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COMPARATIVE ANALYSIS OF HEMATOLOGICAL PARAMETERS BASED ON DEVELOPMENT TYPE USING COMPLETE BLOOD COUNT BIOMARKERS

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Abstract
The parameters of complete blood count (CBC) give valuable data on the leukocytes, erythrocytes, and platelets and are commonly used to assess physiological status. Nevertheless, there is limited literature on in-depth analyses of variation between various CBC biomarkers using the same dataset. This study analyzed variations in hematological biomarkers based on development type using complete blood count measurements and explored gender-related differences and correlations among hematological parameters. A cross-sectional analysis was conducted using a publicly available hematological dataset containing 300 observations. After preprocessing and data cleaning, 24 hematological parameters were analyzed. Descriptive statistics were summarized using median and interquartile range (IQR) due to skewed distributions. Independent sample t-tests were used to compare hematological parameters between development type groups and between gender groups, and Pearson correlation analysis examined relationships among biomarkers. Significant differences between development groups were identified in basophil percentage, hematocrit, platelet count, platelet distribution width, and platelet large cell ratio. Platelet-related parameters were higher in Development Type 2, while hematocrit was higher in Development Type 1. Gender-based analysis showed higher lymphocyte percentage in males and higher neutrophil percentage in females. Correlation analysis demonstrated a strong inverse relationship between lymphocyte and neutrophil percentages and additional associations among erythrocyte and platelet indices. These findings indicate that hematological variation between development groups is most evident in platelet-related biomarkers.

Keywords: *blood biomarkers, complete blood count, hematology, platelets, blood cells*

1. Introduction

One of the most commonly applied types of laboratory tests in clinical medicine and biomedical research is the complete blood count (CBC). It gives a quantitative value of the circulating blood constituents such as leukocytes, erythrocytes and platelets, which all indicate the immune status, oxygen transport capacity and hemostatic balance. Since CBC analysis is a relatively inexpensive, quick, and routine procedure, it is one of the basic instruments that can be used to evaluate physiological parameters and identify the initial signs of illness (Ware, 2020). CBC parameters have become invaluable in clinical diagnostics and in biomedical studies in the population at large due to their capacity to give detailed information on the processes happening in the organism. The parameters of CBC are also considered useful markers of immune and inflammatory activity. Differences in the leukocyte count and differential distributions have the capacity to show the hidden immune responses, infections, as well as inflammatory conditions. These hemoglobin indicators thus provide valuable information on physiological adaptations to the environmental and pathological stressors. Owing to this, CBC testing has become a common clinical practice to aid diagnostic assessment and patient care in various healthcare fields (Pabón-Rivera et al., 2023). Recent studies also demonstrated the importance of hematological parameters in comprehending the development of the disease and immune dysregulation. Evidence of changes in blood cell counts and leukocyte differentials has been documented in a variety of infectious diseases in which lymphocyte and neutrophil alterations can be indicators of the severity of immune damage and disease severity (Palladino, 2021). Similarly, CBC parameters have also been explored as possible biomarkers of clinical prognosis and disease progression in infectious diseases and their value as obtainable indicators of systemic physiological alterations (Zheng et al., 2020).

In addition to infectious diseases, hematological parameters based on CBC tests have been linked to a wide variety of chronic illnesses. It has been revealed that changes in the number of blood cells and inflammatory markers can be useful in the context of cardiovascular and metabolic conditions. The biomarkers can hence aid in risk identification and an earlier sign of disease-associated physiological changes (Seo and Lee, 2022). Specifically, leukocyte and platelet indices have been coupled to inflammatory processes in cardiovascular pathology. CBC parameters have been shown to be of clinical value in severe systemic conditions like sepsis. Leukocyte counts and platelet index changes may also be used as early warning signs of an infection and the severity of the disease, allowing clinicians to assess the prognosis and correct treatment (Agnello et al., 2021). The diagnostic and prognostic value of the CBC biomarkers in threatening diseases only stresses the necessity to comprehend variability in the hematological measurements. Besides disease-related applications, CBC biomarkers have been investigated as an indicator of inflammatory homeostasis and immune status in healthy populations. Hematological parameters like neutrophil-to-lymphocyte ratios and platelet-associated parameters have been suggested as convenient markers of overall inflammation and immune control (Fei et al., 2020). These indices bring out the complicated relationships among immune cells, erythrocytes, and platelets in ensuring physiological homeostasis.

Biological variation is also a factor which is significant in the interpretation of hematological information. Blood biomarkers may vary widely inter-individually in healthy people as a result of genetic influences, environmental influences, and physiological conditions. This knowledge of these variations is critical to determining consistent reference ranges and differentiating between normal biological variation and a clinical level abnormality (Aziz et al., 2019). Another significant part of CBC analysis is Red blood cell indices. Mean corpuscular volume, mean corpuscular hemoglobin and red cell distribution width are also very important parameters to give information on the morphology and functionality of erythrocytes. The measures can be found in the clinical hematology practice to diagnose various types of anemia and other hematology conditions (Doig and Zhang, 2017). erythrocyte and platelet indices have also been observed to change in chronic disease conditions. As an illustration, hematological changes have been detected in chronic kidney disease patients, with red blood cell index and the number of platelets sensitive to metabolic changes in chronic diseases and inflammatory reactions (Asaduzzaman et al., 2018). These results depict the usefulness of CBC biomarkers in revealing significant data regarding the physiological changes of the body in diseases. Moreover, hematological parameters might be affected by nutritional factors. The investigations of nutritional anemia have found that alterations of erythrocyte indices are correlated with the changes in the leukocyte and platelet counts, which means that nutritional status might influence more than a single aspect of hematological physiology (Senapati, 2017). These kinds of interactions depict the complicated biological correlation among various blood parameters. Even though a relatively small number of studies have examined changes in CBC biomarkers in particular disease conditions, comparatively fewer studies have examined the patterns of hematological variation in many blood parameters at once in large sets of data. The number of known studies is devoted to separating biomarkers or certain clinical states that can restrict the possibility of discovering more general correlations between hematological indices. This means, therefore, that detailed methods of analysis involving the simultaneous evaluation of various CBC parameters and examining their diversity in varying biological populations are still required. The objective of the current study was to examine changes in the hematological biomarkers as calculated by complete blood count and to compare the findings between the groups of development types through statistical analysis. Besides, the aim of the study was to investigate potential gender-specific differences in the hematological parameters and to test the correlations between various CBC biomarkers to gain a deeper insight into the patterns of hematological variability in the dataset.

2. Methodology

2.1 Study Design

This study used a cross-sectional analytical design, which aims to identify differences in hematological biomarkers among various groups of development types based on a publicly available hematological dataset. The study aimed at determining any statistical changes in complete blood count (CBC) parameters and finding out the relationships between hematological variables. A structured computational workflow was used to carry out all the analyses with an aim of having reproducibility and transparency of the analytical process.

2.2 Data Source

The data used in this research consists of a publicly available hematological dataset (Abdul-Jabbar and Farhan, 2022). The dataset has the complete blood count data of various hematological parameters such as leukocyte indices, erythrocyte indices, and platelet-related biomarkers. It involves laboratory values that are normally applied in clinical hematology like white blood cell count, lymphocyte percentage, neutrophil percentage, red blood cell index, platelet count and platelet parameters. The dataset is available publicly, and no personal information can be identified; thus, it did not need any further ethical approval to use it.

2.3 Dataset Variables

It was a dataset with 300 observations and comprised of demographic variables and hematological parameters calculated using complete blood count (CBC) measurements. The variables that were analyzed included white blood cell parameters (WBC, LYMp, MONp, NEUp, EOSp, BASOp, LYMn, MONn, NEUn, EOSn, BASOn), red blood cell parameters (RBC, HGB, HCT, MCV, MCH, MCHC, RDWSD, RDWCV), and platelet parameters (PLT, MPV, PDW, PCT, PLCR). In addition, two categorical variables, i.e., Gender and Development type (DevTyp), were included, with development type serving as the primary grouping variable for statistical comparisons.

2.4 Data Preprocessing

The statistical analysis was performed after data preprocessing to ensure the consistency and reliability of the data set. Variables that were not in numeric format were translated to numeric ones where necessary. Moreover, the variables of type of Gender and Development were considered as categorical variables to be analyzed. The identification variable used in the data was excluded, as it was not subjected to statistical analysis, as it lacked the information to be analyzed. The purpose of these preprocessing measures was to preserve data integrity and minimize possible biases due to the absence of values or irregularities in the format.

2.5 Statistical Analysis

As a method to describe the distribution of the hematological biomarkers, statistical analyses were performed to evaluate the possible differences among the development type groups. Since various hematological variables exhibited skewed distributions and extreme values, the central tendency has been summarized through median and interquartile range (IQR) instead of mean and standard deviation, which is a more powerful method of representing the central tendency in non-normally distributed data. Independent samples t-tests were used to assess differences in hematological biomarkers across the type of development to determine the significance of the mean value of one parameter in relation to the mean value of the other parameter. The statistical significance was set at p less than 0.05. Further comparisons have been done with the aim of finding out gender-based variations in the hematological parameters with independent sample t-tests. In order to test further relations between hematological biomarkers, Pearson correlation was used, and a correlation matrix generated was plotted with a heatmap to help interpret the relationship between the hematological indices.

2.6 Data Visualization

The distributions of hematological biomarkers were illustrated in graphical form, and the statistical findings were interpreted with the help of graphical representation. The correlation heatmap was created to show the association between the hematological parameters, and the violin plots were created to analyze the distributions of biomarkers that revealed statistically significant difference between the two types of development. These diagrams added more details to the statistical comparisons and assisted in demonstrating tendencies in the dataset.

3. Results

3.1 Distribution of Hematological Biomarkers

A total of 300 observations were included in the final analysis following data cleaning and preprocessing. The dataset comprised 24 hematological parameters derived from complete blood count measurements. As shown in Table 1, the median white blood cell (WBC) count was 7.39 (IQR: 5.59–10.27). Lymphocyte percentage (LYMp) had a median value of 30.70 (IQR: 21.67–39.45), while neutrophil percentage (NEUp) showed a median of 53.74 (IQR: 44.77–64.97). Platelet count (PLT) displayed substantial variability with a median value of 226.15 (IQR: 128.95–316.13). Among erythrocyte-related indices, the median hematocrit (HCT) was 33.40 (IQR: 27.80–39.90), while hemoglobin (HGB) demonstrated a median of 10.40 (IQR: 8.70–12.80). Platelet-related indices also exhibited notable dispersion, including platelet distribution width (PDW) with a median of 17.40 (IQR: 7.60–18.70) and platelet large cell ratio (PLCR) with a median of 41.65 (IQR: 30.78–48.95). Overall, these descriptive statistics highlight considerable heterogeneity across several hematological parameters within the study population.

Table 1. Distribution of hematological biomarkers in the study population (n = 300).

Variable	Median	Q1	Q3	IQR
WBC	7.39	5.59	10.27	4.68
LYM%	30.70	21.67	39.45	17.78
MON%	9.00	6.21	12.34	6.13
NEU%	53.74	44.77	64.97	20.20
EOS%	1.99	0.89	4.17	3.28
BASO%	0.30	0.18	0.48	0.30
RBC	4.24	3.60	4.87	1.27
HGB	10.40	8.70	12.80	4.10
HCT	33.40	27.80	39.90	12.10
MCV	84.50	78.20	91.60	13.40
MCH	26.70	22.48	29.00	6.52
MCHC	31.00	28.98	33.03	4.05
RDWSD	48.30	43.90	56.35	12.45
RDWCV	14.70	13.18	18.33	5.15
PLT	226.15	128.95	316.13	187.18
MPV	8.80	7.90	9.53	1.63
PDW	17.40	7.60	18.70	11.10
PCT	0.21	0.12	0.29	0.17
PLCR	41.65	30.78	48.95	18.17

3.2 Distribution of Development Types and Gender

Table 2 summarizes the categorical composition of the dataset. Out of the 300 observations, 178 people (59.33%) were under the gender category 0 and 122 people (40.67%) fell under gender group 1. In terms of type of development, there were 94 samples (31.33%) of Development Type 1 and 206 samples (68.67%) of Development Type 2. This distribution shows that the Development Type 2 was more often represented in the considered dataset.

Table 2. Distribution of categorical variables in the study population.

Variable	Category	Count	Percentage (%)
Gender	0	178	59.33
Gender	1	122	40.67
DevTyp	1	94	31.33
DevTyp	2	206	68.67

3.3 Comparison of Hematological Biomarkers by Development Type

In order to determine the differences that might be present among the types of development, the independent sample t-tests were applied to all hematological parameters. Table 3 provides a summary of the results of the comparisons. The statistically significant differences between type of development were found on five biomarkers ($p < 0.05$). They were percentage basophilia (BASOp), hematocrit (HCT), the number of platelets (PLT), platelet distribution width (PDW), and platelet large cell ratio (PLCR). Development Type 2 had much higher parameters related to the platelet than Development Type 1 had. Specifically, platelet count was significantly elevated in Development Type 2 (270.94 ± 180.28) compared with Development Type 1 (194.42 ± 116.28, $p < 0.001$). Similarly, PDW and PLCR were markedly higher in Development Type 2, suggesting greater variability and proportion of larger platelet cells in this group. Conversely, hematocrit values were significantly higher in Development Type 1 (35.01 ± 8.10) relative to Development Type 2 (32.22 ± 10.11, $p = 0.011$). The percentage of basophils also showed a modest but statistically significant increase in Development Type 2. These results show that platelet-related indices are the most striking hematological variations of the development groups.

Table 3. Significant hematological differences between development types.

Variable	DevTyp 1 Mean ± SD	DevTyp 2 Mean ± SD	p-value
PDW	8.546 ± 8.366	18.050 ± 1.589	<0.001
PLT	194.418 ± 116.279	270.941 ± 180.282	<0.001
PLCR	28.440 ± 16.597	46.055 ± 27.232	<0.001
HCT	35.013 ± 8.095	32.221 ± 10.110	0.011
BASOp	0.369 ± 0.184	0.538 ± 1.059	0.027

3.4 Gender-Based Differences in Hematological Parameters

Further comparisons were done in order to evaluate the possibility of differences in hematological markers based on gender. There were two parameters which showed significant differences statistically. The percentage of lymphocytes was also significantly greater in male participants (35.61 + 22.08) than in female participants (30.47 + 13.94) (p = 0.024). On the contrary, the percent of neutrophils was higher in females (57.10 ± 22.29), compared to males (48.08 ± 21.85) (p = 0.0006). The rest of the hematological parameters did not show statistically significant gender differences.

3.5 Correlation Structure of Hematological Biomarkers

Pearson correlation analysis was also used to study the relationships between the hematological biomarkers (Figure 1). There were a number of trends. There was a significant negative relationship between the lymphocyte percentage and the neutrophil percentage, as the two leukocyte populations have an opposite relationship. The erythrocyte indices were also moderately correlated with platelet-related parameters, and these results indicate that physiological connections exist between these two hematological elements.

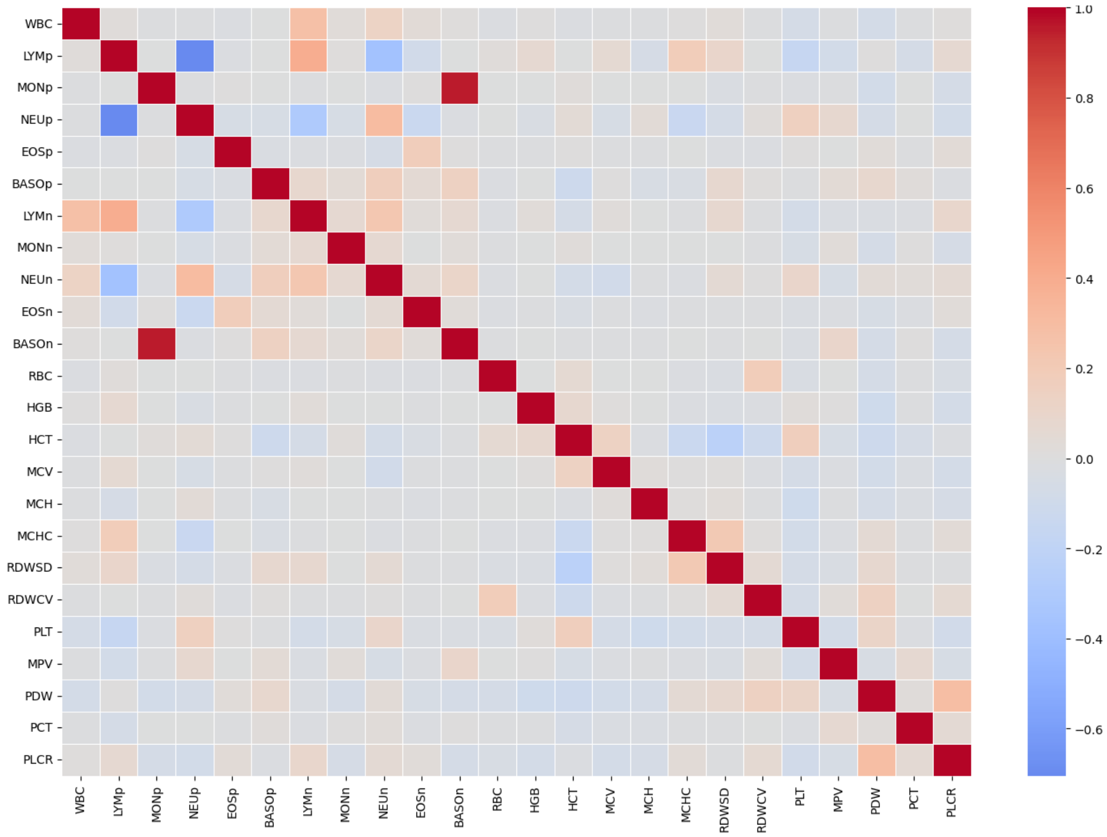

Figure 1. Correlation heatmap of hematological biomarkers.

3.6 Distribution of Significant Biomarkers Across Development Types

In order to further discuss those biomarkers that showed a significant difference between groups, the distributions of BASOp (Figure 2), HCT (Figure 3), PLT (Figure 4), PDW (Figure 5), and PLCR (Figure 6) were analyzed across the types of development. The distributions show the evident differences by groups.

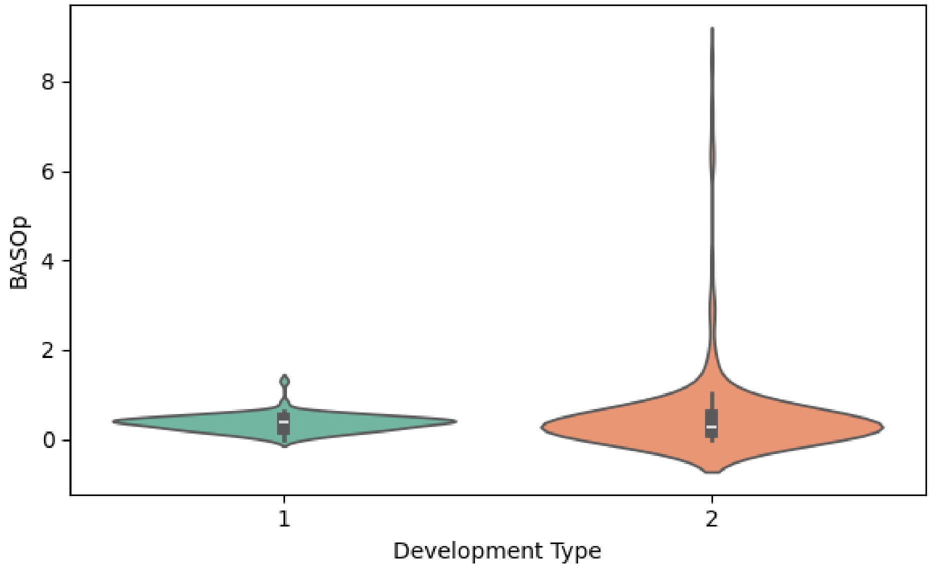

Figure 2. Distribution of basophil percentage (BASOp) by development type.

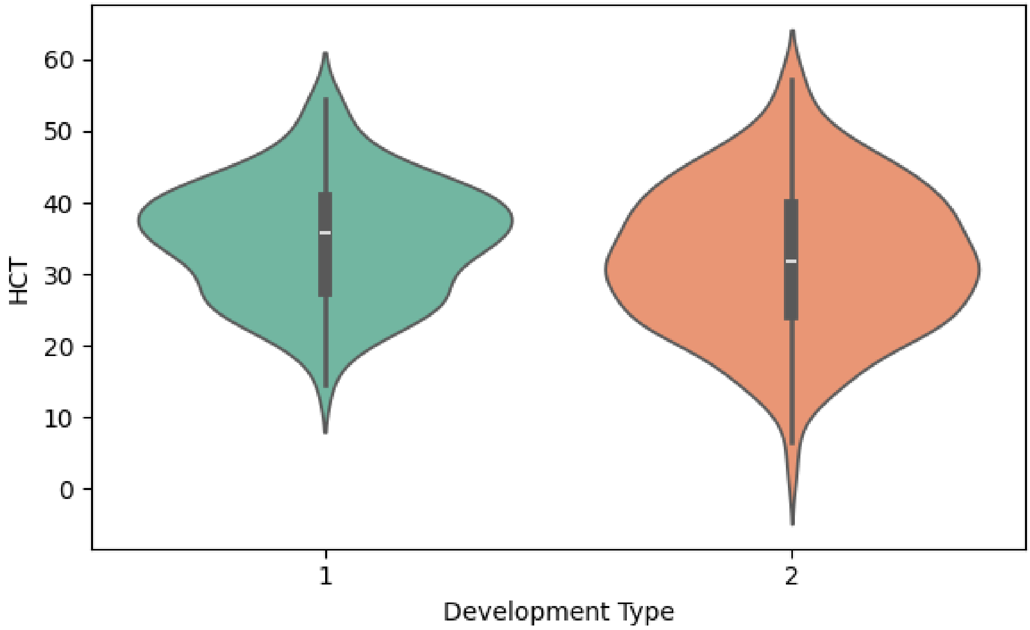

Figure 3. Distribution of hematocrit (HCT) by development type.

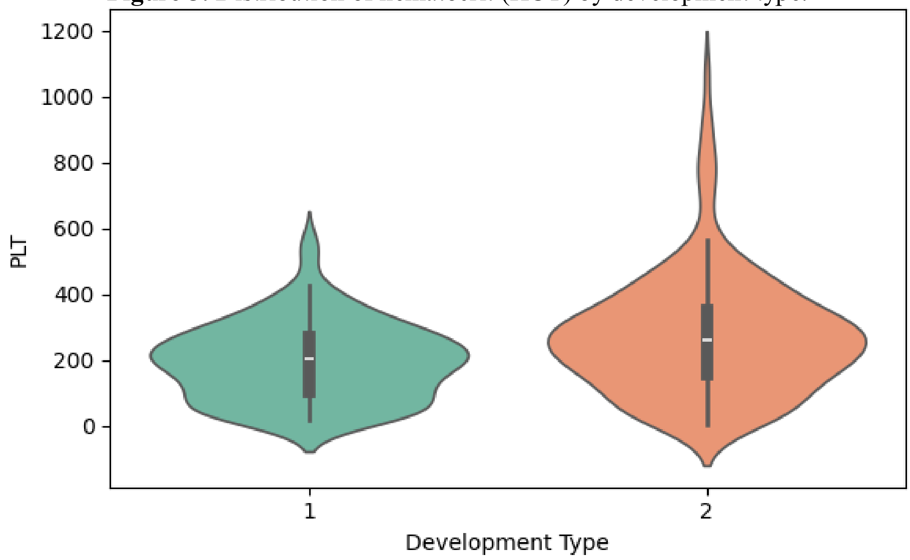

Figure 4. Distribution of platelet count (PLT) by development type.

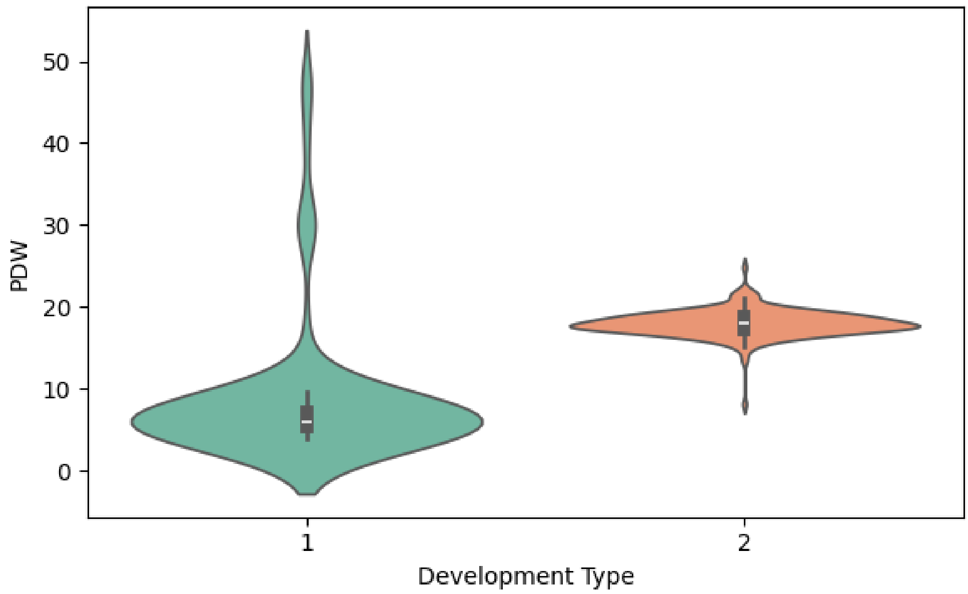

Figure 5. Distribution of platelet distribution width (PDW) by development type.

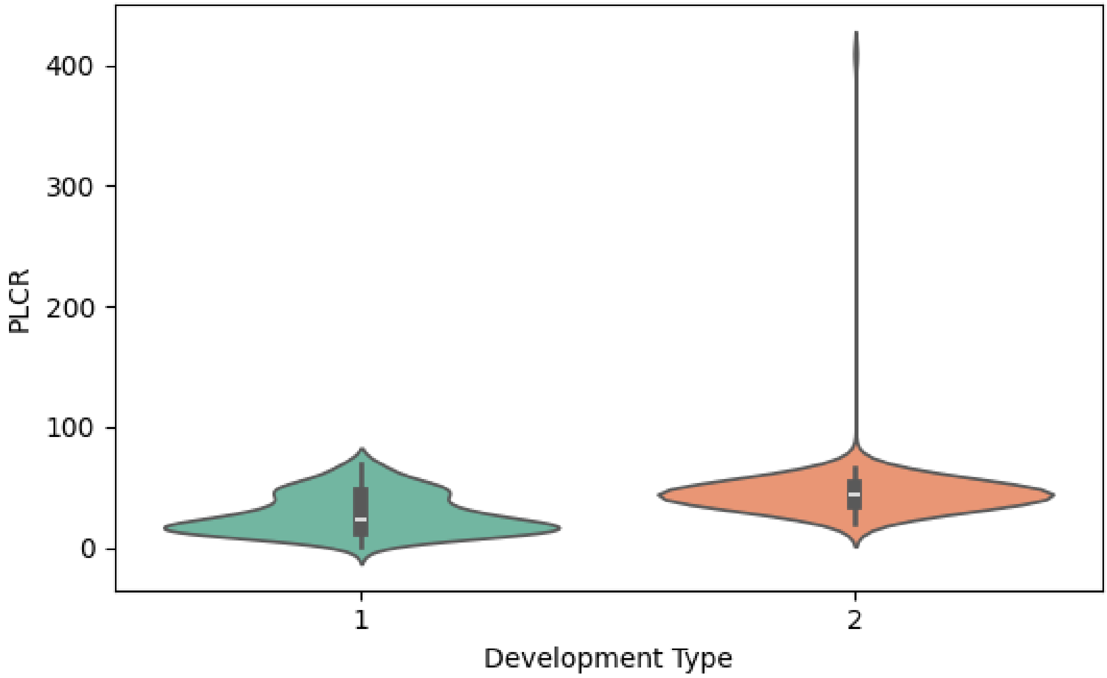

Figure 6. Distribution of platelet large cell ratio (PLCR) by development type.

The parameters related to platelets- PLT, PDW and PLCR- demonstrate significantly larger central tendencies, and the wider dispersion in Development Type 2. Conversely, the values of hematocrit are slightly higher in Development Type 1. Here, the basophil percentage is also more erratic in Development Type 2, just as in the statistical comparisons above. All of these graphical illustrations reinforce the statistical results and indicate platelet indices as a critical discriminative hematological variable between the development groups.

4. Discussion

The comparisons found a number of hematological variations in development groups, and the most prominent changes were in platelet-related variables. Development Type 2 had an increased count of platelets, distribution width, and platelet large cell ratio; Development Type 1 had a relatively higher value in hematocrit. The percentage of basophils also increased slightly in Development Type 2. Altogether, these results show that platelet-related indices are the most obvious hematological variations between the two groups. Platelets are implicated in not only hemostasis but also inflammatory and immune responses, and platelet indices changes can indicate platelet production, platelet activation or platelet turnover. The increased PDW and PLCR values in Development Type 2 might thus be taken as evidence of more variability in the platelet size and platelet activity. Conversely, the differences in erythrocyte mass or plasma volume control among the groups may be manifested by higher hematocrit values in the Development Type 1. Correlation analysis also indicated anticipated correlations between parameters of leukocytes, especially the negative correlation between lymphocyte percentage and neutrophil percentage. This kind of pattern indicates the physiological balance among leukocyte differentials. The correlations that were observed, in general, indicate that the hematological parameters do not work as independent markers but as interconnected biological systems.

Past studies have established that differences in hematological parameters are often linked to the inflammatory and general physiological mechanisms. Platelet index and leukocyte parameter changes have been reported with infectious diseases, including COVID-19, in which hematological changes have been correlated with disease progress and inflammatory reactions (Khalid et al., 2021). Other related results have been documented in metabolic disorders, where comparative analysis has indicated that diabetic patients with type 2 diabetes mellitus can record abnormalities in the level of leukocytes in the body and platelet indices with healthy subjects (Ebrahim et al., 2022). Similar hematological studies within inflammatory skin diseases have also demonstrated that immune biomarkers and blood cell parameters can vary across disease categories, indicating that hematological parameters can represent systemic immune control mechanisms (Bakic et al., 2023). Moreover, the platelet indices have been examined as the possible markers of thrombotic and inflammatory activities, which emphasizes the clinical importance of platelet-related biomarkers in vascular and inflammatory disorders (Jang et al., 2023). The previous literature has also highlighted that hematological parameters can differ in a large spectrum of clinical conditions and, thus, CBC biomarkers can reflect different physiological and pathologic conditions. The comparative studies conducted on various diseases have demonstrated that the trend of the leukocyte, erythrocyte and platelet parameters may vary depending on the respective biological condition (Gao et al., 2019). Likewise, there have been reports of studies on the inflammatory and periodontal conditions that have indicated alterations in CBC parameters relating to systemic inflammatory conditions (Luthra et al., 2019).

Studies that revolved around metabolic and chronic diseases have also shown positive relationships between hematological indices and the state of the diseases. As an illustration, comparative studies of type 2 diabetes have found that red blood cell, white blood cell, and platelet parameters differed between the populations compared to the healthy ones, which hints at the fact that CBC profiles can be objective expressions of metabolic and inflammatory changes (Essawi et al., 2023). Other literature reviews focusing on hematological aspects of diabetic patients have also found a difference in parameters of leukocytes and platelets (Arkew et al., 2021). Other clinical conditions, including preeclampsia, have also been reported to show variations in the erythrocyte indices, and hematological differences could indicate variations in physiological control and vascular activity (Gutierrez-Aguirre et al., 2017).

The results of the current study add to the existing body of knowledge that the routine hematological parameters might yield any beneficial information on the differences in biological variability among various groups. Due to the prevalence of the CBC testing and its frequent use in clinical practice, the development of trends in the variation of hematological biomarkers might assist in better deciphering of laboratory findings, both in clinical and investigational practice. Specifically, platelet-driven variations in this analysis are evident, indicating that platelet indices could be informative variables in considering hematological variability between biological clusters.

A number of points must be taken into account when analyzing these results. A secondary dataset was used in the analysis, access to other clinical or demographic data that can impact hematological parameters was not available. Moreover, the causal connections between the type of development and the hematological variation cannot be developed due to the cross-sectional design. The distributions of some variables were also skewed and extreme, and could interfere with statistical comparisons, even with data preprocessing. Further analysis of larger and more diverse populations, including more clinical variables, should be conducted in the future. The longitudinal studies could assist in deciding whether the differences in platelet and erythrocyte indices are maintained over the time. The number of biomarkers and clinical outcomes should be potentially extended to enhance the knowledge on the associations between hematological parameters and the larger physiological processes.

5. Conclusion

The regular hematological parameters showed that there were quantifiable changes in the analyzed development groups, and that platelet-related indices were the most significantly different. Development Type 2 had more platelets, platelet distribution width, and platelet large cell ratio, whereas Development Type 1 had more hematocrit. The percentage of basophils also varied across groups, but the level of the change was relatively small. The results show that the difference in CBC-based biomarkers does not occur equally across the hematological domains and that platelet-related parameters could be especially informative in terms of identifying group-specific trends. Inverse correlation between the percentages of lymphocytes and neutrophils also contributes to the fact that there are coordinated biological interactions among hematological variables. Collectively, the findings indicate that CBC biomarkers can offer valuable information about the hematological variation among development groups. Nevertheless, the interpretation needs to be reserved due to the secondary nature of the dataset and the lack of other clinical information. More studies where large, clinically characterized groups are used should be conducted to validate these trends and establish their biological meanings.

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