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Research Article

Prevalence of Anemia and Hematological Profiles among Medical Students at Sana'a University: A High-Altitude Cross-Sectional Study

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Abstract

Background: Anemia remains a significant global public health challenge. However, its prevalence among health professions students residing in high-altitude regions—where physiological adaptations may alter standard hematological parameters—is not well documented. This study aimed to determine the prevalence of anemia and evaluate the complete hematological profiles of medical students at Sana'a University, Yemen, a city situated at approximately 2,250 meters above sea level. Methods: A cross-sectional study was conducted among 100 undergraduate students (51 males and 49 females) aged 19–25 years at the Faculty of Medicine and Health Sciences, Sana'a University. Venous blood samples were collected and analyzed for Complete Blood Count (CBC) parameters using an automated Sysmex XN-330 hematology analyzer. Anemia was initially defined according to the World Health Organization (WHO) sea-level criteria (hemoglobin [Hb] <13.0 g/dL for males and <12.0 g/dL for females). The potential impact of altitude-specific adjustments was also evaluated.

Results: The overall mean hemoglobin concentration was 15.63 ± 1.73 g/dL. Sex-stratified analysis revealed significantly higher mean Hb levels in males (16.96 ± 1.20 g/dL) compared to females (14.24 ± 0.91 g/dL) ($p < 0.001$). Other mean hematological indices were as follows: packed cell volume (PCV) 47.05 ± 4.73%, Red Blood Cell (RBC) count 5.43 ± 0.59 × 10^{12}/L, Mean Corpuscular Volume (MCV) 86.39 ± 7.63 fL, and Mean Corpuscular Hemoglobin (MCH) 28.82 ± 2.24 pg. Using the unadjusted WHO sea-level criteria, the prevalence of anemia in this cohort was 0%. However, applying the recommended WHO altitude adjustment for Sana'a (+1.0 g/dL) revises the diagnostic thresholds to 14.0 g/dL for males and 13.0 g/dL for females, potentially identifying anemic cases, particularly among female participants. Conclusion: No anemia was detected in this sample of medical students using standard sea-level criteria, a finding likely attributable to high health literacy and physiological adaptation to Sana'a's altitude. This study highlights the critical need to establish altitude-specific hematological reference ranges for the Yemeni population to prevent the misdiagnosis of anemia in high-altitude regions.

Keywords: Anemia; Medical Students; Sana'a University; Hemoglobin; High Altitude; Yemen.

INTRODUCTION

Anemia is a major global public health concern and a common clinical manifestation of diverse underlying pathological conditions. It is characterized by a reduction in Red Blood Cell (RBC) count and/or Hemoglobin (Hb) concentration, ultimately leading to impaired oxygen delivery to body tissues and subsequent physiological dysfunction [1,2]. The burden of anemia extends beyond clinical symptoms, as it is associated with reduced physical performance, impaired cognitive function, decreased productivity, and increased morbidity, particularly among young and economically active populations. Despite decades of research and global health initiatives, anemia continues to affect a substantial proportion of the world's population. The World Health Organization (WHO) recognizes anemia as a critical indicator of both nutritional status and overall population health. However, the accurate diagnosis of anemia remains challenging due to variations in environmental, physiological, and demographic factors. One of the most important yet often overlooked determinants is altitude. Individuals residing at high altitudes experience physiological adaptations, including increased hemoglobin concentration, as a compensatory response to reduced oxygen partial pressure. Consequently, the use of standard sea-level diagnostic thresholds in such settings may lead to misclassification, either underestimating or overestimating the true burden of anemia [3,4]. The etiology of anemia is complex and frequently multifactorial. Iron deficiency remains the most common cause globally, accounting for nearly half of all cases [5,6]. Nevertheless, other contributing factors—including micronutrient deficiencies (such as vitamin B12 and folate), chronic infections, inflammatory conditions, and blood loss—play significant roles, particularly in low- and middle-income countries. Among young adults, menstrual blood loss, suboptimal dietary intake, and lifestyle-related factors further contribute to the risk of anemia. Medical students constitute a unique population that may be particularly susceptible to anemia despite their relatively high level of health awareness. The demanding nature of medical education is often associated with chronic stress, irregular eating habits, sleep deprivation, and reduced physical activity. These factors, combined with potential financial constraints and

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limited access to balanced nutrition in resource-limited settings, may increase vulnerability to hematological abnormalities [7,8]. Importantly, existing evidence indicates that higher educational status does not necessarily confer protection against anemia, underscoring the need for targeted assessment even within academically privileged groups [9-12]. The burden of anemia is disproportionately higher in developing countries, where it remains a persistent and multifaceted public health challenge [13-19]. In Yemen, the situation is further aggravated by prolonged conflict, economic instability, and a deteriorating healthcare infrastructure. These conditions have significantly impacted food security and nutritional status, thereby increasing the population's susceptibility to anemia and other micronutrient deficiencies. Furthermore, Sana'a, the capital city of Yemen, is located at an altitude of approximately 2,250 meters above sea level. This high-altitude environment introduces an additional layer of complexity in the interpretation of hematological parameters. Although the WHO recommends altitude-specific adjustments for hemoglobin thresholds, such corrections are not consistently applied in clinical practice or research settings, particularly in low-resource countries. This gap may lead to inaccuracies in prevalence estimates and hinder effective public health interventions. Given these considerations, there is a clear need for context-specific investigations that account for both environmental and population-specific factors. Therefore, this study aimed to determine the prevalence of anemia and comprehensively evaluate the hematological profiles of medical students at Sana'a University. In addition, it sought to assess the impact of applying altitude-adjusted hemoglobin thresholds on anemia classification in this high-altitude urban population, thereby contributing to more accurate diagnosis and improved epidemiological understanding.

MATERIALS AND METHODS

Study Design and Setting

A cross-sectional study was conducted at the Faculty of Medicine and Health Sciences, Sana'a University, Sana'a, Yemen. Sana'a is situated at an altitude of approximately 2,250 meters above sea level, a factor known to influence hematological parameters, particularly hemoglobin concentration. The study was carried out over a two-month period, from January to February 2024, under standardized environmental and laboratory conditions to ensure data consistency.

Study Population and Sampling

The study population consisted of 100 undergraduate students (51 males and 49 females) aged between 19 and 25 years. Participants were recruited using a simple random sampling technique from multiple academic departments, including Human Medicine, Pharmacy, Nursing, and Medical Laboratory Sciences, to ensure representation of diverse health-related disciplines.

Inclusion criteria included apparently healthy students within the specified age group who agreed to participate voluntarily. Individuals with known chronic diseases, recent infections, or those currently taking medications that could affect hematological parameters were excluded from the study to minimize potential confounding factors.

All participants were informed about the purpose and procedures of the study, and written informed consent was obtained before enrollment, in accordance with ethical research standards.

Data Collection and Laboratory Analysis

Approximately 3 mL of venous blood was collected aseptically from each participant using sterile disposable syringes and transferred into K3-EDTA anticoagulant vacutainer tubes. All samples were properly labeled and processed on the same day of collection to avoid pre-analytical variations. Complete Blood Count (CBC) analysis was performed using a calibrated Sysmex XN-330 automated hematology analyzer at the AULAQI Specialized Medical Laboratory in Sana'a. This analyzer is widely recognized for its precision and reliability in hematological assessments. Strict internal quality control measures were implemented daily using control samples, and the laboratory adhered to Standard Operating Procedures (SOPs) to ensure the accuracy, reproducibility, and validity of the results.

Diagnostic Criteria

Anemia was initially defined based on the World Health Organization (WHO) hemoglobin cut-off values at sea level: Hemoglobin (Hb) concentration <13.0 g/dL for adult males and <12.0 g/dL for non-pregnant adult females. Considering the high-altitude location of Sana'a, an adjustment factor of +1.0 g/dL was taken into account for interpretative and discussion purposes, in line with WHO recommendations for populations residing at elevated altitudes. This adjustment is essential to avoid overestimation of anemia prevalence in high-altitude settings due to physiological increases in hemoglobin levels.

Statistical Analysis

Data were entered, cleaned, and analyzed using IBM SPSS Statistics version 24.0. Descriptive statistics were computed for all variables, including means, Standard Deviations (SD), and ranges for continuous data. Inferential statistical analysis was performed using the independent samples t-test to compare mean hematological parameters between male and female participants. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 100 undergraduate students participated in this study, including 51 males (51%) and 49 females (49%), with a mean age of 22.77 ± 1.73 years. The overall hematological parameters of the study population are presented in Table 1. The mean hemoglobin concentration was 15.63 ± 1.73 g/dL. Other hematological parameters included packed cell volume (47.05 ± 4.74%), red blood cell count (5.43 ± 0.60 × 10^{12}/L), mean corpuscular volume (86.39 ± 7.63 fL), mean corpuscular hemoglobin (28.83 ± 2.24 pg), and mean corpuscular hemoglobin concentration (33.19 ± 1.07 g/dL). Sex-based comparisons are presented in Table 2. Male participants demonstrated significantly higher mean hemoglobin, PCV, and RBC values compared to females ($p < 0.001$). However, no significant difference was observed in MCV values between the two groups ($p = 0.08$). Based on WHO sea-level criteria, no cases of anemia were identified in the study population. However, after applying altitude-adjusted hemoglobin cut-offs, several female participants were found to have hemoglobin values close to the diagnostic threshold, suggesting possible underestimation of anemia prevalence when standard sea-level criteria are used.

Table 1: Overall Hematological Parameters of the Study Population

Parameter	Mean ± SD
Hb (g/dL)	15.63 ± 1.73
PCV (%)	47.05 ± 4.74
RBC (×10^{12}/L)	5.43 ± 0.60
MCV (fL)	86.39 ± 7.63
MCH (pg)	28.83 ± 2.24
MCHC (g/dL)	33.19 ± 1.07

Table 2: Comparison of Hematological Parameters Between Male and Female Participants

Parameter	Males (n=51) Mean ± SD	Females (n=49) Mean ± SD	p-value
Hb (g/dL)	16.96 ± 1.20	14.24 ± 0.91	<0.001
PCV (%)	50.66 ± 3.27	43.29 ± 2.60	<0.001
RBC ($\times 10^{12}$/L)	5.76 ± 0.55	5.08 ± 0.41	<0.001
MCV (fL)	87.68 ± 6.90	85.06 ± 8.20	0.08

DISCUSSION

This study aimed to assess the prevalence of anemia and evaluate hematological profiles among medical students in Sana'a, a high-altitude city in Yemen. The principal finding was a 0% prevalence of anemia when applying the standard World Health Organization (WHO) sea-level criteria. The mean hemoglobin levels observed—16.96 g/dL for males and 14.24 g/dL for females—were notably higher than the global averages reported for similar age groups [7]. The most plausible explanation for the elevated hemoglobin levels observed in this study is physiological adaptation to the high altitude of Sana'a (~2,250 meters above sea level). At higher altitudes, reduced atmospheric oxygen pressure stimulates erythropoiesis, leading to increased hemoglobin concentration and red blood cell production in order to enhance oxygen delivery to tissues [20]. This adaptive mechanism explains the relatively high hemoglobin values recorded, with some male participants reaching levels as high as 19.2 g/dL. While such levels may suggest polycythemia in low-altitude settings, they are generally considered normal among individuals residing long-term at high altitudes [21,22]. The use of universal sea-level hemoglobin cut-offs in high-altitude populations remains controversial [23-26]. The WHO recommends adjusting hemoglobin thresholds upward by approximately 0.8–1.3 g/dL for populations living at elevations between 2,000 and 2,500 meters [27]. Applying a conservative adjustment of +1.0 g/dL in this study would increase the diagnostic thresholds to 14.0 g/dL for males and 13.0 g/dL for females. Under these adjusted criteria, all male participants would still be classified as non-anemic. However, some female participants, particularly those with hemoglobin values close to 12.0 g/dL, may be reclassified as anemic. This finding suggests that the reported 0% anemia prevalence may be underestimated due to the use of unadjusted diagnostic thresholds. It highlights the importance of applying altitude-specific criteria when assessing anemia in high-altitude populations. The findings of this study differ from those reported by Nassar et al. (2021), who documented a 4.5% prevalence of anemia among final-year medical students at Sana'a University [20]. This discrepancy may be attributed to differences in sample characteristics, study design, or temporal changes in nutritional status and health awareness among students. In contrast, studies conducted in low-altitude regions of Yemen, such as Hodeida, have reported significantly higher prevalence rates of anemia (30.4%) [28]. This variation underscores the combined influence of environmental and socioeconomic factors on hematological parameters. While altitude promotes increased erythropoiesis, factors such as malnutrition, infection, and limited access to healthcare contribute to higher anemia prevalence in lower-altitude and resource-limited settings [22-30]. One of the main strengths of this study is its focus on a high-altitude population, which provides valuable insight into hematological adaptations in such environments. Additionally, the use of an automated hematology analyzer ensured accurate and reliable measurement of hematological parameters. However, several limitations should be acknowledged. First, the relatively small sample size (n = 100) may limit the generalizability of the findings to the broader student population or the general Yemeni population. Second, the study did not include biochemical markers of iron status, such as serum ferritin or transferrin saturation, which are essential for confirming iron deficiency anemia. Furthermore, inflammatory markers such as C-reactive protein were not assessed, which may have helped differentiate between anemia of chronic disease and iron deficiency anemia. The absence of these parameters limits the ability to fully interpret the underlying causes of potential anemia cases.

CONCLUSIONS

In conclusion, this study found no cases of anemia among a sample of medical students in Sana'a when using standard, sea-level WHO criteria. This finding is likely a combined result of the participants' high health literacy and the physiological erythropoietic response to living at high altitude. However, the application of recommended altitude-adjusted thresholds would potentially identify cases of anemia, particularly in females, highlighting the critical need for context-specific diagnostic approaches.

RECOMMENDATIONS

Based on the findings of this study, it is recommended to establish population-specific, altitude-adjusted hematological reference ranges for individuals living in high-altitude regions such as Sana'a to improve the accuracy of anemia diagnosis. Clinical laboratories should incorporate altitude-corrected hemoglobin thresholds into routine reporting to avoid misclassification. Furthermore, future research should include larger and more representative sample sizes, as well as comprehensive biochemical markers such as serum ferritin and inflammatory indicators, to better distinguish between physiological adaptation and true anemia. Additionally, periodic screening programs among university students are encouraged to ensure early detection and prevention of hematological abnormalities.

ETHICAL APPROVAL

This study was conducted in accordance with the Declaration of Helsinki. The research protocol was approved by the Ethics Committee of the Faculty of Medicine, Sana'a University. Written informed consent was obtained from all participants after a full explanation of the study's purpose and procedures. Participant confidentiality was ensured through the use of anonymized codes for all data.

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