THE EFFECT OF CIGARETTES ON RED BLOOD CELLS IN ACTIVE TEENAGE SMOKERS IN LEKOBALO VILLAGE, KOTA BARAT DISTRICT

Laras Puspita Taib[1)], Parhan Hanuna[2)]
[1,2)]Universitas Bina Mandiri Gorontalo
E-mail: laraspuspita2121@gmail.com, farhanhanuna2@gmail.com

ABSTRACT

Cigarette smoking during adolescence may affect hematological function through exposure to carbon monoxide, oxidative compounds, and other tobacco-related toxicants. This study aimed to determine the association between cigarette smoking frequency and red blood cell (RBC) values among active adolescent smokers in Lekobalo Village, Kota Barat District. A quantitative analytical observational study with a cross-sectional design was conducted in September 2025. The study involved 30 active smokers aged 15–19 years who consumed 3–10 cigarettes per day and were selected using random sampling. Smoking frequency was assessed through self-reported daily cigarette consumption, while RBC values were determined through laboratory examination of venous blood samples. Descriptive statistics and inferential analysis were performed, with statistical significance set at $p < 0.05$. Participants reported a mean smoking frequency of 6.13 ± 2.193 cigarettes per day, while the mean RBC concentration was 4.2020 ± 0.29847 million/µL, with values ranging from 3.70 to 4.76 million/µL. Inferential analysis demonstrated a statistically significant association between smoking frequency and RBC examination results ($F = 11.623$, $p < 0.001$). These findings indicate that variation in cigarette consumption was associated with variation in RBC values among adolescent smokers. However, the cross-sectional design does not establish a causal relationship. Early smoking prevention, cessation counseling, and appropriate hematological monitoring should be strengthened to reduce potential biological consequences of tobacco exposure among adolescents.

Keywords: *adolescent smokers; cigarette smoking; red blood cells; smoking frequency; hematological parameters*

INTRODUCTION

Cigarette smoking remains one of the most important preventable public health problems worldwide, contributing substantially to premature mortality and a broad spectrum of chronic diseases. Tobacco smoke contains a complex mixture of toxic substances that can affect multiple physiological systems, particularly the cardiovascular and respiratory systems. The health consequences of smoking are not limited to prolonged exposure in adulthood; smoking initiation during adolescence may establish patterns of nicotine dependence that persist into adulthood and consequently increase cumulative exposure to tobacco-related toxicants [1]. Adolescents who smoke are therefore an important population for early prevention because the biological and behavioral consequences of tobacco exposure may develop while critical processes of physical and neurological maturation are still occurring.

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The hematological system is among the biological systems potentially affected by cigarette smoke. Cigarette smoke contains carbon monoxide (CO), oxidizing compounds, particulate matter, and various toxic elements that can interact with blood components. Carbon monoxide has a particularly important role because it binds to hemoglobin with substantially greater affinity than oxygen, forming carboxyhemoglobin and consequently reducing the capacity of blood to transport and deliver oxygen to tissues [2]. At the same time, exposure to cigarette smoke can increase oxidative stress and disturb antioxidant defenses, potentially affecting the structural and functional integrity of erythrocytes. Experimental and laboratory evidence has demonstrated alterations in erythrocyte membranes and antioxidant status associated with cigarette smoking, including changes that may increase susceptibility to oxidative damage and hemolysis [3][4][5].

The presence of toxic elements in cigarette smoke further raises concerns regarding blood quality. Research involving packed red blood cells from smokers has identified toxic elements that may accumulate in blood components, suggesting that tobacco exposure can have consequences extending beyond the respiratory tract [6]. Smoking-related oxidative processes may also alter the morphology and biochemical characteristics of erythrocytes. Such changes are clinically relevant because erythrocytes are responsible for transporting oxygen throughout the body, and impairment of their integrity or oxygen-carrying function may contribute to symptoms associated with reduced tissue oxygenation. Thus, investigating the relationship between cigarette exposure and red blood cell characteristics may provide an important perspective for understanding the systemic effects of smoking.

Adolescence represents a particularly critical period for tobacco prevention. During this developmental stage, young people are exposed to biological, psychological, and social factors that may increase susceptibility to tobacco initiation and continued use. Nicotine exposure during adolescence can contribute to dependence, while social environments and peer influence can strongly shape smoking behavior [7][8]. Evidence from adolescent populations also indicates that smoking behavior is associated with a combination of individual and environmental factors, including peer-related influences and perceptions of tobacco use [9][10]. Early initiation is particularly concerning because adolescents who begin smoking at a younger age have more opportunity for prolonged exposure and may experience greater cumulative health risks over time.

The situation observed in Lekobalo Village, Kota Barat District, provides an important local context for examining this issue. Based on preliminary observations conducted by the researchers in July 2025, smoking behavior among adolescents in the area appeared concerning. Brief interviews with 10 male adolescents encountered in the neighborhood revealed that all participants identified themselves as active smokers, reporting consumption of approximately three to ten cigarettes per day. Most reported initiating smoking at 15–17 years of age, primarily because of curiosity, invitations from peers, or the desire to relieve stress. Seven of the 10 adolescents reported having smoked for more than one year, whereas three had smoked for less than one year.

The preliminary observation also identified a potential gap between smoking behavior and awareness of its physiological consequences. Several adolescents reported experiencing relatively nonspecific symptoms such as fatigue, dizziness, or a pale complexion but had never undergone blood testing. Only two of the 10 adolescents reported having undergone blood testing at a community health center, and neither had received detailed information regarding their laboratory results. Although these observations cannot be interpreted as evidence of smoking-induced hematological abnormalities, they indicate a population in which active adolescent smoking is accompanied by limited awareness and monitoring of possible systemic health effects.

Previous studies have established associations between cigarette smoke exposure, oxidative stress, erythrocyte damage, toxic-element exposure, and disturbances in blood-related physiology [6][3][4][5][2]. However, much of the existing evidence has focused on adult smokers, laboratory models, blood donors, or broader populations. Evidence specifically describing red blood cell characteristics among active adolescent smokers within community-level settings remains comparatively limited. This limitation is particularly relevant in areas where adolescent smoking is prevalent but access to health screening and awareness of smoking-related physiological consequences may be limited. Local evidence is necessary to determine whether patterns of tobacco exposure observed in the community are accompanied by measurable differences in red blood cell parameters.

Therefore, examining red blood cell parameters among active teenage smokers in Lekobalo Village is important both scientifically and from a public health perspective. Such evidence may contribute to a more comprehensive understanding of the early biological consequences of tobacco exposure and provide locally relevant information for health education, screening, and adolescent smoking-prevention programs. Accordingly, this study aims to investigate the effect of cigarette smoking on red blood cells among active teenage smokers in Lekobalo Village, Kota Barat District.

Literatur Review

Cigarette Smoking and Adolescent Health

Cigarette smoking during adolescence represents an important public health concern because tobacco exposure begins during a period of substantial physiological and behavioral development. Adolescents may initiate smoking because of curiosity, peer influence, psychosocial factors, and perceptions of smoking behavior. Evidence from recent research indicates that individual and social factors contribute significantly to smoking initiation and continuation among adolescents [9]. More importantly, smoking initiation during adolescence may establish patterns of tobacco dependence that persist into adulthood and increase cumulative exposure to tobacco-related toxicants. Longitudinal evidence suggests that early smoking initiation is associated with adverse health consequences later in life, emphasizing the importance of identifying the biological effects of smoking at an early age [11].

Although the cardiovascular consequences of adolescent smoking have received increasing attention, evidence concerning its effects on hematological parameters remains comparatively limited. Studies have demonstrated that smoking

exposure can affect vascular function even among adolescents, suggesting that physiological consequences may emerge before the development of clinically apparent smoking-related disease [12]. This observation supports the importance of examining biological markers that may reflect the early systemic effects of cigarette exposure, including red blood cell (RBC) parameters.

Cigarette Toxicants and Erythrocyte Structure and Function

Cigarette smoke contains a complex mixture of chemically reactive and toxic substances that can interact with blood components. Among the most relevant substances are carbon monoxide, reactive oxygen species, and other compounds capable of inducing oxidative and cellular damage. Because erythrocytes are continuously exposed to circulating toxicants and depend heavily on antioxidant mechanisms to maintain membrane integrity, they may be particularly susceptible to oxidative injury.

Previous microscopic investigations have demonstrated that cigarette smoking can influence erythrocyte membrane characteristics and fluidity. Changes in membrane structure may interfere with the ability of erythrocytes to maintain their normal shape and deformability, potentially affecting their passage through the microcirculation [13]. More recent evidence further indicates that the intensity of cigarette smoking may be associated with progressive biochemical and morphological alterations in erythrocytes, suggesting a possible exposure-response relationship between smoking intensity and erythrocyte damage [14].

Carbon monoxide represents another important mechanism linking cigarette smoking with erythrocyte function. Once inhaled, carbon monoxide binds to hemoglobin to form carboxyhemoglobin, reducing the effective capacity of hemoglobin to transport oxygen. Consequently, repeated exposure to cigarette smoke may interfere with oxygen delivery and contribute to physiological adaptations associated with chronic exposure. Wang et al. [2], emphasized that cigarette smoking can influence blood circulation and oxygen transport through multiple mechanisms, highlighting the importance of considering hematological consequences when evaluating the systemic effects of smoking.

Oxidative Stress and Erythrocyte Damage

Oxidative stress is considered one of the principal mechanisms through which cigarette smoke can damage erythrocytes. Tobacco smoke contains oxidants that can increase the generation of reactive oxygen species and disturb the balance between oxidative processes and endogenous antioxidant defenses. Since erythrocyte membranes contain polyunsaturated fatty acids that are vulnerable to lipid peroxidation, excessive oxidative stress may compromise membrane stability and cellular function.

Experimental evidence supports this mechanism. Hossain et al. [15], reported that acute cigarette smoke exposure was associated with oxidative damage and inflammatory responses involving erythrocytes. These findings suggest that the effects of cigarette smoke on blood cells may occur even following relatively short-term exposure. Similarly, microscopic evidence of altered erythrocyte membrane characteristics among smokers indicates that oxidative and chemical insults may translate into observable structural changes [13].

However, erythrocytes possess antioxidant defense mechanisms that can partially counteract cigarette smoke-induced oxidative damage. The extent to which these defenses can compensate for continued exposure may depend on smoking intensity, duration, individual physiological characteristics, and overall antioxidant status. The observation of graded biochemical and morphological changes according to smoking intensity provides further support for the possibility that prolonged or heavier exposure may produce more pronounced erythrocyte alterations [14].

Hemoglobin, Red Blood Cell Count, and Hematological Changes

The hematological response to cigarette smoking is not necessarily characterized by a reduction in RBC count. Instead, smokers may demonstrate increased RBC counts, hemoglobin concentrations, and hematocrit values as physiological adaptations to repeated carbon monoxide exposure and reduced oxygen availability. Pedersen et al. [16], using data from the Copenhagen General Population Study and Mendelian randomization analyses, reported associations between smoking and increased white and red blood cell counts. These findings indicate that smoking may influence hematopoietic processes in addition to directly affecting circulating erythrocytes.

Similarly, comparative hematological research has demonstrated differences in several blood parameters between smokers and nonsmokers, supporting the systemic influence of tobacco exposure on hematological status [17]. These changes may represent a compensatory response to impaired oxygen transport rather than evidence of improved erythrocyte function. Thus, an elevated RBC count or hemoglobin concentration should not necessarily be interpreted as a beneficial effect of smoking; rather, it may reflect physiological adaptation to chronic exposure to carbon monoxide and other tobacco-related toxicants.

Evidence also suggests that smoking affects multiple blood cell populations. Increased white blood cell counts have been observed among smokers, indicating the presence of systemic inflammatory responses accompanying smoking exposure [16]. Therefore, the effects of smoking on erythrocytes should be considered within the broader context of hematological and systemic responses rather than as an isolated alteration in RBC count.

Smoking Intensity and Duration of Exposure

The magnitude of smoking-related hematological effects may depend on both the intensity and duration of exposure. A recent study specifically examining graded cigarette smoking intensity reported biochemical and morphological alterations in erythrocytes across different levels of smoking exposure, strengthening the possibility of a dose-response relationship [14]. This finding is particularly relevant when studying adolescent smokers because individuals within the same age group may differ considerably in the number of cigarettes consumed per day and the duration of their smoking behavior.

Nevertheless, the available evidence remains insufficient to establish a consistent dose-response pattern specifically among adolescent smokers. Much of the existing research has been conducted among adult populations or experimental models [15][17][2]. Differences in age, duration of exposure, smoking intensity, nutritional status, and

physiological development may influence the hematological response to tobacco smoke. Consequently, findings from adult smokers cannot necessarily be generalized directly to adolescents.

RESEARCH METHODS

Study Design and Setting

This study employed a quantitative analytical observational design with a cross-sectional approach to examine the association between cigarette smoking habits and red blood cell (RBC) parameters among active adolescent smokers. The study was conducted in Lekobalo Village, Kota Barat District, Gorontalo City, Indonesia, with laboratory examinations performed at Otanaha Regional Hospital, Gorontalo City. Data collection and laboratory examinations were conducted in September 2025.

Study Population and Participants

The study population comprised active adolescent smokers residing in Lekobalo Village. Participants were recruited based on predefined eligibility criteria. The inclusion criteria were adolescents aged 15–19 years who were active smokers of filtered kretek cigarettes and reported consuming approximately 3–10 cigarettes per day. Participants were required to be willing to participate in the study and undergo blood examination. Individuals with conditions or characteristics that could substantially affect hematological measurements, as determined during participant screening, were excluded.

A total of 30 adolescents met the study criteria and were included in the final analysis. Participants were selected using random sampling from the eligible population. The final sample consisted of adolescents aged 15–19 years, with smoking consumption ranging from 3 to 10 cigarettes per day.

Variables and Measurements

The independent variable was cigarette smoking habit, operationalized as the average number of cigarettes consumed per day. Smoking frequency was recorded based on participants' self-reported daily cigarette consumption and ranged from 3 to 10 cigarettes per day.

The dependent variable was the red blood cell parameter obtained from laboratory examination. Venous blood samples were collected from each participant and examined at Otanaha Regional Hospital. The RBC concentration was reported in million cells/µL. The observed RBC values ranged from 3.70 to 4.76 million/µL, with a mean of 4.2020 ± 0.29847 million/µL.

In addition to laboratory measurements, demographic and smoking-related information, including age and daily cigarette consumption, was collected using a structured data collection form. Age was recorded in completed years.

Blood Sample Collection and Laboratory Examination

Blood specimens were collected from each participant following standard venous blood collection procedures. Samples were subsequently examined in the laboratory of Otanaha Regional Hospital using established hematological examination procedures. The resulting RBC values were recorded for statistical analysis. Laboratory results were also categorized as normal or abnormal according to the reference range applied by the laboratory.

To minimize measurement-related variability, blood collection and laboratory analysis were performed using standardized procedures by trained personnel. Laboratory results were

documented using participant identification codes rather than personal identifiers.

Data Management and Statistical Analysis

Data were coded, entered, and analyzed using statistical software. Descriptive statistics were used to summarize participants' demographic characteristics, smoking habits, and RBC examination results. Categorical variables were presented as frequencies and percentages, whereas continuous variables were summarized using the minimum, maximum, mean, and standard deviation.

Prior to inferential analysis, assumptions for parametric statistical testing were assessed. The Shapiro–Wilk test was used to evaluate the normality of the distributions of RBC examination results and smoking habit data. Both variables demonstrated acceptable normality, with p-values of 0.333 and 0.086, respectively. Homogeneity of variance was assessed using Levene's test, which yielded $F = 2.088$ and $p = 0.088$, indicating that the homogeneity assumption was satisfied.

The relationship between smoking habits and RBC examination results was subsequently evaluated using a parametric inferential test. Given the study's research objective and the available variables, the analysis examined whether variation in daily cigarette consumption was associated with differences in RBC values. Statistical significance was determined using an alpha level of 0.05. A p-value < 0.05 was considered statistically significant.

Ethical Considerations

The study was conducted in accordance with the principles of research involving human participants. Participants were informed about the study procedures, the purpose of the research, the blood collection process, and the voluntary nature of participation before data collection. Participation was based on informed consent, with appropriate consent procedures applied for participants who were minors. Participant confidentiality was maintained throughout data collection, analysis, and reporting, and individual identities were not disclosed in the research results.

RESEARCH RESULT

Participant Characteristics

A total of 30 active adolescent smokers from Lekobalo Village were included in the study. Participants were between 15 and 19 years of age. The largest proportion of participants was 19 years old (30.0%), followed by 17 years (23.3%), 16 years (20.0%), 18 years (16.7%), and 15 years (10.0%).

Table 1. Age Distribution of Active Adolescent Smokers

Age (years)	n	%
15	3	10.0
16	6	20.0
17	7	23.3
18	5	16.7
19	9	30.0
Total	30	100.0

Source: Primary data, 2025.

The participants were predominantly 19 years old, accounting for nearly one-third of the study sample. The youngest age group, aged 15 years, represented 10.0% of participants.

Smoking Habits

Daily cigarette consumption ranged from 3 to 10 cigarettes per day, with a mean of 6.13 ± 2.193 cigarettes per day. The distribution of smoking frequency is presented in Table 2.

Table 2. Distribution of Participants According to Daily Cigarette Consumption

Cigarettes/day	n	%
3	4	12.9
4	4	12.9

5	5	16.1
6	4	12.9
7	5	16.1
8	3	9.7
9	2	6.5
10	3	9.7
Total	30	100.0

Source: Primary data, 2025.

The most frequently reported smoking levels were 5 and 7 cigarettes per day, each accounting for 16.1% of participants. Consumption of 3, 4, and 6 cigarettes per day was reported by 12.9% of participants for each category. The least frequent consumption level was 9 cigarettes per day (6.5%).

Red Blood Cell Examination

Laboratory examination demonstrated that RBC values varied from 3.70 to 4.76 million/µL. The mean RBC concentration was 4.2020 ± 0.29847 million/µL. The descriptive statistics for RBC values and smoking frequency are presented in Table 3.

Table 3. Descriptive Statistics of Red Blood Cell Values and Smoking Frequency

Variable	N	Minimum	Maximum	Mean	SD
Red blood cells (million/µL)	30	3.70	4.76	4.2020	0.29847
Smoking frequency (cigarettes/day)	30	3	10	6.13	2.193

Source: Primary data, 2025.

The findings indicate considerable variation in daily cigarette consumption, while RBC concentrations showed a narrower distribution around the sample mean. The mean RBC concentration should be interpreted according to the reference interval and clinical characteristics of the laboratory used in the study.

Classification of Red Blood Cell Examination Results

Based on the reference classification applied in the study, 7 participants (22.6%) were categorized as having normal RBC examination results, whereas 23 participants (74.2%) were categorized as having abnormal results.

Table 4. Classification of Red Blood Cell Examination Results

RBC examination result	n	%
Normal	7	22.6
Abnormal	23	74.2
Total	30	100.0

Source: Primary data, 2025.

Abnormal RBC findings were more frequently observed than normal findings among the participants. However, the categorical interpretation should be considered together with the continuous RBC values presented in Table 3 and the specific laboratory reference range used for classification.

Normality and Homogeneity Testing

Before inferential analysis, the distribution of the study variables was assessed using the Shapiro–Wilk test. Both RBC examination results and smoking frequency showed p-values greater than 0.05, indicating no statistically significant departure from normality. The results are presented in Table 5.

Table 5. Shapiro–Wilk Normality Test

Variable	W	N	p-value
Red blood cell examination	0.961	30	0.333
Smoking frequency	0.939	30	0.086

Source: Primary data, 2025.

The RBC examination results showed W = 0.961 (p = 0.333), while smoking frequency showed W = 0.939 (p = 0.086). Both variables therefore met the prespecified normality criterion (p > 0.05).

Homogeneity of variance was assessed using Levene's test. The test

produced an F value of 2.088 with p = 0.088, indicating that the homogeneity assumption was not violated.

Table 6. Homogeneity of Variance Test

Comparison	F	p-value	Interpretation
RBC examination and smoking frequency	2.088	0.088	Homogeneous

Source: Primary data, 2025.

Because the p-value exceeded 0.05, there was no statistically significant evidence of unequal variances.

Association Between Smoking Frequency and Red Blood Cell Values

The inferential analysis demonstrated a statistically significant association between smoking frequency and RBC examination results. The reported F statistic was 11.623, with a significance value of $p < 0.001$.

Table 7. Inferential Analysis of Smoking Habit and Red Blood Cell Examination

Variables	N	F	p-value
Smoking frequency – RBC examination	30	11.623	<0.001

Source: Primary data, 2025.

The statistical result indicates that variation in smoking frequency was significantly associated with variation in RBC examination results among the participants. Because the observed p-value was below the significance threshold of 0.05, the null hypothesis was rejected.

Nevertheless, the statistical finding should be interpreted as an association rather than definitive causation, given the cross-sectional design. Furthermore, the available analysis does not provide an effect size or confidence interval, which are important for evaluating the magnitude and precision of the observed association.

DISCUSSION

Association Between Smoking Frequency and Red Blood Cell Parameters

The present study found a statistically significant association between cigarette smoking frequency and red blood cell (RBC) examination results among active adolescent smokers in Lekobalo Village, Kota Barat District ($F = 11.623$, $p < 0.001$). Participants reported smoking between 3 and 10 cigarettes per day, with a mean consumption of 6.13 ± 2.193 cigarettes per day, while RBC concentrations ranged from 3.70 to 4.76 million/µL. This finding suggests that differences in the intensity of cigarette exposure may be accompanied by variation in erythrocyte-related parameters even among adolescents who had already initiated regular smoking.

The observed association is biologically plausible because cigarette smoke contains carbon monoxide (CO), reactive oxidants, particulate matter, and other toxic substances capable of affecting blood physiology. CO is particularly relevant to erythrocyte function because it binds strongly to hemoglobin and forms carboxyhemoglobin, thereby interfering with normal oxygen transport. Repeated exposure may produce a state of relative tissue hypoxia and trigger physiological adaptations in erythropoiesis [2]. Therefore, variation in daily cigarette consumption may result in different levels of exposure to CO and other tobacco-related toxicants, potentially contributing to differences in RBC-related measurements.

The present finding is consistent with evidence from the Copenhagen

General Population Study, which demonstrated associations between smoking and increased red and white blood cell counts [16]. This relationship has been interpreted partly as a physiological response to smoking-induced hypoxia and systemic inflammatory stimulation. Similarly, a comparative hematological study reported differences in hematological parameters between smokers and nonsmokers, further supporting the systemic effects of cigarette exposure on blood physiology [17]. Although these studies were primarily conducted in adult populations, their findings provide a physiological framework for understanding why measurable hematological responses may also occur among younger smokers.

Importantly, an association between smoking and RBC values should not automatically be interpreted as evidence that smoking improves erythrocyte status. An increase in RBC-related parameters may represent a compensatory response to impaired oxygen availability rather than a beneficial physiological adaptation. Chronic exposure to CO can reduce the effective oxygen-carrying capacity of blood, potentially stimulating erythropoietic responses. Thus, an apparently higher RBC concentration may coexist with impaired oxygen delivery at the tissue level [2].

Potential Role of Oxidative Stress in Erythrocyte Alterations

Another plausible mechanism underlying the observed association is oxidative stress. Cigarette smoke contains numerous oxidizing substances capable of increasing reactive oxygen species and disrupting endogenous antioxidant defenses. Erythrocytes are particularly vulnerable to oxidative injury because their membranes contain substantial amounts of polyunsaturated fatty acids and because they continuously transport oxygen, creating conditions in which oxidative reactions can occur.

Experimental evidence indicates that cigarette smoke exposure can induce oxidative damage and inflammatory responses involving erythrocytes. Hossain et al. [15], demonstrated that cigarette smoke exposure was associated with oxidative injury and inflammatory changes, supporting the biological possibility that tobacco exposure can affect erythrocytes even before the development of clinically apparent disease. Similarly, Pretorius et al. [13], reported alterations in erythrocyte membrane fluidity and structural characteristics among smokers. These structural changes may compromise erythrocyte deformability and their ability to traverse the microcirculation efficiently.

More recent evidence provides additional support for an exposure-dependent mechanism. Biswas et al. [14], reported graded biochemical and morphological alterations in erythrocytes according to cigarette smoking intensity. This observation is particularly relevant to the present study because daily cigarette consumption varied considerably among participants. The mean consumption of 6.13 cigarettes per day therefore represents not merely a behavioral characteristic but potentially an indicator of differing levels of exposure to tobacco-related oxidative and chemical stress.

Nevertheless, the present study did not directly measure oxidative stress

markers, carboxyhemoglobin concentrations, antioxidant status, or erythrocyte membrane morphology. Consequently, the biological mechanisms described above should be regarded as plausible explanations supported by previous literature rather than mechanisms directly demonstrated by the present data. Future studies incorporating biomarkers such as carboxyhemoglobin, malondialdehyde, antioxidant enzymes, or detailed erythrocyte morphological assessment would provide stronger mechanistic evidence.

Interpretation of RBC Values Among Adolescent Smokers

The mean RBC concentration in the present study was 4.2020 ± 0.29847 million/µL, with observed values ranging from 3.70 to 4.76 million/µL. The relatively narrow distribution suggests that although participants differed in smoking frequency, their RBC concentrations remained within a relatively concentrated range. This finding illustrates an important distinction between statistical association and overt hematological abnormality. Tobacco exposure may influence erythrocyte physiology without necessarily producing clinically pronounced changes in RBC concentration in every individual.

The adolescent age of the participants is also relevant to interpretation. Adolescence is characterized by ongoing physiological development, and hematological parameters may be influenced by age, sex, nutritional status, growth, and other biological factors. Because the present sample consisted of adolescents aged 15–19 years, differences in developmental stage may contribute to variation in RBC values independently of smoking exposure. This is particularly important when interpreting the observed statistical association because the cross-sectional design cannot establish whether smoking preceded the observed hematological differences.

The findings also reinforce the importance of distinguishing erythrocyte quantity from erythrocyte quality and function. Cigarette smoking may alter membrane characteristics, oxidative status, oxygen transport, and deformability even when the absolute RBC count does not show a substantial decrease. Pretorius et al. [13] and Biswas et al. [14], demonstrated that cigarette exposure can be associated with structural and biochemical changes in erythrocytes. Consequently, relying solely on RBC concentration may underestimate the biological effects of tobacco exposure.

Smoking Intensity as a Potential Exposure Gradient

The distribution of cigarette consumption in the present study ranged from 3 to 10 cigarettes per day. This variation provides an opportunity to consider smoking frequency as an exposure gradient rather than treating all adolescent smokers as a homogeneous group. The statistically significant result suggests that the intensity of daily cigarette consumption may be relevant to variation in RBC measurements.

This interpretation is supported by experimental and observational evidence indicating that greater cigarette exposure can produce more pronounced biological effects. Biswas et al. [14], specifically reported graded erythrocyte alterations across different levels of smoking intensity. The biological basis for such a

gradient may involve cumulative exposure to CO, oxidants, particulate matter, and other toxic substances. Greater exposure could increase oxidative burden and place greater demands on endogenous antioxidant and compensatory mechanisms.

However, the present study cannot establish a definitive dose-response relationship. Daily cigarette consumption was based on self-reported smoking frequency, and the study did not quantify lifetime tobacco exposure, duration of smoking in pack-years, depth of inhalation, or exposure to other tobacco products. Moreover, all participants were smokers, meaning that the study does not include a nonsmoking comparison group. Therefore, the findings should be interpreted as evidence of an association between variation in smoking frequency among adolescent smokers rather than proof of a graded causal effect of smoking on RBC parameters.

Relevance of Adolescent Smoking to Early Hematological Health

The findings have particular relevance because the participants were adolescents rather than adults with prolonged smoking histories. Previous research has established that adolescence is a critical period for the development of nicotine dependence and persistent tobacco use [9][11]. Early exposure may therefore represent the beginning of a longer period of cumulative tobacco exposure. Detecting measurable differences in hematological parameters at this stage may indicate that biological effects of smoking can emerge relatively early in the smoking trajectory.

The local preliminary observations conducted in Lekobalo Village further strengthen the public health relevance of these findings. The initial interviews indicated that adolescent smokers commonly consumed 3–10 cigarettes per day, with several reporting more than one year of smoking. Some adolescents also reported fatigue, dizziness, and pale appearance, although these symptoms cannot be attributed specifically to smoking on the basis of the present study. Nevertheless, the combination of early smoking initiation, continued cigarette consumption, and limited awareness of potential systemic consequences highlights the importance of early prevention and health screening.

From a public health perspective, interventions targeting adolescent smokers should therefore not focus exclusively on respiratory consequences. Communicating the potential cardiovascular and hematological consequences of tobacco exposure may provide an additional strategy for increasing adolescents' awareness of the immediate biological consequences of smoking. Community-based education, smoking cessation counseling, and appropriate health screening may be particularly relevant in settings where adolescent smoking is common.

Comparison With Previous Evidence

The present findings broadly support previous evidence that cigarette smoking is associated with measurable hematological changes. Pedersen et al. [16], identified associations between smoking and increased RBC and white blood cell counts, while Mohammed Hussein et al. [17], reported differences in hematological parameters between smokers and nonsmokers. These studies

suggest that tobacco exposure can influence both erythrocyte-related parameters and broader systemic inflammatory processes.

At the cellular level, the findings are also compatible with research demonstrating cigarette-associated erythrocyte membrane alterations [13] and oxidative damage [15]. Furthermore, Biswas et al. [14], provides recent evidence that smoking intensity may influence the degree of erythrocyte biochemical and morphological alterations. Collectively, these studies support a multifactorial model in which cigarette smoking affects erythrocytes through interacting pathways involving CO-mediated hypoxia, oxidative stress, inflammation, and compensatory hematopoietic responses.

Nevertheless, the present study differs from much of the existing literature because it specifically examines active adolescent smokers within a community setting. Most previous hematological investigations have involved adults, experimental animals, blood donors, or broader populations. Consequently, the current findings contribute preliminary community-level evidence regarding the relationship between smoking intensity and RBC parameters during adolescence.

Clinical and Public Health Implications

The observed association between smoking frequency and RBC examination results has several implications. First, it suggests that adolescent smoking should be regarded as a behavior with potential systemic biological consequences rather than merely a future risk factor for chronic disease. Second, the findings support the value of early health education emphasizing that tobacco exposure can affect blood physiology and oxygen transport. Third, community-level screening and counseling may help identify adolescents who require smoking cessation support and further health assessment.

However, laboratory screening should not be interpreted in isolation. RBC concentration is only one component of hematological health, and smoking-related alterations may occur in hemoglobin, hematocrit, erythrocyte indices, leukocyte counts, platelet parameters, oxidative stress markers, and erythrocyte morphology. A more comprehensive hematological assessment would therefore provide a clearer characterization of the biological effects of adolescent smoking.

Strengths and Limitations

This study has several strengths. It focuses on an understudied population of adolescent smokers in a community setting and combines behavioral information on cigarette consumption with laboratory-based RBC measurements. The inclusion of participants with different levels of daily cigarette consumption also allows preliminary assessment of whether variation in smoking intensity corresponds to variation in RBC parameters.

Several limitations should nevertheless be considered. First, the cross-sectional design prevents determination of temporal sequence and causality. Second, the sample size was relatively small, comprising only 30 participants from a single village, which limits statistical power and generalizability. Third, smoking exposure was based on self-reported daily cigarette consumption and was not validated using

biochemical measures such as cotinine or carboxyhemoglobin. Fourth, potentially important confounding factors—including nutritional status, anemia history, physical activity, passive smoke exposure, duration of smoking, alcohol or other substance exposure, and underlying health conditions—were not comprehensively controlled. Finally, the study assessed RBC concentration but did not directly evaluate hemoglobin, hematocrit, erythrocyte indices, oxidative stress biomarkers, or erythrocyte morphology.

These limitations indicate that the present findings should be interpreted as preliminary evidence of an association rather than definitive evidence that cigarette smoking causes changes in RBC concentrations. Future research should use larger multicenter samples, include nonsmoking controls, quantify cumulative smoking exposure, incorporate objective biomarkers of tobacco exposure, and apply multivariable statistical models to control for potential confounders.

CONCLUSION

This study demonstrates that cigarette smoking frequency is significantly associated with red blood cell values among active adolescent smokers in Lekobalo Village, Kota Barat District. Differences in the number of cigarettes consumed per day were accompanied by variation in RBC examination results, indicating that smoking intensity may be related to hematological changes even during adolescence. The findings are biologically plausible considering the potential effects of cigarette smoke exposure on oxygen transport, oxidative balance, and erythrocyte physiology. However, the observed association should not be interpreted as definitive evidence of a causal effect because the study used a cross-sectional design, involved a relatively small sample from a single community, and did not comprehensively control for potential confounding factors. Future research should involve larger and more diverse adolescent populations, include nonsmoking comparison groups, objectively assess tobacco exposure, and examine additional hematological and oxidative stress parameters. At the community level, strengthening adolescent smoking-prevention programs, smoking cessation counseling, health education on the hematological consequences of tobacco exposure, and appropriate health screening is recommended to support early identification and reduction of the potential biological effects of smoking.

REFERENCES

[1] A. J. Jacques-Tiura and X. Chen, “Health and Smoking,” in *The Wiley Blackwell Encyclopedia of Health, Illness, Behavior, and Society*, Wayne State University School of Medicine, United States: wiley, 2014, pp. 1–6. doi: 10.1002/9781118410868.wbehibs359.

[2] J. Wang, Y. Wang, W. Zhou, Y. Huang, and J. Yang, “Impacts of cigarette smoking on blood circulation: do we need a new approach to blood donor selection?,” *J. Heal. Popul. Nutr.*, vol. 42, no. 1, 2023, doi: 10.1186/s41043-023-00405-2.

[3] R. E. Boehm *et al.*, “Cigarette smoking and antioxidant defences in packed red blood cells prior to storage,” *Blood Transfus.*, vol. 18, no. 1, pp. 40–48, 2020, doi: 10.2450/2019.0166-19.

[4] A. J. Burgara-Estrella *et al.*,

"Atomic force microscopy and Raman spectra profile of blood components associated with exposure to cigarette smoking," *RSC Adv.*, vol. 10, no. 20, pp. 11971–11981, 2020, doi: 10.1039/d0ra01384f.

[5] P. Pannuru, D. R. Vaddi, R. R. Kindinti, and N. Varadacharyulu, "Increased erythrocyte antioxidant status protects against smoking induced hemolysis in moderate smokers," *Hum. Exp. Toxicol.*, vol. 30, no. 10, pp. 1475–1481, 2011, doi: 10.1177/0960327110396527.

[6] R. Boehm *et al.*, "Toxic elements in packed red blood cells from smoker donors: a risk for paediatric transfusion?," *Vox Sang.*, vol. 114, no. 8, pp. 808–815, 2019, doi: 10.1111/vox.12854.

[7] I. N. Defoe, J. S. Dubas, L. H. Somerville, P. Lugtig, and M. A. G. van Aken, "The unique roles of intrapersonal and social factors in adolescent smoking development," *Dev. Psychol.*, vol. 52, no. 12, pp. 2044–2056, 2016, doi: 10.1037/dev0000198.

[8] L. D. Makadia, P. J. Roper, J. O. Andrews, and M. S. Tingen, "Tobacco Use and Smoke Exposure in Children: New Trends, Harm, and Strategies to Improve Health Outcomes," *Curr. Allergy Asthma Rep.*, vol. 17, no. 8, 2017, doi: 10.1007/s11882-017-0723-0.

[9] S. Altwicker-Hámori *et al.*, "Risk factors for smoking in adolescence: evidence from a cross-sectional survey in Switzerland," *BMC Public Health*, vol. 24, no. 1, 2024, doi: 10.1186/s12889-024-18695-4.

[10] G. H. Tee and G. Kaur, "Correlates of current smoking among Malaysian secondary school children.," *Asia. Pac. J. Public Health*, vol. 26, no. 5 Suppl, pp. 70S-80S, 2014, doi: 10.1177/1010539514540468.

[11] A. Amialchuk and O. Sapci, "The long-term health effects of initiating smoking in adolescence: Evidence from a national longitudinal survey," *Heal. Econ. (United Kingdom)*, vol. 31, no. 4, pp. 597–613, 2022, doi: 10.1002/hec.4469.

[12] S. K. Hee, Y. G. Tae, W. L. Hee, K. Lee, and M. H. Young, "Effects of smoking on the pulse wave velocity and ankle brachial index in adolescents," *Korean Circ. J.*, vol. 37, no. 9, pp. 414–418, 2007, doi: 10.4070/kcj.2007.37.9.414.

[13] E. Pretorius, J. N. Du Plooy, P. Soma, I. Keyser, and A. V Buys, "Smoking and fluidity of erythrocyte membranes: A high resolution scanning electron and atomic force microscopy investigation," *Nitric Oxide - Biol. Chem.*, vol. 35, pp. 42–46, 2013, doi: 10.1016/j.niox.2013.08.003.

[14] P. Biswas, J. Sikdar, S. Dey, B. Basak, S. K. Paul, and R. Haldar, "Unveiling the Influence of the Graded Impact of Cigarette Smoking Intensity on the Biochemical and Morphological Alterations of Erythrocytes," *Cell Biochem. Biophys.*, vol. 84, no. 1, pp. 1407–1417, 2026, doi: 10.1007/s12013-025-01958-1.

[15] S. Hossain *et al.*, "Acute cigarette smoke exposure induces oxidative damage and inflammation in Wistar rats: impact on lungs and erythrocytes," *African J. Biol. Sci. (South Africa)*, vol. 3, no. 1, pp. 120–128, 2021, doi: 10.33472/AFJBS.3.1.2021.120-128.

[16] K. M. Pedersen, Y. Çolak, C. Ellervik, H. C. Hasselbalch, S. E. Bojesen, and B. G. Nordestgaard, "Smoking and Increased White and Red Blood Cells: A Mendelian Randomization Approach in the Copenhagen General Population

Study," *Arterioscler. Thromb. Vasc. Biol.*, vol. 39, no. 5, pp. 965–977, 2019, doi: 10.1161/ATVBAHA.118.312338.

[17] S. Mohammed Hussein, H. Hasan Aziz, W. Hameed Abed, and K. Fadhil Kadhim, "Comparative study of hematological parameters among smokers and nonsmokers in Basra city, Iraq," *Hum. Pathol. Reports*, vol. 38, 2024, doi: 10.1016/j.hpr.2024.300762.