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# Comparison of routine blood parameters by altitude and residence duration in the Western Sichuan Plateau

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A R T I C L E I N F O

*Keywords:*
High-altitude acclimatization
Routine blood test
Altitude
Residence duration
Hypoxia

A B S T R A C T

*Background:* This study explores how routine blood test parameters change over time in acclimatized individuals at different altitudes on the Western Sichuan Plateau.
*Methods:* Healthy men aged 20–40 from low-altitude areas who moved to Ganzi Prefecture to live and work were recruited. The observation sites were Guzan Town (1400 m), Kangding County Seat (2500 m), Luhuo County Seat (3400 m), and Litang County Seat (4100 m). Participants at the same altitude were grouped according to residence duration. The relationships between blood test parameters, altitude, and residence duration were analyzed.
*Results:* After moving to the plateau, white blood cell, red blood cell, hemoglobin, and hematocrit levels rose quickly in the short term, then declined and stabilized. In contrast, platelet levels increased steadily and were positively correlated with altitude.
*Conclusions:* Changes in blood parameters during high-altitude acclimatization are significant physiological responses to hypoxia and are affected by both altitude and residence duration.

## 1. Introduction

In recent years, with the continuous improvement in transportation infrastructure and the development of transportation networks, more people have migrated from low-lying areas to high-altitude regions for living and working purposes. The unique environment of high-altitude areas, characterized by low pressure and low oxygen, can significantly affect human physiological functions. As an essential carrier for transportation and regulation in the human body, various blood parameters can be changed accordingly. Failure to promptly and accurately understand these changes will severely hinder the health assessment, disease prevention, and diagnosis of people newly arriving in high-altitude areas. Therefore, understanding changes in routine blood parameters at different altitudes and over time is crucial for the health and quality of life of individuals and for improving the local medical system and formulating public health policies. A high-altitude environment exerts significant effects on human physiological functions, particularly in the blood system [1]. Altitude increases, and the partial pressure of oxygen decreases. This hypoxic condition triggers acclimatization of physiological responses aimed at maintaining normal bodily functions [2]. One such response is the elevation of red blood cell (RBC) and hemoglobin (HGB) levels [3], which enhances the oxygen-carrying capacity of the blood [4]. In a hypoxic environment, the body increases erythropoietin (EPO) secretion to adapt to such conditions [5]. EPO stimulates hematopoietic stem cells (HSC) to

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differentiate and proliferate into erythroid progenitor cells (EPC), leading to an increase in the production of RBCs and enhancement of blood oxygen-carrying capacity [6]. However, the extensive proliferation of EPCs inhibits the acquisition of growth factors, such as thrombopoietin (TPO) [7]. Meanwhile, it occupies more space in the hematopoietic microenvironment of the bone marrow. This restricts the differentiation and proliferation of HSCs toward megakaryocyte progenitor cells (MPC), thereby suppressing platelet (PLT) production. This phenomenon involves stem cell competition between RBCs and PLTs in a hypoxic environment [8]. Studies indicate that during acclimatization of the human body to high altitudes, there are differences in the changes in blood parameters among people of different ethnic groups [9].

Despite extensive research on these adaptive mechanisms, these studies have focused on changes in blood parameters at a single altitude and for specific durations of residence. This narrow focus has limited the comprehensiveness of the findings and has failed to elucidate the dynamic patterns of blood cell behavior across different altitudes and over extended periods. To address this gap, we investigated the effects of living altitude and duration of residence on routine blood test parameters. We employed a comprehensive research methodology that involved collecting blood samples from acclimatized individuals at multiple altitudes and after different durations of residence. Our primary objective was to detect and analyze changes in the relevant routine blood parameters. Our findings provide more precise, scientifically robust, and personalized reference indicators for the diagnosis and treatment of diseases associated with alterations in routine blood parameters among acclimatized populations at different altitudes and with varying residence durations.

## 2. Methods

### 2.1. Data

In accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [10], we submitted a series of issues related to the screening of experimental subjects and experimental methods to the Ethics Committee of Ya'an People's Hospital for review and approval before starting the experiment. This study selected healthy males aged 20–40 years who came from the plains and worked and lived in Guza Town, Kangding County, the county seat of Kangding County, the county seat of Luhuo County, and the county seat of Litang County in Ganzi Prefecture, Sichuan Province, as the research subjects. Before screening, all potential participants were provided with detailed information regarding the research objectives, procedures, risks, and benefits. After they were fully informed, they signed an informed consent form. The participants were grouped according to the time of arrival in the plateau area, which was categorized into four time periods: less than 6 months, 6 months to 1 year, 1–2 years, and more than 2 years. In each of the four aforementioned regions, 100 research subjects were selected for each of the four time periods. That is, 400 people were selected in each region for the four time periods, and 1600 people were selected from the four regions, categorized into 16 groups with 100 people in each group. The inclusion criteria were as follows: (1) no inflammatory diseases and no use of antibiotics, anticancer drugs, or anticoagulants in the past month; (2) a body mass index between 18.5 and 23.9 kg/$m^2$; (3) normal cardiopulmonary function; (4) normal liver and kidney function; and (5) no history of immune system or hematological diseases.

### 2.2. Methodology

#### 2.2.1. Detection method

Two milliliters of venous blood were collected using EDTA-K2 anticoagulated vacuum tubes (Becton, Dickinson and Company, Plymouth, United Kingdom) [11]. Complete blood counts and differential analyses were performed using a Sysmex XN9000 automated hematology analyzer (Toshiba Medical Systems Corp., Kyoto, Japan) and its associated reagents. Calibration was performed using the corresponding standard materials. All procedures were conducted in strict accordance with the standard operating procedures. The Sysmex XN-9000 automatic hematology analyzer employs advanced technologies, including semiconductor laser flow cytometry for cell analysis. Its design and operational principles do not impose strict altitude restrictions, allowing it to function accurately even in high-altitude regions.

#### 2.2.2. Detection parameters

The routine blood test parameters investigated in this study included the white blood cell (WBC) count, RBC count, PLT count, HGB, and hematocrit (HCT) levels. The data were processed using Microsoft Excel 365 (Microsoft Corp., Redmond, WA, USA).

#### 2.2.3. Statistical methods

Data analysis was performed using SPSS (version 25.0; IBM Corp., Armonk, NY, USA). Quantitative data following a normal distribution are expressed as the mean ± standard deviation. A one-way analysis of variance was used to compare the groups of quantitative data, and the least significant difference test was used to perform further pairwise comparisons when significant differences were observed. Statistical significance was set at $P < 0.05$.

## 3. Results

### 3.1. Guzan (1400 m)

Analysis of the results of routine blood tests for people with different durations of residence in Guzan, Kangding, Luhuo, and Litang areas shows that the data all conform to the normal distribution. Figs. 1–5 intuitively demonstrate the changing trends of different altitudes, time periods, and indicators. In the Guzan area, the levels of WBCs, HGB, and HCT decrease as the duration of residence increases, while the PLT level rises as the duration of residence increases. Significant differences are observed between the three groups with a residence duration of more than 6 months and the group with a residence duration of less than 6 months. No significant differences were observed among the groups with a residence duration of more than 6 months.

### 3.2. *Kangding (2500 m)*

In Kangding, the levels of WBCs, HGB, and HCT decrease as the length of residence increases. Pairwise comparisons among the four groups with different lengths of residence show significant differences. The level of RBCs decreases as the length of residence increases. There is no statistical difference among the groups with a residence time of more than one year. The PLT level increases as the length of residence increases. The PLT values of the groups with a residence time of more than one year are higher than those of the groups with a residence time of less than one year.

### 3.3. *Luhuo (3400 m)*

In Luhuo, HGB and HCT levels drop with longer residence. Pairwise comparisons of four residence-time groups show statistically significant differences. WBC count decreases as residence time increases, with no significant difference between two groups with over 1-year stay. RBC count also declines, with the group having less than a 6-month stay having a higher count than those with over a 6-month stay. The group with less than 1-year stay has a higher count than the group with over 2-year stay. However, there is no significant difference in RBC count between the group with less than 1-year stay and the 1–2-year stay group, or between the 1–2-year stay group and the group with over 2-year stay. PLT levels rise with longer stay; the group with over 1-year stay has higher PLT levels than the group with less than 1-year stay, and there is no significant difference between the 1–2-year stay group and the group with over 2-year stay.

### 3.4. *Litang (4100 m)*

In Litang, the levels of WBCs, RBCs, HGB, and HCT decrease as the length of residence increases. Pairwise comparisons of the four residence-time groups show these differences are statistically significant. The PLT level rises with longer residence. There is no significant statistical difference between the group with a residence time of 1–2 years and the group with a residence time of 6 months to 1 year, or between the group with a residence time of 1–2 years and the group with a residence time of over 2 years.

### 3.5. *Comparison of the group with less than 6 months across different altitudes*

In each group with a residence time of less than 6 months, the levels of WBCs, RBCs, HGB, HCT, and PLT increase as the altitude rises, and the differences among all groups are statistically significant.

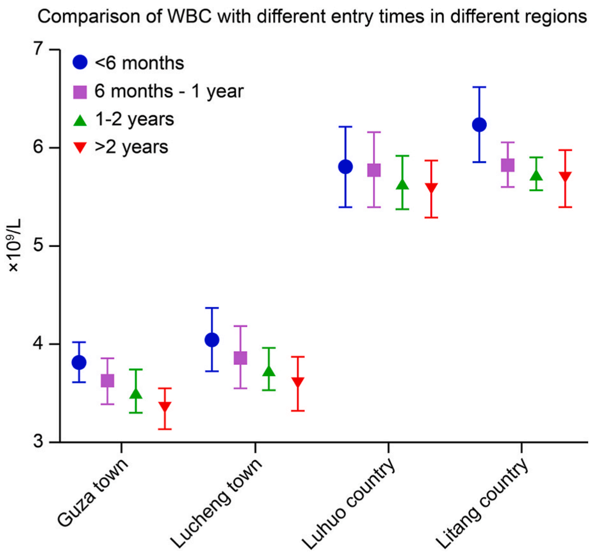


**Fig. 1.** Comparison of white blood cell with different entry times in different regions.

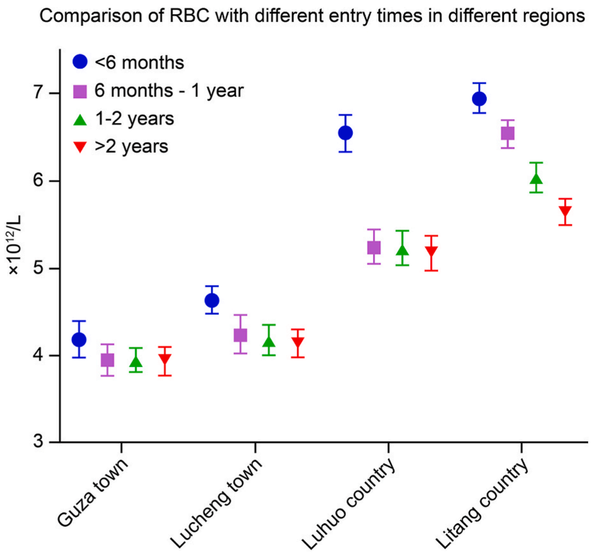


**Fig. 2.** Comparison of red blood cells with different entry times in different regions.

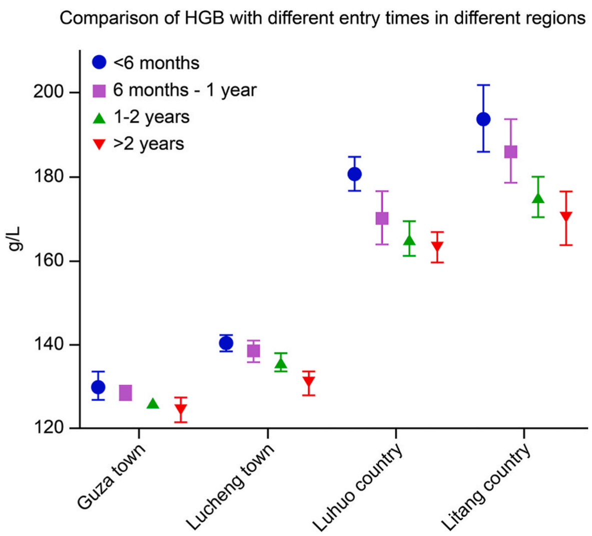


**Fig. 3.** Comparison of hemoglobin with different entry times in different regions.

### *3.6. Comparison of the group with 6 months to 1 year across different altitudes*

In each group with a residence time of 6 months to 1 year, the levels of WBCs, RBCs, HGB, and HCT increase as the altitude rises, and the differences among all groups are statistically significant. The PLT level is the highest in the Litang area, followed by Luhuo, Guzan, and Kangding. There is no statistically significant difference between Guzan and Kangding.

### *3.7. Comparison of the 1–2 years group across different altitudes*

In each group with a residence time of 1–2 years, the levels of WBCs, RBCs, HGB, and HCT increase as the altitude rises, and the differences among all groups are statistically significant. The PLT levels in Litang and Luhuo are higher than those in Guzan and Kangding. However, there is no statistically significant difference in PLT levels between Litang and Luhuo, nor between Guzan and Kangding.

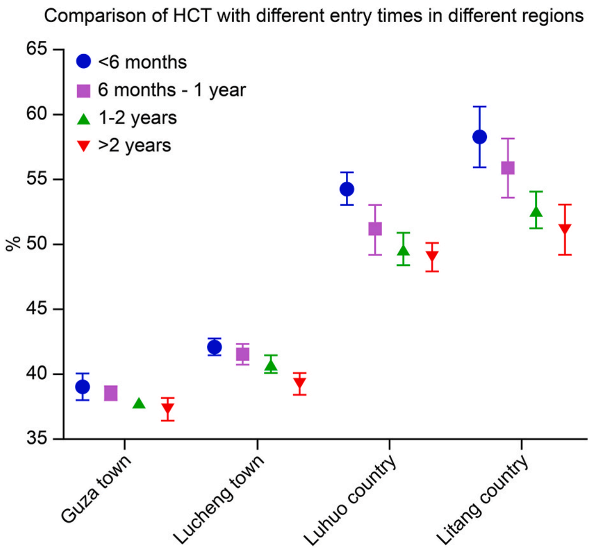


**Fig. 4.** Comparison of hematocrit with different entry times in different regions.

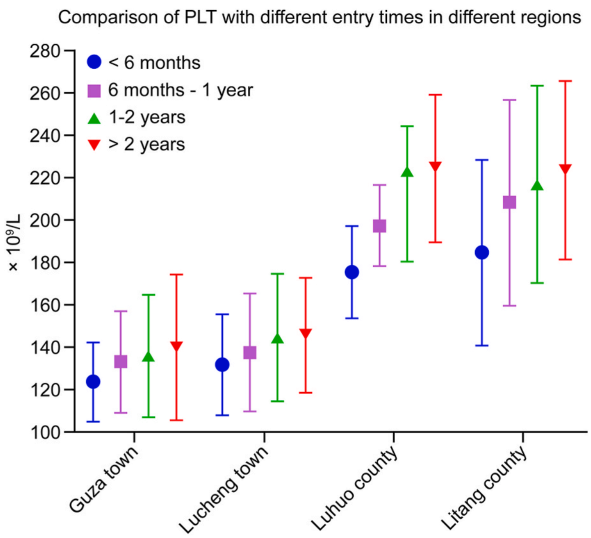


**Fig. 5.** Comparison of platelet with different entry times in different regions.

### *3.8. Comparison of the group with more than 2 years across different altitudes*

In each group with a residence time of more than 2 years, the levels of WBCs, RBCs, HGB, and HCT increase as the altitude rises, and the differences among all groups are statistically significant. The PLT levels in Litang and Luhuo are higher than those in Kangding and Guzan. However, there is no statistically significant difference in PLT levels between Litang and Luhuo, nor between Kangding and Guzan.

## 4. Discussion

### *4.1. Effects of high altitude on RBC and HGB*

RBC count and HGB level are key indicators for assessing the effect of high altitude on human physiological functions. The main challenge in high-altitude environments is the reduced partial pressure of oxygen, which directly leads to a decrease in blood-oxygen saturation. In response, the body initiates a series of adaptive mechanisms, most notably increasing RBC production and HGB levels. This process begins with the kidneys secreting more EPO, which stimulates the bone marrow to accelerate RBC production, thereby increasing the number of RBCs and the level of HGB in the blood to enhance oxygen transport capacity. Previous studies have shown that even under extreme conditions above 3000 m, RBC counts and HGB levels exhibit a significant upward trend [3], leading to compensatory polycythemia, also known as high-altitude polycythemia [12]. The symptoms of high-altitude polycythemia become more pronounced at higher altitudes [13]. Studies on high-altitude stationed military personnel have found that their average RBC and HGB levels are significantly higher than those of a low-altitude control group and within the upper limit of national standard ranges [14]. In this study, RBC, HGB, and HCT levels were significantly higher in individuals residing in high-altitude areas for less than 6 months than in those living in lowland areas. A positive correlation was observed between these indicators and altitude, as shown by comparisons across different altitudes. It has also been confirmed that after migrating to high-altitude regions, the compensatory increase in RBC and HGB levels leads to a significant increase in blood viscosity and inhibition of fibrinolysis [15], resulting in a hypercoagulable and hypofibrinolytic state [16]. The body undergoes a series of adaptive changes as it progressively adjusts to a hypoxic environment. For example, increasing the size of RBCs enhances the oxygen exchange surface area, thereby improving tissue oxygenation [17,18]. Consequently, it was observed that within 6 months, RBC, HGB, and HCT levels rapidly increased, then gradually declined over time, eventually stabilizing [1]. This gradual compensation is an essential mechanism by which the body adapts to a hypoxic environment to reduce blood viscosity and maintain normal hemodynamics and microcirculation.

### *4.2. Effects of high altitude on WBC count*

Zhang et al. [19] suggested that WBC count increases significantly under short-term hypoxic conditions at high altitudes, consistent with the findings of this study. Low oxygen levels at high altitudes trigger immune system activation, promoting WBC production through the upregulation of proinflammatory cytokines, which helps meet the body's needs for inflammation and tissue repair in response to hypoxia. This increase in the WBC count may reflect an adaptive immune response to chronic hypoxia in high-altitude environments. Some studies have shown that chronic hypoxia can activate the nuclear factor kappa-light-chain-enhancer of activated B cell (NF-κB) pathway [20], thereby promoting the mobilization and proliferation of WBCs, particularly neutrophils and monocytes. Additionally, increased ultraviolet radiation at high altitudes may induce the release of inflammatory mediators through DNA damage and oxidative stress, further stimulating an increase in WBC counts [21]. In this study, a rapid increase in WBC count was observed within the first six months of moving to a high altitude. A comparison across altitudes showed that this increase was more pronounced at higher altitudes than at lower altitudes. However, the WBC count gradually decreased over time, consistent with the results of previous studies [22]. This decline is mainly attributed to reduced immune stress with prolonged residence at high altitudes, resulting in "acquired acclimatization" [23].

### *4.3. Effects of high altitude on PLT count*

PLTs primarily function in hemostasis and coagulation. In adults, PLT formation involves two steps: first, HSCs differentiate into mature megakaryocytes, and second, megakaryocytes release PLTs through a process known as PLT production. Mejuto et al. [24] reported that increases in RBC and HGB levels can lead to increased blood viscosity, which activates and consumes PLTs extensively and reduces their numbers. However, high altitudes trigger a stress response in the body [25], leading HSCs to a transition from a quiescent to a proliferative state [26,27]. After more than 6 months of residence, the RBC, HGB, and HCT levels gradually declined and stabilized. The reduction in RBC and HGB levels also decreases their inhibitory effects on PLTs, leading to a gradual increase in PLT counts [8,28]. RBC and HGB levels decreased over time at high altitudes, which is consistent with the findings of Zou et al. [29]. This was accompanied by an increase in PLT count.

In conclusion, our study shows that when people migrate from low-altitude areas to high-altitude areas, they will immediately undergo physiological adjustments to adapt to the hypoxic environment. As the altitude increases, in order to enhance the body's oxygen-carrying capacity, the levels of RBCs and HGB rise, which is a crucial compensatory mechanism. At the same time, hypoxia activates the immune system, increasing the WBC count, which helps the body resist potential threats during the adaptation period.

In addition, when people first enter high-altitude areas, the body's stress response causes an increase in the PLT count, but this increase is limited by the rise in RBC and HGB levels. After living at high altitude for six months, the levels of RBC, HGB, and HCT gradually decrease and stabilize. The decrease in RBC and HGB levels reduces the inhibition on PLT and causes the PLT count to gradually increase over time.

This study has some limitations. For example, the subjects of our study are Han Chinese men who migrated from low-altitude areas, rather than local indigenous people. Therefore, the role of genetic factors in the process of high-altitude adaptation has not been fully understood.

Future research will further clarify the age distribution of participants, the altitude range, and ethnic classification to gain a more detailed understanding of how routine blood parameters vary among different altitudes, genders, and ethnic groups.

Additionally, altitude factors are highly likely to cause human dehydration, which in turn affects the final test results of blood cell concentration. However, this key factor was not considered in this study. Although accurate assessment of the impact of dehydration in a high-altitude environment is challenging, it should be addressed. We hope to have in-depth discussions with subsequent researchers, jointly explore appropriate methods, and conduct specialized research on this issue.

## 5. Conclusions

Numerous factors influence blood indices in the plateau environment, and the influencing mechanism is complex. The standard reference ranges of routine blood tests formulated based on the population in low-altitude areas cannot accurately reflect the health status of individuals living in the hypoxic environment at high altitudes.

## CRediT authorship contribution statement

**Liang Wan:** Writing – original draft, Conceptualization. **Qing Yuan:** Writing – original draft, Conceptualization. **Mingxia Tang:** Writing – original draft, Formal analysis, Data curation. **Zhu Zhu:** Writing – original draft, Formal analysis, Data curation. **Yanwu Liu:** Writing – original draft, Formal analysis, Data curation. **Zhenglin Huang:** Writing – review & editing, Visualization, Investigation. **Shuzhi Zhou:** Writing – review & editing, Visualization, Investigation. **Ling Zhang:** Writing – review & editing, Visualization, Investigation. **Qiaoling Wang:** Writing – review & editing, Visualization, Investigation. **Yuntao Guo:** Writing – original draft, Formal analysis, Data curation. **Jian Yang:** Writing – review & editing, Validation.

## Data availability

The data will be made available upon request.

## Ethical statement

This study was conducted in strict accordance with all applicable ethical guidelines and regulations. Throughout the research process, the rights, privacy, and dignity of all the participants were fully respected and protected. All participants voluntarily signed written informed consent forms after fully understanding the research objectives, methods, and potential risks and benefits. We implemented strict confidentiality measures to ensure that the participant's personal information and research data were adequately protected. The data will only be used for analysis related to this study and will not be disclosed to any third party. Before the implementation of this research plan, the ethical review of the Ethics Committee of Ya'an People's Hospital was passed (approval number 2023011). Throughout the entire research process, we have strictly adhered to the requirements and suggestions put forward by this committee to ensure the scientific, legal, and ethical nature of the research.

## Declaration of generative AI in scientific writing

The authors declare that generative AI has not been used in scientific writing.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Glossary

WBC: White blood cells, which play a crucial role in the human immune system by fighting infections and pathogens. White blood cells can detect and destroy harmful microorganisms and abnormal cells within the body.

HGB: Hemoglobin, a protein in red blood cells responsible for carrying oxygen.

HCT: Hematocrit, which refers to the proportion of red blood cells in the total blood volume.

PLT: Platelets, also known as thrombocytes, are essential for blood clotting and bleeding cessation.

RBC: Red blood cells, also called erythrocytes, are responsible for transporting oxygen to tissues and organs throughout the body.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.plabm.2025.e00467.

## Data availability

Data will be made available on request.

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