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Research Article

Prevalence of Iron Deficiency in Anemic and Non-Anemic School-Going Adolescent Girls and Its Association with Cognitive Function

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ABSTRACT

Background: Iron deficiency anemia is the most common nutritional deficiency disorder in India and continues to be a major public health concern. Adolescent girls, particularly during late school age and early adolescence, are highly susceptible to iron deficiency. In addition to hematological effects, iron deficiency is associated with impaired growth and development, reduced immune function, decreased physical work capacity, and diminished cognitive performance. **Objectives:** To determine the prevalence of iron deficiency among anemic and non-anemic school-going adolescent girls and to assess its impact on cognitive functions. **Methods:** This cross-sectional study was conducted in a secondary school comprising girls aged 12–15 years (classes VI–IX) in a rural area of central India. Serum ferritin levels were measured using the ELISA method to assess iron status. Cognitive function was evaluated using mathematics scores, a multi-component test assessing memory, attention, and verbal learning, and intelligence quotient (IQ) scores. **Results:** Iron deficiency was observed in both anemic and non-anemic girls. Scholastic performance, IQ scores, and cognitive parameters—including mental balance, attention and concentration, verbal memory, and recognition—were significantly reduced in iron-deficient girls compared to non–iron-deficient counterparts. **Conclusion:** Iron deficiency adversely affects cognitive function and academic performance in adolescent girls, even in the absence of anemia. Early detection and timely intervention are essential to improve cognitive outcomes and overall development in this vulnerable population.

Keywords: Iron Deficiency; Anemia; Adolescent Girls; Cognitive Function; Serum Ferritin; Scholastic Performance

INTRODUCTION

Iron deficiency anemia (IDA) is the most common nutritional deficiency disorder worldwide and remains a significant public health challenge, particularly in developing countries like India [1]. According to global estimates, a large proportion of adolescent girls are affected due to increased iron requirements during periods of rapid growth, menstrual blood loss, and inadequate dietary intake [2].

Adolescence, especially the age group of 12–15 years, represents a critical phase of physical, psychological, and cognitive development. During this period, iron plays a vital role not only in hemoglobin synthesis but also in various metabolic processes, including neurotransmitter synthesis, myelination, and brain development [3]. Iron deficiency, even in the absence of anemia, can adversely affect multiple organ systems and lead to significant functional impairments [4].

The consequences of iron deficiency extend beyond hematological abnormalities. It has been associated with impaired immune function, reduced physical work capacity, and poor growth [5]. More importantly, iron deficiency has a profound impact on cognitive functions such as attention, memory, learning, and intelligence quotient (IQ), which are crucial for academic performance [6]. Studies have shown that iron deficiency during adolescence can result in decreased scholastic achievement and reduced mental performance [7].

Serum ferritin is widely regarded as a reliable biomarker for assessing body iron stores and is commonly used for diagnosing iron deficiency, even before the onset of anemia [8]. Early identification of iron deficiency using such sensitive indicators is essential to prevent long-term cognitive and developmental consequences.

Despite the high prevalence of iron deficiency among adolescent girls in India, limited data are available regarding its impact on cognitive functions, particularly among non-anemic individuals. Understanding this relationship is crucial, as cognitive impairment may occur even before clinical anemia becomes evident. Therefore, the present study was undertaken to assess the prevalence of iron deficiency among anemic and non-anemic school-going adolescent girls and to evaluate its effect on cognitive functions in this vulnerable population.

Materials and Methods

Study Design and Participants

This cross-sectional study was conducted in the Department of Physiology at Venkateshwara Institute of Medical Sciences, Amroha, Uttar Pradesh, after obtaining approval from the Institutional Ethics Committee.

Adolescent girls aged 12–15 years studying in classes VI to IX from a nearby secondary school were included in the study. Prior permission was obtained from the school authorities. Participation was voluntary, and written informed consent was obtained from the parents or guardians of all participants. A structured questionnaire was used to collect information regarding demographic characteristics, medical and menstrual history, parental education, and dietary habits.

Assessment of Anemia and Iron Deficiency

Venous blood samples were collected under aseptic conditions for laboratory analysis. Hemoglobin concentration was measured using an automated cell counter. Serum ferritin levels were estimated using enzyme-linked immunosorbent assay (ELISA) following standard laboratory protocols.

Based on hemoglobin and serum ferritin levels, participants were categorized into three groups:

- **Group I:** Anemic and iron-deficient (Hb < 12 g/dL and serum ferritin < 12 µg/L)
- **Group II:** Non-anemic but iron-deficient (Hb ≥ 12 g/dL and serum ferritin < 12 µg/L)
- **Group III:** Non-anemic and non–iron-deficient (Hb ≥ 12 g/dL and serum ferritin ≥ 12 µg/L)

Cognitive Function Assessment

Cognitive function was assessed using scholastic performance, memory evaluation, and intelligence testing.

- **Scholastic performance:** Mathematics scores (out of 100) were obtained from the final term report cards of the participants.
- **Memory, attention, and verbal learning:** These parameters were assessed using the PGI Memory Scale,

which includes ten subtests such as remote memory, recent memory, attention and concentration, immediate and delayed recall, and visual and verbal retention.

- **Intelligence quotient (IQ):** IQ was evaluated using the Bhatia Battery Performance Test, which includes Koh's Block Design Test and the Pass-Along Test. [9-10]

Statistical Analysis

The collected data were entered and analyzed using SPSS software version 29.0. Results were expressed as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was used to compare variables among the three groups. Independent sample t-test was applied for pairwise comparisons. A p-value of less than 0.05 was considered statistically significant.

Results

A total of 90 adolescent girls aged 12–15 years were initially considered for the study. Consent was obtained from 82 participants. Out of these, 58 students underwent complete evaluation, including hemoglobin estimation, serum ferritin measurement, and cognitive assessment, as 2 students refused blood sampling. Among the evaluated participants, 58 girls had hemoglobin levels <12 g/dL, while 30 had hemoglobin ≥12 g/dL. Thus, the prevalence of anemia among school-going adolescent girls was **66.7%**. The overall mean hemoglobin level in the study population was **11.23 ± 0.85 g/dL**.

Distribution of Study Groups

Severity of Anemia

Among the 58 anemic girls:

- **32 (55.17%)** had mild anemia (Hb 10–12 g/dL)
- **3 (5.2%)** had moderate anemia (Hb 7–10 g/dL)
- **2 (3.4%)** had severe anemia (Hb <7 g/dL)

Thus, mild anemia was the most prevalent form observed in the study population.

Iron Deficiency Status

Serum ferritin estimation was performed in 82 participants, out of whom 63 had serum ferritin levels <12 µg/L, indicating iron deficiency. Therefore, the prevalence of iron deficiency was **approximately 76.8%**. Among the 58 anemic girls, 45 were found to have low serum ferritin levels, indicating iron deficiency anemia (IDA). Based on the total study population (n = 82), the prevalence of iron deficiency anemia was approximately **54.9%**. The remaining 12 anemic girls with normal ferritin levels were further investigated. Peripheral smear examination, reticulocyte count, and hemoglobin electrophoresis revealed:

- Sickle cell trait in 4 students
- Sickle cell disease in 1 student
- Thalassemia minor in 1 student
- Macrocytic anemia (likely due to vitamin B12/folate deficiency) in 6 students

These cases were excluded from further analysis.

Table 1 shows the distribution of participants along with mean serum ferritin and hemoglobin levels.

Group	Number of Students	Mean Serum Ferritin (µg/L)	Mean Hemoglobin (g/dL)
Anemic iron deficient (Group I)	40	8.46 ± 0.46	11.45 ± 0.97
Non-anemic iron deficient	12	10.21 ± 0.88	12.45 ± 0.77

Group	Number of Students	Mean Serum Ferritin (µg/L)	Mean Hemoglobin (g/dL)
(Group II)			
Non-anemic non–iron-deficient (Group III)	17	25.22 ± 0.97	12.80 ± 0.83

Scholastic Performance

The mean mathematics scores of the participants in different groups are presented in **Table 2**.

Group	Number of Students	Mean Score ± SD
Group I	50	47.15 ± 3.54
Group II	12	52.58 ± 6.00
Group III	17	62.47 ± 7.67

The difference in mathematics scores was:

- **Highly significant** between Group I and Group III ($p < 0.0001$)
- **Significant** between Group II and Group III ($p = 0.001$)

Cognitive Function (Multicomponent Test Scores)

Cognitive function assessed using the multicomponent test (MCT) revealed that Group III consistently performed better than Groups I and II.

Key findings:

- **Mental balance:** Significant difference between Group I vs Group III ($p < 0.0001$) and Group II vs Group III ($p = 0.002$)
- **Attention and concentration:** Significant difference between Group I vs Group III ($p < 0.0001$) and Group II vs Group III ($p = 0.004$)
- **Verbal retention (similar pairs):** Significant differences for Group I vs III ($p < 0.0001$) and Group II vs III ($p = 0.002$)
- **Verbal retention (dissimilar pairs):** Significant differences between Group I vs III ($p = 0.002$) and Group II vs III ($p = 0.031$)
- **Recognition:** Significant differences observed between Group I vs III ($p = 0.036$) and Group II vs III ($p = 0.042$)

Table 3 summarizes the mean MCT scores:

Test	Group I (Mean ± SD)	Group II (Mean ± SD)	Group III (Mean ± SD)
Recent memory	4.94 ± 0.48	5.09 ± 0.88	5.10 ± 1.10
Remote memory	5.57 ± 0.69	5.84 ± 0.83	5.24 ± 0.75
Mental balance	1.60 ± 0.43	2.10 ± 0.50	2.40 ± 0.36

Test	Group I (Mean ± SD)	Group II (Mean ± SD)	Group III (Mean ± SD)
Attention & concentration	11.53 ± 0.99	12.40 ± 1.60	16.80 ± 2.60
Delayed recall	8.30 ± 1.68	8.50 ± 0.95	8.72 ± 1.20
Immediate recall	1.89 ± 0.43	1.82 ± 0.51	1.94 ± 0.64
Verbal retention (similar)	4.14 ± 0.95	4.21 ± 0.24	4.87 ± 0.28
Verbal retention (dissimilar)	4.30 ± 1.04	4.38 ± 0.62	4.75 ± 0.45
Visual retention	2.26 ± 0.75	2.44 ± 0.68	2.91 ± 0.60
Recognition	7.79 ± 1.74	8.10 ± 1.68	9.10 ± 2.10

Intelligence Quotient (IQ)

IQ assessment using Kohl's Block Design Test and Pass-Along Test showed:

- Significant difference between Group I and Group III ($p < 0.0001$)
- Significant difference between Group II and Group III ($p = 0.0024$)

Table 4 presents the IQ-related scores:

Group	Kohl's Block Design	Pass-Along Test	TQ	Mean IQ (± SD)
Group I	11.74	12.82	193.8	97.4 ± 8.1
Group II	12.85	15.71	202.5	103.1 ± 5.56
Group III	14.70	17.10	213.4	105.4 ± 5.9

Summary of Findings

Cognitive function—including scholastic performance, memory, attention, and IQ—was significantly lower in both anemic iron-deficient and non-anemic iron-deficient groups compared to the non-anemic non–iron-deficient group. These findings indicate that iron deficiency, even in the absence of anemia, adversely affects cognitive performance.

Discussion

Cognitive functions such as verbal learning, attention, concentration, and memory play a critical role in academic performance. In the present study, both anemic and non-anemic iron-deficient adolescent girls demonstrated significantly lower scholastic performance, as reflected by reduced mathematics scores, compared to non–iron-deficient participants. These findings are consistent with previous studies, including that by Prestonjee [11], which reported lower academic scores among iron-deficient adolescents irrespective of anemia status. Similarly, Sungthong et al. [12] observed poorer academic performance in Thai schoolchildren with iron deficiency.

Assessment of cognitive function using the multicomponent test revealed that iron-deficient participants (both anemic and non-anemic) had significantly lower scores in domains such as mental balance, attention, and verbal retention. However, no significant differences were observed in recent memory, remote memory, delayed recall, immediate recall, and visual retention. These findings suggest that iron deficiency selectively affects specific cognitive domains, particularly those related to attention and higher-order processing.

Importantly, the present study demonstrates that cognitive impairment is evident even in non-anemic iron-deficient individuals, indicating that iron deficiency per se, independent of anemia, adversely affects brain function. This observation is supported by the randomized controlled trial conducted by Bruner et al. [13], which showed significant improvement in verbal learning and memory following iron supplementation in non-anemic iron-deficient adolescent girls. Similarly, studies by Seshadri et al. [14] and Sen and Kanani [15] have reported improvements in attention, memory, and overall cognitive performance following iron and folic acid supplementation in children and adolescents.

The assessment of intelligence quotient (IQ) further revealed significantly lower scores among iron-deficient participants compared to their non–iron-deficient counterparts. These findings are in agreement with earlier studies by Pollitt et al. [16] and Soemantri et al. [17], which also reported reduced IQ levels in iron-deficient individuals. The biological basis for these findings may be attributed to the role of iron in neurotransmitter synthesis, myelination, and energy metabolism in the brain. Iron deficiency may impair dopaminergic function and hippocampal activity, thereby affecting attention, memory, and learning processes.

Conclusion

The present study demonstrates that iron deficiency, both with and without anemia, is associated with significantly reduced cognitive performance among school-going adolescent girls. Participants with iron deficiency exhibited lower scholastic achievement, as well as impaired attention, verbal learning, mental balance, and IQ scores compared to non–iron-deficient individuals. Notably, cognitive impairment was observed even in non-anemic iron-deficient participants, indicating that iron deficiency alone, prior to the development of anemia, can adversely affect cognitive function. The severity of impairment was greatest among anemic iron-deficient individuals. The prevalence of anemia and iron deficiency anemia in the present study was high, highlighting the need for early detection and intervention. These findings underscore the importance of implementing preventive strategies, including iron and folic acid supplementation programs for adolescent girls, to mitigate both hematological and cognitive consequences of iron deficiency.

Conflict of Interest

The authors declare no conflict of interest.

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