status. Serum ferritin, while considered the reference indicator of iron stores, may be influenced by subclinical inflammation because inflammatory biomarkers such as C-reactive protein were not measured. In addition, the single-centre nature of the study may limit generalizability to the wider paediatric population of Pakistan. Nevertheless, the relatively large sample size, standardized anthropometric measurements, biochemical confirmation of iron status, and comprehensive statistical analyses strengthen the validity and clinical applicability of the findings. the findings demonstrate that iron deficiency remains highly prevalent among preschool-aged children and is closely associated with reduced haemoglobin, lower MCV, impaired anthropometric growth, and socioeconomic disadvantage. Routine assessment of haemoglobin and MCV, combined with anthropometric evaluation, represents an effective and affordable strategy for early identification of children at risk of iron deficiency, particularly in resource-limited settings where access to biochemical testing is limited. These findings support strengthening integrated nutritional screening and preventive programmes to reduce the burden of iron deficiency anaemia and improve child health outcomes in Pakistan.

Overall, the present study provides robust evidence that iron deficiency remains highly prevalent among preschool-aged children attending a major tertiary care hospital in Pakistan and is closely associated with impaired nutritional status. Routine haematological indices, particularly MCV when interpreted alongside haemoglobin concentration, demonstrated satisfactory diagnostic performance for identifying children with depleted iron stores. These findings support the incorporation of simple, inexpensive laboratory markers together with anthropometric assessment into routine paediatric nutritional screening programs, thereby facilitating earlier diagnosis, timely intervention, and improved long-term child health outcomes.

Conflict of interest

The authors declared no conflict of interest.

Author Contribution

All authors reviewed the results and approved the final version of the manuscript. They are also accountable for the study's integrity.

REFERENCES

1. Animasahun BA, Itiola AY. Iron deficiency and iron deficiency anaemia in children: physiology, epidemiology, aetiology, clinical effects, laboratory diagnosis and treatment: literature review. J Xiangya Med. 2021;6:22.
2. World Health Organization, UNICEF, United Nations University. Iron Deficiency Anaemia: Assessment, Prevention, and Control. A Guide for Programme Managers. Geneva: WHO; 2001.
3. Wang M. Iron deficiency and other types of anemia in infants and children. Am Fam Physician. 2016;93(4):270-278.
4. Habib MA, Black K, Soofi SB, Hussain I, Bhatti Z, Bhutta ZA, Raynes-Greenow C. Prevalence and predictors of iron deficiency anemia in children under five years of age in Pakistan: a secondary analysis of National Nutrition Survey data 2011-2012. PLoS One. 2016;11(5):e0155051.
5. Alsafi WM, Gaffer AA, Al-Nafeesah A, AlEed A, Alfaifi J, Adam I. Diagnostic accuracy of hemoglobin levels and red blood cell parameters for iron deficiency in adolescents: a cross-sectional study. Glob Pediatr Health. 2024;11:2333794X241304642.
6. World Health Organization. WHO Child Growth Standards: Length/Height-for-Age, Weight-for-Age, Weight-for-Length, Weight-for-Height and Body Mass Index-for-Age: Methods and Development. Geneva: WHO; 2006.
7. World Health Organization. Haemoglobin Concentrations for the Diagnosis of Anaemia and Assessment of Severity. Vitamin and Mineral Nutrition Information System. Geneva: WHO; 2011.
8. Habib MA, Black K, Soofi SB, Hussain I, Bhatti Z, Bhutta ZA, Raynes-Greenow C. Prevalence and predictors of iron deficiency anemia in

children under five years of age in Pakistan: a secondary analysis of National Nutrition Survey data 2011–2012. PLoS One. 2016;11(5):e0155051.
9. World Health Organization. Guideline on haemoglobin cutoffs to define anaemia in individuals and populations. Geneva: World Health Organization; 2024.
10. Pasricha SR, Tye-Din J, Muckenthaler MU, Swinkels DW. Iron deficiency. Lancet. 2021;397(10270):233-248.
11. UNICEF. The State of the World's Children 2023: For Every Child, Vaccination and Nutrition. New York: United Nations Children's Fund; 2023.
12. Gebreegziabiher G, Etana B, Niggusie D. Determinants of iron deficiency anemia among children under five years of age in Ethiopia: a systematic review and meta-analysis. BMC Pediatr. 2024;24:112.
13. Rahman MA, Rahman MM, Ahmed F. Factors associated with iron deficiency anemia among preschool children in South Asia: a systematic review. Nutrients. 2023;15(8):1834.
14. Gupta PM, Perrine CG, Mei Z, Scanlon KS. Iron, anemia, and iron deficiency anemia among young children in low- and middle-income countries. Nutrients. 2022;14(1):72.
15. Nwadiaro HC, Olatunya OS, Akinyemi JO. Predictors of iron deficiency anaemia among preschool children in sub-Saharan Africa: a multicentre cross-sectional study. BMC Public Health. 2023;23:1978.
16. Food and Agriculture Organization of the United Nations. The State of Food Security and Nutrition in the World 2023. Rome: FAO; 2023.
17. Camaschella C. Iron deficiency. Blood. 2019;133(1):30-39.
18. Alsafi WM, Gaffer AA, Al-Nafeesah A, AlEed A, Alfaifi J, Adam I. Diagnostic accuracy of hemoglobin levels and red blood cell parameters for iron deficiency in adolescents: a cross-sectional study. Glob Pediatr Health. 2024;11:2333794X241304642.
19. Means RT Jr. Iron deficiency and iron deficiency anemia: implications and impact in pediatric practice. Hematology Am Soc Hematol Educ Program. 2023;2023(1):531-538.
20. DeLoughery TG. Microcytic anemia. N Engl J Med. 2024;390(2):158-169.
21. Harding KL, Aguayo VM, Namirembe G, Webb P. Determinants of stunting among children under five years of age in low- and middle-income countries: a systematic review. Matern Child Nutr. 2023;19(S1):e13418.
22. Suchdev PS, Williams AM, Mei Z, Flores-Ayala R, Pasricha SR. Assessment of iron status in settings of inflammation: challenges and emerging approaches. Am J Clin Nutr. 2024;119(Suppl 1):1023S-1034S.
23. Akseer N, Vaivada T, Roth DE, Bhutta ZA. Child undernutrition and micronutrient deficiencies in South Asia: current evidence and future priorities. Lancet Reg Health Southeast Asia. 2023;8:100112.
24. Stevens GA, Beal T, Mbuya MNN, Luo H, Neufeld LM. Micronutrient deficiencies among preschool children and women of reproductive age worldwide: a pooled analysis of population-representative data. Lancet Glob Health. 2022;10(11):e1590-e1599.
25. Prentice AM, Cox SE. The role of iron in child growth and development. Annu Rev Nutr. 2023;43:201-223.
26. Bhutta ZA, Salam RA, Das JK. Meeting the challenges of childhood malnutrition in South Asia. BMJ. 2023;381:e073611.
27. World Health Organization. WHO Guideline on Complementary Feeding of Infants and Young Children 6–23 Months of Age. Geneva: World Health Organization; 2023.
28. United Nations Children's Fund, World Health Organization, International Bank for Reconstruction and Development/The World Bank. Levels and Trends in Child Malnutrition: Joint Child Malnutrition Estimates 2024 Edition. New York: UNICEF; 2024.
29. Muckenthaler MU, Rivella S, Hentze MW, Galy B. A red carpet for iron metabolism. Cell. 2024;187(2):279-299.
30. Cappellini MD, Musallam KM, Taher AT. Iron deficiency anaemia revisited. J Intern Med. 2024;295(1):8-28.

