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LIFESTYLE FACTORS AND SYSTEMIC INFLAMMATION AMONG WORKERS: AN ANALYSIS OF THE NEUTROPHIL–LYMPHOCYTE RATIO

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ABSTRACT

Low-grade systemic inflammation is an important determinant of chronic disease risk and long-term workers' health outcomes. The neutrophil-to-lymphocyte ratio (NLR) is a simple and cost-effective haematological biomarker that reflects systemic inflammatory status and may be influenced by modifiable lifestyle factors. This study examined the association between smoking behaviour, physical activity, and systemic inflammation among mining workers. A cross-sectional analytical study was conducted using periodic medical check-up data from 567 bauxite mining workers in Indonesia collected between June 2023 and January 2024. Multiple linear regression analysis was performed while controlling for age, body mass index (BMI), and length of employment to minimise potential confounding effects. The regression model was statistically significant ($p < 0.001$; Adjusted $R^2 = 0.190$), indicating that the included variables explained a meaningful proportion of variance in NLR. Physical activity showed a significant negative association with NLR ($\beta = -0.366$; $p < 0.001$), whereas smoking behaviour ($\beta = 0.202$; $p < 0.001$) and age ($\beta = 0.115$; $p = 0.003$) were positively associated with systemic inflammation. BMI and years of service were not significant predictors in the final model. These findings suggest that lifestyle factors, particularly physical activity and smoking, play an important role in systemic inflammation among mining workers. Integrating targeted lifestyle interventions into occupational health programmes may help reduce inflammation-related health risks and improve long-term workforce sustainability.

KEYWORDS: Industrial Hygiene, Mining Workers, Neutrophil-To-Lymphocyte Ratio, Occupational Health, Physical Activity, Smoking Behaviour, Systemic Inflammation.

1. INTRODUCTION

Systemic inflammation of low-grade, which is chronic, is a critical biological process involved in the etiology of numerous chronic diseases, such as cardiovascular diseases, metabolic dysfunctions, or work-related pulmonary or cardiometabolic diseases (Xia et al., 2023). The inflammation-based biomarkers based on the results of regular haematological tests are becoming more and more used in the context of occupational health epidemiology as they are feasible, cost-effective, and sensitive to physiological and lifestyle-related alterations (Rezaei et al., 2024). One of them is the neutrophil-to-lymphocyte ratio (NLR), which indicates the ratio of innate and adaptive immune responses and is considered to be a steady and predictive marker of systemic inflammation preceding a wide range of undesirable health outcomes (Carollo et al., 2025).

Lifestyle determinants are significant factors of systemic inflammation (Ebrahimi et al., 2024). It is also known that cigarette smoking can cause chronic inflammation by inducing an amplification of oxidative stress and an increase in the production of pro-inflammatory cytokines, which eventually results in a significant number of neutrophils and the decrease in the percentage of circulating lymphocytes (Addissouky et al., 2024). A number of epidemiological studies have repeatedly shown that the neutrophil-to-lymphocyte ratio (NLR) was higher in smokers than in non-smokers, which shows a persistent systemic inflammatory activation due to tobacco smoke exposure (Komiyama & Ozaki, 2021). In contrast, physical exercise has the protective influence on systemic inflammation (Fink et al., 2023). Regular exercise could reduce chronic low-grade inflammation by a number of biological processes, such as decreased adipose tissue mass, increased insulin sensitivity, better endothelial activity, and even immune responses (Dawod, 2025). The population-based analysis has shown that high physically active people are less likely to have high neutrophil-to-lymphocyte ratio (NLR) values in contrast to people with a sedentary lifestyle (Guo et al., 2024).

Besides the lifestyle factors, other individual factors that can affect systemic inflammation and should be considered as the possible confounding variables include age, body mass index (BMI), and length of employment (Tejada et al., 2022). The phenomenon of inflammaging is related to advancing age that is characterized by a condition of chronic low-grade inflammation that increases with age (Saavedra et al., 2023). An increased BMI, especially one that is associated with visceral adiposity, is also connected with the greater production of pro-inflammatory cytokines (Moghbeli et al., 2021). In the meantime, length of employment could be a cumulative long-term exposure to occupational exposures, and may potentially mediate the inflammatory responses (Straumfors et al., 2025).

Within the framework of occupational health, the mining industry is a population that may be at risk of developing systemic inflammation because of a set of hazard factors, one of which is exposure to mineral dust, and another one is heavy physical work, unhealthy smoking behaviour, and lack of exercise. The systemic inflammation in workers is not only linked to the high risk of developing chronic diseases but can also impact negatively the capacity to work, the level of fatigue, and occupational safety (Zhang et al., 2024). In line with this, the need to monitor inflammatory biomarkers is a vital section of industrial hygiene in place and occupational health programmes in mining settings especially as an attempt to prevent occupational diseases and non-communicable diseases in workers.

In as much as the association between lifestyle determinants and inflammation has been widely studied in the general population, there has been little evidence regarding mining workers, particularly in the developing countries. There is a dearth of studies that specifically investigate the impact of smoking behaviour and physical activity in respect of systemic inflammation in haematological biomarkers like neutrophil-to-lymphocyte ratio (NLR) in relation to Indonesian mining workers populations.

It is on this basis that the current study focused on investigating the relationship between lifestyle variables, especially smoking behaviour and physical activity, with systemic inflammation as neutrophil-to-lymphocyte ratio (NLR), adjusted by the variables of age, body mass index (BMI), and length of employment. The research was carried out with references to the mining employees who worked at the bauxite mining company located in West Kalimantan, Indonesia. The analysis was included in the use of periodic medical check-up (MCU) to help in the implementation of industrial hygiene practice and the biomarker-based occupational health programmes in the Indonesian mining industry.

2. METHODS

2.1. Study Design and Setting

In this research, the analytical observational design was used in the form of a cross-sectional design based on secondary data, which were the

Recapitulation of Periodic Medical Check-Up (MCU) Results gathered between June 2023 and 3 January 2024. The target population was the mining workers of a mining company located in West Kalimantan, Indonesia. The information was received with the employees of the company that was located in West Kalimantan.

The firm has an open-pit mining system in the bauxite extraction which includes land clearing, excavation, loading of the material, hauling and preliminary process of the extracted ore. Such operational traits encompass diverse job activities with different degree of physical working load, exposure to respirable mineral dust, noise, vibration among other occupational environmental exposures.

All these work-related exposures, together with life style aspects of workers, might contribute to physiological health and systemic inflammatory reactions. The employment of medical check-up (MCU) data in the study is a part of the application of an industrial hygiene programme and biomarker-based occupational health surveillance. This is done to help in detecting early health disability as well as in assisting preventive measures on occupational illnesses and non-communicable illnesses among the mining workers.

The Health Research Ethics Committee of Dr. Moewardi Regional General Hospital, Surakarta granted ethical approval for this study (Approval No. 147/II/HREC/2026). Although the medical check-up data were collected between June 2023 and January 2024, formal ethical approval for the secondary data analysis was obtained in 2026 prior to manuscript submission. All data analysed in this study were fully de-identified to ensure the confidentiality of the workers' identities.

2.2. *Population and Sample*

The study population comprised all employees who underwent periodic medical examinations (medical check-ups, MCU) at a mining company during the study period. The dataset included 567 workers who participated in the MCU between June 2023 and January 2024. A total sampling technique was employed, whereby all MCU records meeting the study criteria were included as the study sample. The inclusion criteria consisted of active employees who underwent the MCU during the study period, had complete haematological examination data, and possessed available information on body mass index (BMI), age, length of employment, smoking behaviour, and physical activity. The exclusion criteria comprised incomplete MCU records and workers with indications of acute infection based on the medical documentation obtained during the MCU.

2.3. *Study Variables*

The dependent variable in this study was the neutrophil-to-lymphocyte ratio (NLR) as an indicator of systemic inflammation. The NLR value was calculated as the ratio of the absolute neutrophil count to the absolute lymphocyte count based on routine haematological test results obtained from the periodic medical examinations. Mathematically, NLR was derived by dividing the neutrophil count by the lymphocyte count (NLR = neutrophils/lymphocytes). NLR was utilised as a biomarker of systemic inflammation because it reflects the balance between innate and adaptive immune responses. It has been widely applied in epidemiological and occupational health research as a sensitive indicator of chronic low-grade inflammation associated with physiological changes and lifestyle-related factors.

The primary independent variables were lifestyle factors, specifically smoking behaviour and physical activity. Both variables were obtained from periodic medical examination records and the company's occupational health questionnaire. Smoking behaviour were measured based on the number of cigarettes consumed per day, as self-reported by the workers at the time of the medical check-up. This variable was analysed as an indicator of daily tobacco exposure intensity. Physical activity was assessed based on the frequency of exercise per week, as reported in the company's occupational health questionnaire. Respondents were asked to report the number of days per week during which they engaged in structured exercise or physical activity. This variable was used to reflect the workers' routine physical activity level as part of their lifestyle behaviour.

Covariates included in the analytical model were age (years), body mass index (BMI, kg/m^2), and length of employment (years). These variables were selected as potential confounders because epidemiological and occupational health literature has consistently demonstrated their association with systemic inflammation.

2.4. *Data Collection Procedure*

The information used in the studies was in the form of medical records of the periodic occupational health examination (medical check-ups/MCUs) conducted by the occupational health unit of the company. Haematological studies were conducted in one of the clinical laboratories that the company is

affiliated with and the studies were conducted in good compliance with the observed laboratory standard operating procedures to ascertain the validity and reliability of the test outcome. The neutrophil-lymphocyte ratio (NLR) was calculated by the use of neutrophil and lymphocyte counts based on regular blood tests.

The information about the lifestyle, such as smoking behaviour, and physical activity was gathered using a health questionnaire filled out by workers during the MCU. Covariates (age and length of service) were sourced using the personnel administrative records, whereas BMI was computed using the measured body weight and height during health examination. All data were gathered through the occupational health surveillance programme by the company and the introduction of industrial hygiene practices into the mining activity.

2.5. Statistical Analysis

The relationships between lifestyle and systemic inflammation, as indicated by neutrophil-to-lymphocyte ratio (NLR), were performed through statistical analyses, which entailed multiple linear regression. The descriptive statistics were used to start analysing the results by defining the study participants in terms of age, body mass index (BMI), length of employment, smoking behaviour, physical activity, and NLR values.

Before multiple linear regression was conducted, the model was examined on the conformance with classical assumptions. Normality test and visual examination of the distribution of the residuals were used to examine the normality of the residual values. The tolerance values and the Variance Inflation Factor (VIF) were used to assess multicollinearity. Heteroscedasticity was tested by assessing a scatterplot of standardised residuals against standardised predicted values visually to determine that the assumption of homoscedasticity was met.

After that, multiple linear regression analysis has been conducted to establish the relations of smoking behaviour and physical activity (independent variables) on NLR and controlling age, BMI and length of employment as covariates. Statistical significance was reported by the use of regression coefficients, 95% confidence and p-value, with a cut-off point of $p < 0.05$. IBM SPSS Statistics was used to do all statistical analyses.

3. RESULTS

3.1. Respondent Characteristics

A total of 567 workers were included in the analysis. The mean age of the respondents was 37.86 ± 10.40 years, with a mean length of employment of 6.75 ± 3.23 years. The mean body mass index (BMI) was 25.73 ± 4.25 kg/m². The mean neutrophil-to-lymphocyte ratio (NLR), used as an indicator of systemic inflammation, was 1.63 ± 0.50. The average number of cigarettes smoked was 7.82 ± 6.84 per day, while the mean frequency of physical activity was 1.83 ± 1.28 sessions per week. Detailed descriptive statistics are presented in Table 1.

Table 1: Descriptive Statistics of Study Variables (n = 567).

Variable	Minimum	Maximum	Mean	SD
Smoking behaviour (cigarettes per day)	0	20	7.82	6.84
Physical activity (times per week)	0	4	1.83	1.28
Neutrophil-to-lymphocyte ratio (%)	0.30	3.29	1.63	0.50
Age (years)	20	56	37.86	10.40
Body mass index (kg/m²)	18.04	33.00	25.73	4.25
Length of employment (years)	1.0	12.0	6.75	3.23

3.2. Findings of Classical Assumption Tests of Multiple Linear Regression

The normality test of the residues revealed that the residuals were normally distributed as the Kolmogorov-Smirnoff test ($p = 0.200$) and the Shapiro-Wilk test ($p = 0.448$) showed the same. The results of the multicollinearity test revealed that there were no significant intercorrelations of the independent variables, as the Tolerance values were between 0.992 and 0.999 and Variance Inflation Factor (VIF) values had the range of 1.001 to 1.008. These results attest to the fact that the assumption of no multicollinearity was met. When the scatterplot between standardised predicted values and standardised residuals was inspected, the pattern of distribution was very random and no specific structure could be identified, which implied that there was no heteroscedasticity, and thus, it confirmed that the assumption of homoscedasticity was satisfied (Figure 1).

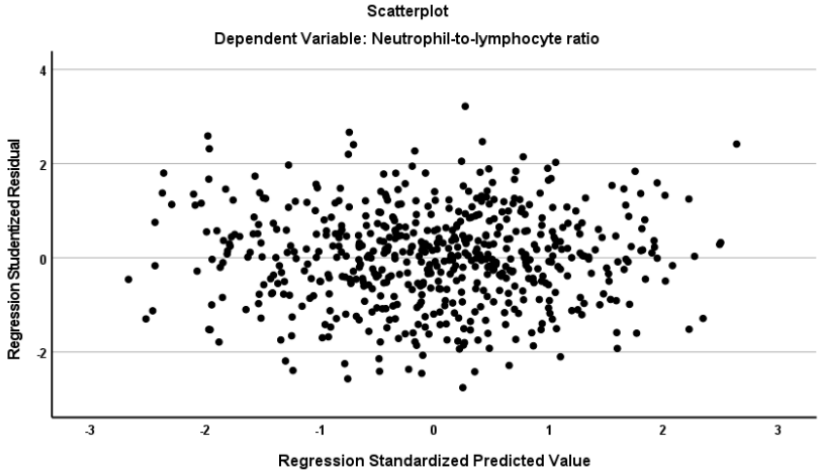

Figure 1: Scatterplot of the heteroscedasticity test for the regression model.

3.3. Regression Model

The result of a multiple linear regression analysis indicated that the general model was statistically significant in the prediction of NLR ($F(5, 561) = 27.63$, $p < 0.001$). The determination coefficient (R^2) was 0.198, and adjusted R^2 was 0.190, which shows that the covariates of the age, BMI, and length of employment explained about 19 percent variance of NLR.

3.4. Results of the Multiple Linear Regression Analysis

The multiple linear regression analysis demonstrated that physical activity exerted the strongest protective effect against systemic inflammation, as indicated by a significant negative association with the neutrophil-to-lymphocyte ratio (NLR) ($B = -0.142$; $\beta = -0.366$; $p < 0.001$). Smoking behaviour was positively and significantly associated with NLR ($B = 0.015$; $\beta = 0.202$; $p < 0.001$), followed by age, which also showed a positive and statistically significant association ($B = 0.006$; $\beta = 0.115$; $p = 0.003$). In contrast, body mass index (BMI) ($B = 0.008$; $\beta = 0.067$; $p = 0.077$) and length of employment ($B = 0.005$; $\beta = 0.032$; $p = 0.397$) were not significantly associated with NLR. Based on the standardised beta coefficients, the relative contribution of the independent variables to NLR was ranked as follows: physical activity > smoking behaviour > age, whereas BMI and years of service contributed minimally to the variability in NLR. The complete results of the multiple linear regression analysis are presented in Table II.

Table 2: Multiple Linear Regression Results for the Neutrophil-to-Lymphocyte Ratio (NLR).

Variable	B	Std. Error	Beta	t	p
Constant	1.333	0.139	–	9.606	<0.001
Smoking habit	0.015	0.003	0.202	5.329	<0.001
Physical activity	-0.142	0.015	-0.366	-9.672	<0.001
Age	0.006	0.002	0.115	3.037	0.003
Body Mass Index (BMI)	0.008	0.004	0.067	1.772	0.077
Length of employment	0.005	0.006	0.032	0.847	0.397

4. DISCUSSION

This study suggests that the association between physical activity and systemic inflammation was negative and significant which shows the largest protective effect toward neutrophil-to-lymphocyte ratio (NLR). To the contrary, NLR had a positive and significant relation with smoking behaviour and age, which means that the higher the number of cigarettes smoked, and the older the individual, the higher the systemic inflammation. In the meantime, there was no statistically significant association between body mass index (BMI) and length of employment and NLR. These results highlight the fact that lifestyle variables, especially exercise and smoking, are the main causes of systemic inflammation in workers in mines. These determinants could affect the ability to work, long-term health, and the possibility of chronic illness.

4.1. Physical activity and NLR Effect

The findings show that the physical activity is

negatively and significantly correlated with NLR (B = -0.142; β = -0.366; p < 0.001) which proves that it is a protective factor against systemic inflammation. This observation is in line with the prior body of research that suggests that moderate and vigorous physical exercise suppresses low-grade chronic inflammation by means such as adipose tissue reduction, insulin sensitivity, and immune response modulation (Collao et al., 2020; Gromkowski et al., 2025; Pahomov et al., 2024). Regular physical activity in the context of mining workers can also improve physiological responses to physical workload and environmental exposures and, therefore, dampen the basal inflammatory responses.

4.2. The Effect of Smoking on NLR

The association between smoking behaviour and NLR was positive and significant (B = 0.015; β = 0.202; p < 0.001), which suggests that smoking of cigarettes is still a strong predictor of systemic inflammation even with other covariates being controlled. Such results correlate with epidemiological data in occupational groups and the entire population that has shown high neutrophil counts and a high NLR in smokers, which can be explained by oxidative stress and the stimulation of pro-inflammatory cytokines (IL-6, TNF-α) (Delgado et al., 2021; Liu et al., 2023; Strzelak et al., 2018). This observation highlights the relevance of occupational health programs, especially workplace smoking policies, and health promotion programs to minimize tobacco exposure in mining workers.

4.3. The Effect of Age on NLR

The age was also positively and significantly correlated with NLR (B = 0.006; β = 0.115; p = 0.003), which proves the idea of inflammaging, i.e., the gradual growth of systemic inflammation with age (Meier et al., 2023; Piber et al., 2019). Even though in the current research the role of age was less than those of physical activity and smoking, this fact shows that older employees are still under threat of high basal inflammation that can be combined with work-related exposures in the mining industry.

4.4. Non-Significant Results: BMI and Length of Employment

It was only BMI (B = 0.008; p = 0.077) and length of employment (B = 0.005; p = 0.397) that had no statistically significant association with NLR. This can be explained by the fairly moderate range of BMI in the sample, with most of the workers having physically demanding jobs, which would potentially nullify the impact of adiposity on the basal inflammatory status (Liqiang et al., 2023). Moreover, the length of employment was relatively short (mean 6.75 ± 3.23 years), and this might have been insufficient to cause cumulative exposure that could cause serious systemic inflammation. Such results are in line with various studies in the industrial context that occupational exposure needs to reach a particular threshold on the duration to cause a quantifiable effect on inflammatory biomarkers (Faruque et al., 2021).

4.5. Occupational Health and Industrial Hygiene Implications

Results in this research have significant implications on industrial hygiene practice in the mining industry. Such approach as intercession of inflammatory biomarkers such as neutrophil-to-lymphocyte ratio (NLR) can be used as a proactive measure to evaluate the health risk of the workers and to determine the efficiency of the lifestyle-based intervention programmes. The intervention plans, with the promotion of physical activity and managing smoking behaviour as the primary goals, could help to decrease systemic inflammation and, at the same time, increase the working capacity, the safety of the occupation, and the overall health of the worker (Baay et al., 2025; Derella et al., 2021; González de Paz & Escalona, 2024; Silva et al., 2024).

4.6. Study Limitations

This research has a number of limitations. First, the cross-sectional design does not allow making a causal inference. Second, self-administered questionnaires were used to gather data on lifestyle; hence, it is impossible to rule out the possibility of information bias. Third, occupational exposures to specific agents, e.g., respirable dust, noise, and physical workload were not directly included in the analysis but some of their potential effects might have been partially addressed by the covariates of age and length of employment.

Despite these shortcomings, the results have shown that physical activity and smoking are the major predictors of systemic inflammation among the mining workers, and BMI and length of employment play a very small role. These findings are valuable empirical evidence of the existing global literature on the relationship between lifestyle factors and systemic inflammation, as well as the significance of lifestyle risk control as part of occupational health programmes.

5. CONCLUSION

The two factors of the systemic inflammation in

mining workers were identified as a physical activity and smoking behaviour, assessed in terms of neutrophil-to-lymphocyte ratio (NLR). Exercise activity provided some protection but smoking was positively related to high NLR values. The length of service and body mass index (BMI) had no significant relationship with systemic inflammation. The results demonstrate the relevance of lifestyle-based interventions in occupational health and industrial hygiene programmes to reduce systemic inflammation and improve the general wellbeing of workers. However, the cross-sectional study does not allow making a causal conclusion and should be followed up with longitudinal research.

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