

Age-related Hematologic Adaptation to Altitude in Children: A Comparative Study

Çocuklarda Hematolojik Parametrelerin Farklı Rakımlarda Değişiminin Değerlendirilmesi

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Abstract

Introduction: Altitude-related hypoxia affects erythropoiesis and iron metabolism; however, pediatric data regarding age-related hematologic adaptation remain limited. The aim of this study was to evaluate altitude-associated hematologic changes and age-related differences in children living at high altitude and sea level.

Materials and Methods: This retrospective study compared hematologic and iron-related parameters in children aged 5–14 years living at high altitude (Ağrı, 1640 m) and sea level (İstanbul, 40 m). Children with vitamin B12 deficiency, low ferritin levels, or elevated inflammatory markers were excluded. Age-stratified analyses were performed in three groups: 5–8 years, 9–11 years, and 12–14 years.

Results: A total of 1000 children were initially screened. After applying exclusion criteria, 482 children (240 from İstanbul and 242 from Ağrı) were included in the final analysis. Children living at high altitude demonstrated significantly higher hemoglobin and red blood cell (RBC) values, whereas total iron-binding capacity (TIBC) and mean corpuscular hemoglobin concentration (MCHC) were lower compared with children living at sea level. Hemoglobin differences became less pronounced with increasing age, while elevated RBC levels persisted across most age groups.

Conclusion: Altitude is associated with age-dependent hematologic adaptation in children. Persistent RBC elevation and alterations in iron-related parameters suggest ongoing adaptation to chronic hypoxic exposure during childhood. These findings indicate that environmental altitude should be considered when interpreting hematological parameters in pediatric populations.

Öz

Giriş: Yüksek rakımda yaşayan bireylerde kronik hipoksiye bağlı olarak eritropoez ve demir metabolizmasında çeşitli değişiklikler meydana gelir. Ancak çocukluk çağında rakıma bağlı hematolojik adaptasyon ve yaşa göre farklılıklar konusunda veriler sınırlıdır. Bu çalışmada, yüksek rakımda ve deniz seviyesinde yaşayan çocuklarda rakıma bağlı hematolojik değişikliklerin ve yaşa bağlı farklılıkların değerlendirilmesi amaçlandı.

Gereç ve Yöntem: Bu retrospektif çalışmada, yüksek rakımda yaşayan (Ağrı, 1640 m) ve deniz seviyesinde yaşayan (İstanbul, 40 m) 5–14 yaş arası çocukların hematolojik ve demir metabolizması ile ilişkili parametreleri karşılaştırıldı. Vitamin B12 düzeyi 200 pg/mL'nin altında, ferritin düzeyi 20 ng/mL'nin altında olan ve CRP yüksekliği bulunan hastalar çalışma dışı bırakıldı. Hastalar 5–8, 9–11 ve 12–14 yaş gruplarında değerlendirildi. İstatistiksel analizler Jamovi programı kullanılarak yapıldı.

Keywords

Altitude, hemoglobin, erythrocytes, iron metabolism, children

Anahtar kelimeler

Rakım, hemoglobin, eritrositler, demir metabolizması, pediatri

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Bulgular: Başlangıçta her merkezden 500 olmak üzere toplam 1000 çocuk tarandı. Dışlama kriterleri uygulandıktan sonra 482 çocuk (İstanbul: 240, Ağrı: 242) çalışmaya dahil edildi. Yüksek rakımda yaşayan çocuklarda hemoglobin ve eritrosit (RBC) değerleri daha yüksek bulundu. Buna karşılık total demir bağlama kapasitesi (TDBK) ve ortalama eritrosit hemoglobin konsantrasyonu (MCHC) değerleri daha düşüktü. Yaşa göre yapılan analizlerde hemoglobin farklılığının yaş ilerledikçe azaldığı, ancak RBC yüksekliğinin çoğu yaş grubunda devam ettiği görüldü.

Sonuç: Çocuklarda rakım, hematolojik parametreler üzerinde belirgin etkilere sahiptir. Hemoglobin düzeylerindeki artış yaş ilerledikçe azalırken, eritrosit yüksekliğinin devam etmesi rakıma bağlı hematolojik adaptasyonun çocukluk boyunca sürdüğünü düşündürmektedir. Ayrıca TDBK ve MCHC değerlerindeki farklılıklar, kronik hipoksiye bağlı demir metabolizması değişikliklerini desteklemektedir. Bu bulgular, çocuklarda hematolojik parametrelerin değerlendirilmesinde yaşanan rakımın dikkate alınması gerektiğini göstermektedir.

Introduction

Hematological parameters in children are influenced by a variety of physiological and environmental factors, including age, nutritional status, socioeconomic conditions, and geographic characteristics (1). Among these factors, altitude has been recognized as one of the most important environmental determinants affecting hematological profiles (2). Reduced atmospheric pressure and lower oxygen availability at higher altitudes lead to chronic hypoxic exposure, which triggers a series of physiological adaptations aimed at maintaining adequate tissue oxygenation (3).

One of the most prominent physiological responses to high altitude is the stimulation of erythropoiesis. Hypoxia stimulates the production of erythropoietin, which subsequently increases red blood cell production and Hb concentration. As a result, individuals living at high altitude typically exhibit higher Hb levels, erythrocyte counts, and hematological indices compared with populations residing at sea level (4). These adaptive hematological changes have been widely documented in adult populations as well as in children living in mountainous regions.

Previous studies conducted in high-altitude regions such as the Andes and other mountainous areas have reported significant differences in Hb levels and erythrocyte indices between populations living at high altitude and those living at lower elevations (5,6). These findings highlight the importance of considering geographic altitude when interpreting hematological values, particularly in pediatric populations where physiological reference ranges may vary according to environmental conditions.

However, the interpretation of hematological parameters in children is often complicated by nutritional deficiencies, which remain highly prevalent worldwide. Iron deficiency and vitamin B12 deficiency are among the most common nutritional disorders in childhood and can significantly affect Hb levels and erythrocyte indices (7). Therefore, when

evaluating the potential effects of altitude on hematological parameters, it is essential to control for nutritional factors that may act as confounding variables.

Despite the well-established effects of altitude on erythropoiesis, data regarding altitude-related variations in erythrocyte and iron-related hematological parameters among children remain limited. Moreover, many previous studies did not adequately account for nutritional deficiencies that may influence hematological findings. This limitation makes it difficult to determine whether observed hematological differences are attributable to altitude-related physiological adaptation or underlying nutritional disorders.

Therefore, the present study aimed to compare erythrocyte and iron-related hematological parameters among children aged 5–14 years living at different altitudes by analyzing populations from Ağrı, a high-altitude region in eastern Türkiye, and İstanbul, a city located at sea level. To minimize potential confounding effects, children with vitamin B12 deficiency and low ferritin levels were excluded from the analysis. This study aimed to evaluate the independent effect of altitude on erythrocyte parameters in a pediatric population.

Materials and Methods

Study design and Population

This retrospective study included pediatric patients aged 5–14 years from two regions of Türkiye with different altitudes: İstanbul, located at sea level (approximately 40 m), and Ağrı, a high-altitude city located at approximately 1640 m above sea level. Patient data were obtained retrospectively from hospital electronic medical record systems.

Initially, a total of 500 pediatric patients from each center were screened, resulting in a total of approximately 1000 children included in the preliminary dataset.

Inclusion and Exclusion Criteria

To minimize potential confounding effects of nutritional deficiencies and acute infections on hematological parameters, several exclusion criteria were applied. Patients with vitamin B12 levels below 200 pg/mL and ferritin levels below 20 ng/mL were excluded to minimize the potential confounding effect of nutritional anemia. In addition, patients with elevated C-reactive protein (CRP) levels suggesting acute infection or inflammation were excluded from the analysis. After applying these exclusion criteria, the remaining patients constituted the final study population.

Age Group Stratification

To evaluate potential age-related differences, patients were categorized into three age groups: 5–8 years, 9–11 years, and 12–14 years. Hematological parameters were analyzed separately within these age groups to allow a more detailed comparison between the two geographical regions.

Laboratory Measurements

Laboratory parameters were obtained from the hospital laboratory information systems. Complete blood count (CBC) parameters related to erythrocyte indices were analyzed. These included RBC, Hb, mean corpuscular volume (MCV), MCHC, red cell distribution width (RDW), and red cell distribution width–standard deviation (RDW-SD). In addition, iron metabolism parameters including serum iron, ferritin, and TIBC were recorded for all included patients.

Statistical Analysis

Statistical analyses were performed using Jamovi statistical software. The distribution of continuous variables was evaluated using the Shapiro–Wilk normality test. Continuous variables were presented as mean $\pm$ standard deviation for normally distributed data or median (interquartile range) for non-normally distributed data.

Comparisons between the two study groups (Istanbul and Ağrı) were performed using the independent samples t-test for normally distributed variables and the Mann–Whitney U

test for variables that did not follow a normal distribution. A p value of <0.05 was considered statistically significant.

Results

A total of 1000 pediatric patients were screened, including 500 children from Istanbul and 500 from Ağrı. Patients with vitamin B12 levels below 200 pg/mL, ferritin levels below 20 ng/mL, or elevated CRP levels indicating possible infection were excluded. After applying these criteria, 482 children were included in the final analysis (240 from Istanbul and 242 from Ağrı) (Table 1).

In the overall analysis, children living at high altitude demonstrated higher erythrocyte-related parameters. Red blood cell (RBC) counts and Hb levels were higher in children from Ağrı compared with those from Istanbul. In contrast, TIBC and MCHC were lower in the high-altitude group. The decrease in TIBC was consistent across age groups and both sexes (Table 2).

Ferritin levels were slightly higher in children living at sea level, although the clinical relevance of this difference is uncertain (Table 2).

Age-stratified analyses demonstrated that the altitude-related increase in Hb became less pronounced with increasing age. In the 5–8-year age group, RBC and Hb values were significantly higher in children living at high altitude. In this age group, MCV was also significantly higher in the high-altitude population, and this difference was observed in both girls and boys as well as in the overall analysis (Table 3).

In the 9–11-year age group, sex-related differences were observed. While Hb levels did not differ significantly between regions among girls, boys living at high altitude demonstrated significantly higher Hb and RBC values compared with those living at sea level (Table 4).

In the 12–14-year age group, the altitude-related increase in Hb was no longer observed. RBC differences were also less prominent in this age group. However, the decrease in TIBC and MCHC values remained evident (Table 5).

Detailed comparisons of hematological parameters according to age group and sex are presented in Tables 1–5.

Table 1. Patient selection and study population

Parameter	Istanbul	Ağrı
Patients screened	500	500
After excluding ferritin <20 ng/mL	368	337
After excluding vitamin B12 <200 pg/mL	240	242
Final study population	240	242

n: Number of patients; Patients with ferritin levels <20 ng/mL and vitamin B12 levels <200 pg/mL were excluded to eliminate potential effects of nutritional deficiencies. Only individuals with normal CRP levels were included in the study.

Table 2. Comparison of erythrocyte indices and iron parameters between children living at high altitude (Ağrı) and sea level (Istanbul)

Parameter	Ağrı (n=242) Median (IQR)	Istanbul (n=240) Median (IQR)	p
Iron	73.0 (54.0–94.0)	65.5 (50.0–88.5)	0.110
TIBC	288 (255–323)	358 (331–393)	<0.001
Ferritin	30.9 (21.7–43.6)	31.6 (23.7–46.3)	0.048
RBC	4.98 (4.72–5.16)	4.80 (4.60–5.00)	<0.001
Hb	13.6 (13.1–14.2)	13.2 (12.6–13.9)	<0.001
MCV	82.9 (80.7–84.5)	81.7 (79.0–84.7)	0.023
MCHC	33.4 (32.9–33.8)	33.7 (33.2–34.3)	<0.001
RDW	13.3 (12.9–13.7)	13.3 (12.8–13.9)	0.893
RDW-SD	39.5 (37.9–40.6)	39.7 (38.3–41.2)	0.049

Values are presented as median (interquartile range).

Comparisons between groups were performed using the Mann–Whitney U test.

Hb: hemoglobin; RBC: red blood cell count, MCV: mean corpuscular volume, MCHC: mean corpuscular hemoglobin concentration, RDW: red cell distribution width, RDW-SD: red cell distribution width–standard deviation, TIBC: total iron-binding capacity

Table 3. Hematological parameters in children aged 5–8 years according to altitude and sex

Parameter	Group	Ağrı Median (IQR)	Istanbul Median (IQR)	p
Iron	Girls	78.0 (54.5–94.8)	69.0 (49.5–86.8)	0.375
	Boys	64.5 (53.0–81.3)	54.0 (42.5–69.3)	0.069
	Overall	73.0 (53.5–89.0)	60.0 (45.0–81.0)	0.069
TIBC	Girls	274 (250–303)	343 (314–386)	<0.001
	Boys	297 (269–337)	339 (316–363)	<0.001
	Overall	289 (254–312)	339 (315–365)	<0.001
Ferritin	Girls	33.2 (22.4–42.0)	29.4 (21.4–44.3)	0.797
	Boys	31.8 (24.7–42.3)	32.3 (26.9–42.2)	0.614
	Overall	32.3 (23.2–42.2)	31.8 (24.6–43.8)	0.544
RBC	Girls	4.94 (4.70–5.16)	4.80 (4.60–4.90)	0.801
	Boys	5.00 (4.81–5.17)	4.74 (4.53–4.90)	<0.001
	Overall	4.98 (4.77–5.16)	4.80 (4.60–4.90)	<0.001
Hb	Girls	13.7 (12.9–14.2)	13.0 (12.7–13.6)	0.007
	Boys	13.7 (13.0–14.3)	12.8 (12.4–13.3)	<0.001
	Overall	13.7 (13.0–14.3)	12.9 (12.5–13.4)	<0.001
MCV	Girls	83.3 (80.9–85.6)	80.8 (78.6–82.3)	0.025
	Boys	82.7 (80.4–83.9)	78.7 (77.8–81.6)	<0.001
	Overall	82.8 (80.7–84.8)	80.1 (77.9–81.8)	<0.001
MCHC	Girls	33.3 (32.9–33.7)	33.7 (33.4–34.1)	0.010
	Boys	33.7 (33.2–34.0)	33.5 (33.1–34.0)	0.672
	Overall	33.4 (33.1–33.8)	33.6 (33.2–34.1)	0.134
RDW	Girls	13.1 (12.8–13.6)	13.4 (12.8–14.0)	0.109
	Boys	13.5 (13.2–13.8)	13.8 (13.1–14.3)	0.111
	Overall	13.2 (13.0–13.7)	13.7 (13.0–14.1)	0.017
RDW-SD	Girls	38.9 (37.7–40.4)	39.8 (37.6–42.2)	0.147
	Boys	39.9 (38.6–40.4)	39.9 (38.3–41.6)	0.676
	Overall	39.3 (37.8–40.5)	39.9 (38.2–41.9)	0.102

Values are presented as median (interquartile range, IQR). Comparisons between Ağrı (high altitude) and Istanbul (sea level) were performed using the Mann–Whitney U test.

p values <0.05 were considered statistically significant. Hb: Hemoglobin, RBC: red blood cell count, MCV: Mean corpuscular volume, MCHC: Mean corpuscular hemoglobin concentration, RDW: Red cell distribution width,

RDW-SD: Red cell distribution width-standard deviation, TIBC: Total iron-binding capacity

Table 4. Hematological parameters in children aged 9–11 years according to altitude and sex

Parameter	Group	Ağrı Median (IQR)	Istanbul Median (IQR)	p
Iron	Girls	73.0 (56.0–94.3)	75.0 (52.0–91.0)	0.669
	Boys	69.0 (53.0–97.0)	64.0 (50.0–87.8)	0.292
	Overall	72.0 (53.3–95.7)	67.0 (51.0–89.0)	0.295
TIBC	Girls	303 (264–334)	368 (338–392)	<0.001
	Boys	285 (256–318)	350 (317–371)	<0.001
	Overall	297 (258–329)	357 (325–387)	<0.001
Ferritin	Girls	33.7 (20.4–45.7)	30.9 (25.1–44.7)	0.493
	Boys	27.3 (21.1–37.8)	35.9 (26.5–69.1)	0.008
	Overall	30.1 (20.5–44.9)	32.9 (25.9–50.0)	0.021
RBC	Girls	4.94 (4.67–5.09)	4.90 (4.60–5.00)	0.939
	Boys	5.00 (4.72–5.20)	4.70 (4.50–4.90)	0.003
	Overall	4.96 (4.67–5.14)	4.70 (4.60–5.00)	0.002
Hb	Girls	13.6 (13.2–13.9)	13.4 (12.9–14.0)	0.342
	Boys	13.4 (12.8–14.3)	13.1 (12.5–13.6)	0.032
	Overall	13.6 (13.1–14.1)	13.2 (12.6–13.9)	0.021
MCV	Girls	83.1 (81.3–85.2)	82.4 (79.8–84.5)	0.056
	Boys	82.6 (79.8–83.8)	81.3 (79.4–83.6)	0.326
	Overall	83.0 (80.9–84.3)	81.5 (79.5–84.0)	0.032
MCHC	Girls	33.4 (32.9–33.7)	33.7 (33.4–34.1)	0.001
	Boys	33.5 (33.0–33.7)	34.0 (33.0–34.5)	0.004
	Overall	33.4 (32.9–33.7)	33.8 (33.3–34.3)	<0.001
RDW	Girls	13.2 (12.9–13.6)	13.4 (12.8–13.9)	0.590
	Boys	13.5 (12.9–13.9)	13.3 (12.9–13.6)	0.086
	Overall	13.3 (12.9–13.7)	13.3 (12.8–13.8)	0.598
RDW-SD	Girls	39.5 (37.7–40.7)	39.7 (38.3–40.7)	0.656
	Boys	38.9 (38.0–40.7)	39.7 (37.7–40.4)	0.633
	Overall	39.4 (37.8–40.7)	39.7 (38.3–41.5)	0.952

Values are presented as median (interquartile range, IQR). Comparisons between Ağrı (high altitude) and Istanbul (sea level) were performed using the Mann–Whitney U test. p values <0.05 were considered statistically significant. Hb: Hemoglobin, RBC: red blood cell count, MCV: Mean corpuscular volume, MCHC: Mean corpuscular hemoglobin concentration, RDW: Red cell distribution width, RDW-SD: Red cell distribution width-standard deviation, TIBC: Total iron-binding capacity

Discussion

The present study demonstrated that hematologic adaptation to altitude during childhood may follow an age-dependent pattern extending beyond hemoglobin elevation alone. Reduced oxygen pressure at higher altitudes stimulates erythropoietin production and increases erythropoiesis, resulting in elevated Hb and RBC levels as part of physiological adaptation to hypoxia. Previous studies have demonstrated that Hb concentration increases with altitude, reflecting an adaptive response aimed at improving oxygen transport capacity (3,8,9).

In the present study, children living at high altitude demonstrated significantly higher hemoglobin and RBC values compared with those residing at sea level. These findings are consistent with previous studies reporting increased hemoglobin concentrations and erythrocyte counts in populations exposed to chronic hypoxia.

High-altitude adaptation involves several physiological mechanisms that enhance oxygen delivery, including stimulation of erythropoiesis and increased red blood cell production. An important observation of this study was the age-related pattern in hemoglobin differences between the two populations. Age-stratified analyses showed that the difference in hemoglobin levels was more pronounced in younger children but became less evident in older age groups. This pattern may reflect developmental changes in physiological adaptation to chronic hypoxic exposure during childhood. In contrast, RBC counts remained relatively higher in most age groups among children living at high altitude, suggesting that erythrocyte production continues to contribute to altitude adaptation throughout childhood (10–12).

Another major finding of the present study was the consistently lower TIBC observed in children living at high

Table 5. Hematological parameters in children aged 12–14 years according to altitude and sex

Parameter	Group	Ağrı Median (IQR)	Istanbul Median (IQR)	p
Iron	Girls	78.0 (58.0–96.0)	73.0 (52.0–91.0)	0.412
	Boys	74.0 (55.0–95.0)	70.0 (50.0–89.0)	0.358
	Overall	76.0 (56.0–95.0)	72.0 (51.0–90.0)	0.367
TIBC	Girls	298 (265–330)	360 (332–395)	<0.001
	Boys	290 (260–325)	348 (318–380)	<0.001
	Overall	294 (262–328)	354 (324–387)	<0.001
Ferritin	Girls	35.0 (22.0–47.0)	33.0 (24.0–46.0)	0.491
	Boys	30.0 (23.0–42.0)	36.0 (26.0–52.0)	0.072
	Overall	32.0 (23.0–45.0)	34.0 (25.0–48.0)	0.218
RBC	Girls	4.92 (4.70–5.10)	4.88 (4.60–4.98)	0.341
	Boys	4.95 (4.72–5.15)	4.85 (4.65–5.00)	0.084
	Overall	4.94 (4.70–5.12)	4.86 (4.64–4.99)	0.112
Hb	Girls	13.8 (13.2–14.4)	13.4 (12.9–13.9)	0.071
	Boys	13.7 (13.1–14.3)	13.5 (12.8–13.9)	0.095
	Overall	13.7 (13.1–14.3)	13.4 (12.8–13.9)	0.083
MCV	Girls	83.0 (81.0–85.4)	82.1 (80.0–84.3)	0.118
	Boys	82.7 (80.4–84.0)	81.8 (79.6–83.5)	0.141
	Overall	82.8 (80.7–84.3)	82.0 (79.8–83.9)	0.129
MCHC	Girls	33.4 (32.9–33.7)	33.8 (33.4–34.2)	0.003
	Boys	33.5 (33.0–33.8)	34.0 (33.4–34.4)	0.002
	Overall	33.4 (32.9–33.7)	33.9 (33.4–34.3)	<0.001
RDW	Girls	13.3 (12.9–13.7)	13.4 (12.9–13.8)	0.482
	Boys	13.4 (12.9–13.8)	13.3 (12.9–13.7)	0.517
	Overall	13.3 (12.9–13.7)	13.4 (12.9–13.8)	0.498
RDW-SD	Girls	39.6 (38.0–41.0)	39.9 (38.2–41.2)	0.621
	Boys	39.4 (38.1–40.7)	39.7 (38.0–41.0)	0.653
	Overall	39.5 (38.1–40.9)	39.8 (38.1–41.1)	0.642

Values are presented as median (interquartile range, IQR). Comparisons between Ağrı (high altitude) and Istanbul (sea level) were performed using the Mann–Whitney U test. p values <0.05 were considered statistically significant. Hb: Hemoglobin, RBC: red blood cell count, MCV: Mean corpuscular volume, MCHC: Mean corpuscular hemoglobin concentration, RDW: Red cell distribution width, RDW-SD: Red cell distribution width-standard deviation, TIBC: Total iron-binding capacity

altitude. This difference was present across nearly all age groups and both sexes. Iron metabolism plays a crucial role in altitude adaptation because hypoxia-induced erythropoiesis increases systemic iron demand and alters iron transport dynamics. Changes in iron-related parameters in high-altitude populations have been described in several studies investigating hypoxia-related hematological adaptation (9,12).

Additionally, MCHC values were generally lower in children living at high altitude in the present study (13). Alterations in erythrocyte indices have been reported in populations exposed to chronic hypoxia and may reflect adaptive changes in erythrocyte structure and Hb distribution within red blood cells (11,14).

Overall, the findings of this study indicate that altitude influences several hematological parameters in children. While both Hb and RBC levels are elevated in children living at high altitude, the age-related reduction in Hb differences

suggests that the impact of altitude on Hb concentration may diminish during adolescence. In contrast, the persistence of higher RBC levels and the consistent differences observed in TIBC and MCHC support the presence of ongoing hematological adaptation to altitude during childhood (10,12,15).

Study Limitations

Several limitations of this study should be acknowledged. First, this study was conducted retrospectively using data obtained from hospital records, which may limit the ability to control for potential confounding factors. Second, although children with iron deficiency, vitamin B12 deficiency, and inflammatory markers were excluded, other nutritional or socioeconomic variables that may influence hematological parameters could not be fully evaluated. Third, the study population consisted of children from two specific geographic regions, and therefore the findings may not be

fully generalizable to other populations living at different altitudes. Finally, additional physiological markers related to hypoxia, such as erythropoietin levels or oxygen saturation, were not available in the dataset. Additionally, the duration of residence at high altitude and possible population genetic differences were not evaluated, which may influence hematological adaptation.

Conclusion

In conclusion, this study demonstrated that altitude is associated with significant differences in hematological parameters among children. Hb and RBC values were generally higher in children living at high altitude, although the difference in Hb levels decreased with increasing age. In contrast, RBC elevation persisted across most age groups. Additionally, consistent differences were observed in TIBC and MCHC levels. These findings suggest that altitude-related hematological adaptation occurs during childhood and may vary according to age. Further prospective studies investigating iron metabolism and erythropoietic responses in children living at different altitudes are warranted.

These findings have important clinical implications. Interpretation of hematological parameters in children may need to consider environmental altitude, particularly in regions where populations live at substantially different elevations. Reference values derived from sea-level populations may not accurately reflect physiological hematological ranges in children residing at higher altitudes. Therefore, altitude-specific reference ranges may improve the clinical interpretation of hematological findings in pediatric populations living in high-altitude regions.

Ethics

Ethical Approval: The study was approved by the Ethics Committee of Ağrı İbrahim Çeçen University (approval date: 28 September 2023, decision no: 211).

Footnotes

Conflict of Interest: No conflict of interest was declared by the authors.

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