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A comparative study of hematological parameters between patients with essential hypertension without cardiovascular comorbidity and in combination with coronary artery disease and chronic heart failure

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Objective. Metabolic disorders such as essential hypertension (EH) have increasingly contributed to the global health burden. The aim of this study was to assess differences in the hematological parameters among hypertensive adults with and without cardiovascular comorbidity and to explore the association between the complete blood count (CBC) indices and the effectiveness of hypertension control, defined by achieving target blood pressure levels (TBPLs) of <140/90 mmHg.

Methods. The study involved 140 outpatients with EH of municipal non-profit enterprise "Hulsk outpatient clinic of general practice of family medicine" of the Stryiv village council (Hylsk village, Zviahel district, Zhytomyr region, Ukraine), which were divided into 3 groups: 1) hypertensive patients without cardiovascular comorbidity (with EH only), 2) hypertensive patients with coronary artery disease (CAD), and 3) hypertensive patients with CAD and chronic heart failure (CHF). The CBC was examined using an automatic hematological analyzer BC-6000 ("Mindray", China).

Results. When comparing the CBC indices in patients with EH versus normotensive individuals, statistically significant differences were found in total white blood cells (WBC) count, relative neutrophil, eosinophil, lymphocyte, monocyte counts, mean platelet volume (MPV), and platelet distribution width (PDW). Moreover, relative lymphocyte count (RLC) was lower by 7.05% (p=0.003) in the EH+CAD+CHF group compared to patients with EH only; relative monocyte count (RMC) was higher by 26.09% (p=0.004) and 23.91% (p=0.010) in the EH+CAD+CHF and the EH+CAD groups, respectively, compared to patients with EH only. MPV and PDW were higher by 12.77 % (p=0.022) and 5.66 % (p=0.021) in the EH+CAD group, respectively, compared to patients with EH only. In addition, significant differences were found in the RMC, which was higher in individuals who achieved TBPLs compared to individuals who did not achieve TBPLs (by 25.00% in the EH group, by 26.53% in the EH+CAD group and by 20.00% in the EH+CAD+CHF group).

Conclusions. We demonstrated that in patients with EH+CAD relative monocyte count and MPV and PDW were significantly higher vs. patients with EH only; in patients with EH+CAD+CHF relative lymphocyte count was significantly lower and relative monocyte count was significantly higher vs. patients with EH only. Furthermore, both in hypertensive patients with cardiovascular comorbidity and patients without cardiovascular comorbidity, relative monocyte counts in individuals who achieved TBPLs was significantly higher than in individuals who did not achieve TBPLs. Improved understanding of the cellular mechanisms connecting monocyte count to blood pressure regulation could enhance our insight into the pathogenesis of EH and contribute to the development of more effective strategies for the prevention of hypertension incidents.

Keywords: metabolic disorders, essential hypertension, cardiovascular comorbidity, complete blood count, blood pressure

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Over the last thirty years, metabolic disorders such as type 2 diabetes mellitus (T2DM), hypertension, obesity, hypercholesterolemia, and metabolic dysfunction-associated steatotic liver disease have increasingly contributed to the global health burden. Among them, hypertension remains the most significant accounting for 226 million disability-adjusted life years in 2021 alone. Despite the substantial progress in pharmacological therapies, its prevalence continues in rise (Marushchak et al. 2023; Zhang et al. 2024; Wang et al. 2025). Approximately 95.0% of all hypertension cases are classified as essential hypertension (EH) also referred as primary or idiopathic hypertension, which affects over 100 million people worldwide and results in ≈20 000 deaths annually due to its complications such as stroke, renal failure, myocardial infarction, and cardiac failure (Dzau and Hodgkinson 2024). In addition to global trends, the Ukrainian population has been exposed to prolonged, high-intensity stressors over recent years, including the COVID-19 pandemia and the onset of full-scale war. These events are likely to influence both the incidence and clinical course of EH by disrupting the physiological homeostasis and intensifying pre-existing risk factors. The pathogenesis of EH is multifactorial and remains only partially understood. Blood pressure (BP) regulation is a dynamic process involving neural, renal, endocrine, vascular, and immune systems including mechanisms governed by the renin-angiotensin system, sympathetic nervous system, inflammatory pathways, and natriuretic peptides (Marushchak et al. 2019a,b; Visseren et al. 2021; Cai et al. 2024; Kostiniuk et al. 2025). Growing evidence suggests that immune activation and chronic low-grade inflammation play a fundamental role in the onset and progression of EH (Marazzato et al. 2022; Shokoples et al. 2024). Recent studies have further expanded this paradigm by identifying novel immune-mediated mechanisms, such as sodium-induced modulation of the gut microbiota, generation of lipid peroxidation products (e.g., isolevuglandins), inflammasome-related cytokine cascades, and involvement of previously uncharacterized immune cell subsets that contribute to vascular damage and end-organ dysfunction (Patrick et al. 2021; Chen et al. 2023; Wang et al. 2023).

Routine hematological testing, particularly complete blood count (CBC), is a widely available low-cost tool with significant diagnostic and prognostic potential (Lusiyanti et al. 2025). Beyond its traditional role in hematological disorders screening, the CBC has gained recognition as a source of surrogate markers for systemic inflammation, such as total and differential white blood cells (WBC) counts, neutrophil-to-lymphocyte ratio (NLR), lymphocyte-to-monocyte ratio (LMR), and platelet-to-lymphocyte ratio (PLR), which also have been reported as an indicator of both systemic and local inflammation linked to the progression and prognosis of EH (Masenga et al. 2020; Sileshi et al. 2021). Moreover, other CBC indices, such as hemoglobin (HGB) level, red blood cell (RBC) count, hematocrit (HCT), platelet (PLT) count, erythrocyte sedimentation rate (ESR), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and red cell distribution width (RDW) have been implicated in heightened cardiovascular risk and progression of EH. In particular, Taha et al. (2024) have performed a multivariate regression analysis and demonstrated that HGB level was positively associated with adults' hypertension (Odd ratio [OR]=1.34, 95% confidence interval [CI]=1.12–1.61). A comparative cross-sectional study, which included 187 adults have revealed that among participants without comorbidities, HGB level had a positive correlation with the systolic BP and mean arterial pressure, i.e., the magnitude of increases in the systolic BP and mean arterial pressure with one g/dl change in HGB level were 3.24 mmHg and 1.87 mmHg, respectively (Ghosh et al. 2021). Huang et al. (2023) have found that participants from the elevated BP group had significantly higher baseline RBC counts, HGB counts, and HCT compared to children and adolescents from the normal BP group. Furthermore, a multilevel mixed logistic regression model showed that risk of prehypertension and hypertension incidence increased by 1.34-, 1.38-, 1.33-fold with a one-quartile increase in levels of RBC, HGB, and HCT, respectively. Merad-Boudia et al. (2019) have reported that lower RBC count had a 3.5-fold risk of developing EH compared to those who have normal RBC count (OR=3.64, 95% CI=1.37–9.65, $p<0.05$). In addition, subjects who had MCV rate below 80 fl were more exposed to EH and subjects who had MCH rate a lower than normal (<27 pg) were less exposed to EH; subjects who had lower PLT count than normal are more exposed to EH. Finally, the increase in ESR increased the risk of EH by 56.63 times compared to subjects with normal ESR ($p=0.001$). Lassale et al. (2018) have demonstrated in population-based prospective cohort study (n=14.362) an increased total WBC, lymphocyte, monocyte and neutrophil counts associated with a higher cardiovascular risk as well as MCV and RDW.

To date, no nationwide survey has been published in Ukraine on the hematological parameters between normotensive adult individuals and hypertensive

ones, particularly in the context of cardiovascular comorbidities. Furthermore, there is a lack of comprehensive data from Ukraine evaluating the relationship between hematological parameters and ability to achieve target blood pressure levels (TBPLs) among patients with EH as well as outpatients.

The present study aimed to assess differences in hematological parameters among hypertensive adults with and without cardiovascular comorbidity and to explore the association between CBC indices and the effectiveness of hypertension control defined by achieving TBPLs of <140/90 mm Hg.

Material and Methods

Study design. The study was carried out on the basis of municipal non-profit enterprises "Hulsk outpatient clinic of general practice of family medicine" of the Stryiv village council (Hylsk village, Zviahel district, Zhytomyr region) and Zviahel multi-field hospital of the Zviahel city council (Zviahel city, Zhytomyr region). This study involved 140 outpatients with EH who were divided into 3 groups: group 1 – hypertensive patients without cardiovascular comorbidity (EH only); group 2 – hypertensive patients with comorbid coronary artery disease (CAD) (EH+CAD); group 3 – hypertensive patients with comorbid CAD and chronic heart failure (CHF) (EH+CAD+CHF) (Table 1).

The average age of patients with EH+CAD (64.86±9.59 years) was by 18.86% higher (p<0.001), and the average age of patients with EH+CAD+CHF (67.49±10.42 years) was by 23.67% higher than the average age of patients with EH only (54.57±6.79 years). Comparing the average age of patients with EH+CAD vs. the average age of patients with EH+CAD+CHF, no significant changes were found (p=0.187) (Table 2). Analyzing the distribution of patients included in the study according to World Health Organization (WHO) age categories (25–44 years – young age; 45–60 years – middle age; 61–74 years – advanced age; 75–90 years – elderly age), significant differences between the study groups were revealed (χ^2=47.47; p<0.001) (Table 2). In particular, among patients with EH and cardiovascular comorbidity, advanced-aged individuals predominated, while in the group of patients with EH only, middle-aged individuals predominated. It should be noted that the highest percentage of elderly individuals (31.11%) was found in the group of patients with EH+CAD+CHF. At the same time, the proportion of young individuals was the smallest and approximately the same in all study groups (2.86 % in EH+CAD group; 2.22 % in EH+CAD+CHF group; 5.00 % in EH only group) (Table 2).

Table 1
Characteristics of the groups of patients included in the study (n=140)

N	Study groups	n	%
1	Patients with EH only	60	42.86
2	Patients with EH+CAD	35	25.00
3	Patients with EH+CAD+CHF	45	32.14

Abbreviations: CAD – coronary artery disease; CHF – chronic heart failure; EH – essential hypertension.

Analyzing the gender distribution of hypertensive patients included in the study, no statistically significant differences were found (χ^2=0.99; p=0.608). At the same time, in each of the groups, the proportion of women exceeded the proportion of men (54.29%, n=19 vs. 45.71%, n=16 in EH+CAD group; 55.56%, n=25 vs. 44.44%, n=20 in EH+CAD+CHF group; 63.33%, n=38 vs. 36.67%, n=22 in EH only group).

There was also a control group (CG) with no disease, which was also followed to obtain the normal values of the hematological profile – 20 practically healthy individuals who were comparable in age and sex to the study groups.

Inclusion and exclusion criteria for the individual groups of patients.

Group 1 inclusion criteria: age of patients from 25 to 85 years, both females and males; verified diagnosis of EH in accordance with current clinical

Table 2
Distribution of patients included in the study according to WHO age categories

Group	Young-aged		Middle-aged		Advanced-aged		Elderly-aged		χ^2, p
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	
EH (n=60)	3	5.00	44	73.33	13	21.67	0	0.00	χ^2=47.47; p<0.001
EH+CAD (n=35)	1	2.86	9	25.71	20	57.14	5	14.29	
EH+CAD+CHF (n=45)	1	2.22	9	20.00	21	46.67	14	31.11	

Abbreviations: CAD – coronary artery disease; CHF – chronic heart failure; EH – essential hypertension; WHO – World Health Organization.

guideline (Mancia et al. 2023); informed consent to participate in the study.

Group 1 exclusion criteria: age less than 25 years and more than 85 years, cardiomyopathies, congenital heart defects, rheumatic heart defects, cardiac arrhythmias, myocarditis, acute myocardial infarction or acute cerebrovascular accident in the last 6 months, verified diagnosis of CAD and/or chronic CHF, the presence of mental and oncological diseases, tuberculosis, secondary arterial hypertension and other diseases in the stage of decompensation, period of pregnancy and lactation, patient's refusal to participate in the study.

Group 2 inclusion criteria: age of patients from 25 to 85 years, both females and males; verified diagnosis of EH in accordance with current clinical guideline (Mancia et al. 2023); stable forms of CAD – angina pectoris (functional classes 2, 3), or anginal equivalent (shortness of breath, dyspnea) in accordance with current clinical guideline (Knuuti et al. 2023); informed consent to participate in the study. CAD diagnosis was based on: planned coronary bypass surgery, planned percutaneous coronary intervention, results of planned coronary angiography, history of hospitalization for CAD (the presence of the disease in patients was confirmed by medical documentation – notes in the outpatient card, statement from inpatient medical card).

Group 2 exclusion criteria: age less than 25 years and more than 85 years, cardiomyopathies, congenital heart defects, rheumatic heart defects, cardiac arrhythmias, myocarditis, acute myocardial infarction or acute cerebrovascular accident in the last 6 months, angina pectoris (functional class 4), verified diagnosis of CHF, the presence of mental and oncological diseases, tuberculosis, secondary arterial hypertension and other diseases in the stage of decompensation, period of pregnancy and lactation, patient's refusal to participate in the study.

Group 3 inclusion criteria: age of patients from 25 to 85 years, both females and males; verified diagnosis of EH in accordance with current clinical guideline (Mancia et al. 2023); stable forms of CAD – angina pectoris (functional classes 2, 3), or anginal equivalent (shortness of breath, dyspnea) in accordance with current clinical guideline (Knuuti et al. 2023); CHF; informed consent to participate in the study. CHF diagnosis was based on the relevant clinical and instrumental manifestations due to current guideline for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology 2021 (McDonagh et al. 2022). The study included patients with stage I–IIA CHF (stages B and C by unified international classification of CHF 2021).

Group 3 exclusion criteria: age less than 25 years and more than 85 years, cardiomyopathies, congenital heart defects, rheumatic heart defects, cardiac arrhythmias, myocarditis, acute myocardial infarction or acute cerebrovascular accident in the last 6 months, angina pectoris (functional class 4), CHF IIB–III (stage D by unified international classification of CHF 2021) or functional class IV according to New York Heart Association Functional Classification, the presence of mental and oncological diseases, tuberculosis, secondary arterial hypertension and other diseases in the stage of decompensation, period of pregnancy and lactation, patient's refusal to participate in the study.

Office BP was measured in the sitting position in the morning (between 8:00 a.m. and 10:00 a.m.) in the doctor's office using a mechanical tonometer with a shoulder cuff Microlife BP AG1–20 ("Microlife", China) according to standard procedure. Patient was at rest at least 10 min before the BP measurement. Systolic and diastolic BP was recorded on the same hand 3 times with 2 min interval, if BP values did not differ by more than 5 mmHg. If there was a greater difference between the obtained values, the fourth measurement was conducted and calculated the mean of three consecutive measurements. Patients were considered to have achieved TBPLs, if at double measurement with an interval of 1 month their office BP was <140/90 mmHg.

Hematological profile laboratory evaluation. Each blood sample (3 ml) obtained in a vacutainer from all subjects was mixed with ethylenediaminetetraacetic acid (EDTA) anticoagulant and examined using an automatic hematological analyzer BC-6000 ("Mindray", China) in the Clinical Diagnostic Laboratory of Zviahel multi-field hospital of the Zviahel city council (Zviahel city, Zhytomyr region). Fourteen CBC parameters were considered and analyzed for all groups such as RBC in count x 10^{12}/L, HGB in g/L, HCT in %, WBC in count x10^9/L, ESR in mm/h, neutrophils in %, lymphocytes in %, monocytes in %, eosinophils in %, basophils in %, platelets (PLT) in count x10^9/L, mean platelet volume (MPV) in fl, platelet distribution width (PDW) in % and plateletcrit (PCT) in %.

Ethics. All the studies were conducted in compliance with the Council of Europe Convention on Human Rights and Biomedicine, which was adopted in 1997; the Helsinki Declaration of the World Medical Association «Ethical principles for medical research involving human subject» (last

revision by the 59th General Assembly of the World Medical Association 01.10.2008). The study protocol was approved by the Ethics Committee of the I Horbachevsky Ternopil National Medical University, Ternopil, Ukraine (protocol No. 77 dated April 18, 2024). Informed consent to participate in the study has been obtained from all participants.

Statistical analysis. Study results were analyzed using STATISTICA 7.0 and Microsoft Excel software. The normality of quantitative variables was assessed using the Kolmogorov-Smirnov test. In case of their parametric distribution quantitative values were described as mean and standard deviation (M±SD) and compared using the Student's t-test. In case of their non-parametric distribution quantitative variables were expressed by median (Me) and interquartile (IQR) range – Q1 (25 percentile) and Q3 (75 percentile), and compared using Mann-Whitney test. Differences were considered statistically significant at a p value <0.05. The frequency values were described as absolute value (n) and percentage (%) and compared using Pearson's χ^2-test and Fisher bilateral test.

Results

Analyzing the CBC indices in hypertensive patients included in the study compared to the CG, statistically significant differences were found only for total WBC count in patients with EH and cardiovascular comorbidity (Table 3). Thus, in the EH+CAD group, total WBC count was lower by 17.14% (p=0.025) compared to CG and in the EH+CAD+CHF group, it was lower by 18.57% (p=0.030) compared to CG. The relative number of neutrophils exceeded the control data by 10.62% (p=0.007) in the EH group, by 12.38% (p=0.034) in the EH+CAD group, and by 13.96% (p=0.001) in the EH+CAD+CHF group (Table 4). At the same time, comparing the percentage of neutrophils in patients with EH and cardiovascular comorbidity vs. hypertensive patients without cardiovascular comorbidity, no significant differences were found.

Opposite-directed changes were revealed in the relative number of lymphocytes. In particular, this indicator was lower by 15.56% (p=0.016) in the

Table 3
Complete blood count indices in hypertensive patients included in the study

Parameter	Group			
	CG (n=20)	EH only (n=60)	EH+CAD (n=35)	EH+CAD+CHF (n=45)
RBC count (10^{12}/L)	4.69 (4.41; 5.00)	4.90 (4.44; 5.10)	4.90 (4.44; 5.10)	4.72 (4.50; 5.06)
	p_{1-2}=0.427 p_{1-3}=0.896 p_{1-4}=0.495 p_{2-3}=0.226 p_{2-4}=0.746 p_{3-4}=0.407			
HGB (g/L)	144.00 (133.50; 153.50)	143.00 (132.50; 155.44)	143.00 (132.50; 155.44)	145.00 (133.00; 149.53)
	p_{1-2}=0.863 p_{1-3}=0.599 p_{1-4}=0.733 p_{2-3}=0.527 p_{2-4}=0.609 p_{3-4}=0,786			
HCT (%)	42.70 (40.20; 44.75)	43.96 (41.35; 45.75)	43.60 (42.50; 45.10)	43.10 (41.80; 45.20)
	p_{1-2}=0.323 p_{1-3}=0.310 p_{1-4}=0.675 p_{2-3}=0.948 p_{2-4}=0.643 p_{3-4}=0.464			
WBC count (10^9/L)	7.00 (5.91; 7.85)	6.40 (5.51; 7.40)	5.80 (5.00; 6.70)	5.70 (5.10; 6.49)
	p_{1-2}=0.175 p_{1-3}=0.025* p_{1-4}=0.030* p_{2-3}=0.101 p_{2-4}=0.126 p_{3-4}=0.685			
PLT count (10^9/L)	228.00 (189.50; 263.50)	224.50 (189.50; 263.00)	221.00 (187.00; 245.00)	213.00 (180.00; 283.00)
	p_{1-2}=0.973 p_{1-3}=0.431 p_{1-4}=0.960 p_{2-3}=0.373 p_{2-4}=0.673 p_{3-4}=0.779			
ESR (mm/h)	6.00 (4.00; 9.50)	6.50 (4.00; 14.00)	7.00 (3.00; 11.00)	6.00 (3.00; 14.00)
	p_{1-2}=0.459 p_{1-3}=0.726 p_{1-4}=0.696 p_{2-3}=0.396 p_{2-4}=0.741 p_{3-4}=0.570			

Note 1: p_{1-2} – the probability of comparing CG and patients with EH only; p_{1-3} – the probability of comparing CG and patients with EH+CAD; p_{1-4} – the probability of comparing CG and patients with EH+CAD+CHF; p_{2-3} – the probability of comparing patients with EH only and patients with EH+CAD; p_{2-4} – the probability of comparing patients with EH only and patients with EH+CAD+CHF; p_{3-4} – the probability of comparing patients with EH+CAD and patients with EH+CAD+CHF. Note 2: *statistically significant results. Abbreviations: CAD – coronary artery disease; CBC – complete blood count; CG – control group; CHF – chronic heart failure; EH – essential hypertension; ESR – erythrocyte sedimentation rate; HCT – hematocrit; HGB – hemoglobin; PLT – platelet; RBC – red blood cell; WBC – white blood cells.

EH only group vs. CG, by 18.81% (p=0.037) in the EH+CAD group and by 21.52% (p=0.001) in the EH+CAD+CHF group. In addition, the percentage of lymphocytes in patients with EH+CAD+CHF was significantly lower by 7.05% vs. patients with EH only (Table 4). A similar trend was observed in the change in the percentage of monocytes in hypertensive patients included in this study. Thus, in the EH group, the percentage of monocytes was lower by 30.30% (p=0.001) compared to control, by 13.64% (p=0.046) in the EH+CAD group and by 12.12% (p=0.039) in the EH+CAD+CHF group. In addition, the relative number of monocytes in patients with EH in combination with CAD and CHF was significantly higher by 26.09% compared to the patients with EH only, and it was significantly higher by 23.91%. in patients with hypertension in combination with CAD compared to the patients with isolated hypertension. Moreover, the number of monocytes in patients with EH in combination with CHD and CHF was higher by 26.09% compared to this laboratory index in patients with EH only (Table 4). Regarding eosinophils, it should be noted that this indicator in patients in all study groups significantly exceeded the data of the CG by 2.0 times. At the same time, statistically significant differences in the number of eosinophils between patients with EH only compared to hypertensive patients with cardiovascular comorbidity were not established (p>0.05) (Table 4). As for the percentage of basophils, we did not find any significant differences in this indicator either by comparing the data of the study groups with the CG or by comparing this indicator in patients with EH only compared to hypertensive patients with cardiovascular comorbidity (Table 4).

Analyzing the platelet parameters in patients with EH, relative to the CG, statistically significant differences were found only in patients with EH and cardiovascular comorbidity (for MPV and PDW, p<0.05) (Table 5). Thus, MPV was higher by 15.22% (p=0.006) and 7.61% (p=0.007) in the EH+CAD group and the EH+CAD+CHF group, respectively, compared to the control data. PDW exceeded the control data by 9.63% (p=0.002) in the EH+CAD group and by 7.64% (p=0.001) in the EH+CAD+CHF group. It should be noted that both MPV and PDW exceeded the data of patients with EH only by 12.77% (p=0.022) and 5.66% (p=0.022), respectively, in patients with EH combined with CAD (Table 5).

The next stage of our work was the analysis of possible associations between CBC indices (which significantly differ from CG or were significantly

Table 4
Differential WBC count in hypertensive patients included in the study

Parameter	Groups			
	CG (n=20)	EH only (n=60)	EH+CAD (n=35)	EH+CAD+CHF (n=45)
Neutrophil count (%)	56.95 (53.40; 60.50)	63.00 (57.40; 68.00)	64.00 (56.40; 67.00)	64.90 (61.40; 67.20)
p_{1-2}=0.007* p_{1-3}=0.034* p_{1-4}=0.001* p_{2-3}=0.431 p_{2-4}=0.365 p_{3-4}=0.078				
Lymphocyte count (%)	36.95 (31.05; 38.95)	31.20 (27.50; 35.10)	30.00 (26.00; 36.70)	29.00 (26.00; 31.00)
p_{1-2}=0.016* p_{1-3}=0.037* p_{1-4}=0.001* p_{2-3}=0.654 p_{2-4}=0.003* p_{3-4}=0.083				
Monocyte count (%)	6.60 (5.95; 7.45)	4.60 (3.00; 5.70)	5.70 (3.80; 6.70)	5.80 (4.80; 7.00)
p_{1-2}=0.001* p_{1-3}=0.046* p_{1-4}=0.039* p_{2-3}=0.010* p_{2-4}=0.004* p_{3-4}=0.965				
Eosinophil count (%)	0.00 0.00; 0.35)	2.00 (0.00; 2.05)	2.00 (1.00; 2.90)	2.00 (1.00; 3.00)
p_{1-2}=0.001* p_{1-3}=0.001* p_{1-4}=0.001* p_{2-3}=0.141 p_{2-4}=0.055 p_{3-4}=0.827				
Basophil count (%)	0.00 (0.00; 0.15)	0.00 (0.00; 0.00)	0.00 (0.00; 0.10)	0.00 (0.00; 0.30)
p_{1-2}=0.785 p_{1-3}=0.840 p_{1-4}=0.619 p_{2-3}=0.654 p_{2-4}=0.284 p_{3-4}=0.734				

Note 1. p_{1-2} – the probability of comparing CG and patients with EH only; p_{1-3} – the probability of comparing CG and patients with EH+CAD; p_{1-4} – the probability of comparing CG and patients with EH+CAD+CHF; p_{2-3} – the probability of comparing patients with EH only and patients with EH+CAD; p_{2-4} – the probability of comparing patients with EH only and patients with EH+CAD+CHF; p_{3-4} – the probability of comparing patients with EH+CAD and patients with EH+CAD+CHF. Note 2. * – statistically significant results. Abbreviations: CAD – coronary artery disease; CG – control group; CHF – chronic heart failure; EH – essential hypertension; WBC – white blood cells.

Table 5
PLT parameters in hypertensive patients included in the study

Parameter	Groups				p
	CG (n=20)	EH only (n=60)	EH+CAD (n=35)	EH+CAD+CHF (n=45)	
MPV (fl)	9.20 (8.70; 9.65)	9.40 (8.80; 10.30)	10.60 (9,10; 11,30)	9.90 (9.40; 10.90)	p_{1-2}=0,157 p_{1-3}=0,006* p_{1-4}=0,007* p_{2-3}=0,022* p_{2-4}=0,107 p_{3-4}=0,385
PDW (%)	15.05 (14.15; 15.90)	15.90 (14.80; 16.20)	16.80 (16.50; 17.00)	16.20 (16.00; 16.50)	p_{1-2}=0,091 p_{1-3}=0,002* p_{1-4}=0,001* p_{2-3}=0,021* p_{2-4}=0,149 p_{3-4}=0,335
PCT (%)	0.22 (0.18; 0.27)	0.23 (0.19; 0.25)	0.24 (0.21; 0.25)	0.24 (0.20; 0.27)	p_{1-2}=0,911 p_{1-3}=0,599 p_{1-4}=0,430 p_{2-3}=0,166 p_{2-4}=0,154 p_{3-4}=0,624

Note 1. p_{1-2} – the probability of comparing CG and patients with EH only; p_{1-3} – the probability of comparing CG and patients with EH+CAD; p_{1-4} – the probability of comparing CG and patients with EH+CAD+CHF; p_{2-3} – the probability of comparing patients with EH only and patients with EH+CAD; p_{2-4} – the probability of comparing patients with EH only and patients with EH+CAD+CHF; p_{3-4} – the probability of comparing patients with EH+CAD and patients with EH+CAD+CHF. Note 2. * – statistically significant results. Abbreviations: CAD – coronary artery disease; CG – control group; CHF – chronic heart failure; EH – essential hypertension; MPV – mean platelet volume; PCT – plateletcrit; PDW – platelet distribution width; PLT – platelets.

Table 6
The association between hematological parameters and achievement/failure to achieve TBPLs in hypertensive patients included in the study

Groups		TBPLs	WBC count (10^9/L)	Neutrophil count (%)	Lymphocyte count (%)	Eosinophil count (%)	Monocyte count (%)	MPV (fl)	PDW (%)
1	**EH only** (n=60)	Achieved (n=21)	6.40 (5.00; 7.70)	59.10 (52.20; 64.00)	33.30 (30.60; 36.10)	2.00 (0.00; 2.80)	5.00 (4.50; 7.20)	9.10 (8.90; 9.80)	16.10 (14.80; 16.30)
		Not achieved (n=39)	6.40 (5.90; 7.06)	63.60 (60.50; 69.00)	30.00 (26.00; 33.90)	2.00 (0.60; 2.00)	4.00 (2.00; 5.40)	9.80 (8.80; 10.30)	15.90 (14.80; 16.10)
			p=0.259	p=0.144	p=0.459	p=0.459	p=0.021*	p=0.904	p=0.960
2	**EH+CAD** (n=35)	Achieved (n=19)	6.00 (5.00; 7.08)	61.00 (54.40; 66.00)	30,00 (26.70; 35.30)	2.00 (0.90; 3.00)	6.20 (5.60; 7.90)	10.60 (9.10; 11.30)	16.20 (15.80; 16.40)
		Not achieved (n=16)	5.30 (5.00; 6.36)	65.00 (57.50; 66.00)	30.00 (26.00; 36.85)	2.00 (2.00; 2.00)	4.90 (2.90; 6.00)	10.20 (9.05; 11.40)	16.00 (15.60; 16.40)
			p=0.337	p=0.276	p=0.197	p=0.711	p=0.039*	p=0.204	p=0.952
3	**EH+CAD+ CHF** (n=45)	Achieved (n=19)	5.40 (4.99; 6.40)	64.00 (61.00; 66.00)	29.00 (25.60; 30.00)	2.00 (1.00; 3.00)	6.00 (5.00; 8.40)	9.60 (8.90; 10.60)	16.00 (15.70; 16.70)
		Not achieved (n=26)	6.55 (5.60; 7.90)	64.50 (61.40; 68.00)	28.10 (26.00; 31.00)	2.00 (1.50; 3.00)	5.00 (3.90; 6.80)	9.80 (9.20; 11.20)	15.85 (15.50; 16.20)
			p=0.390	p=0.741	p=0.653	p=0.711	p=0.036*	p=0.897	p=0.516

Note. * – statistically significant results. Abbreviations: CAD – coronary artery disease; CG – control group; CHF – chronic heart failure; EH – essential hypertension; MPV – mean platelet volume; PDW – platelet distribution width; TBPLs – target blood pressure levels; WBC – white blood cells.

different from each other in study groups) and ability/failure to achieve TBPLs of <140/90 mm Hg. The absence of statistically significant correlations between the total WBC, neutrophil, lymphocyte, eosinophil counts, MPV, PDW, and ability/failure to achieve TBPLs was established in all groups studied (Table 6). At the same time, in both the patients with EH only and with EH and cardiovascular comorbidity, significant differences were found in the relative monocyte count in individuals who achieved TBPLs compared to individuals who did not achieve TBPLs. Thus, the percentage of monocytes in the patients who achieved TBPLs compared to the patients who did not achieve TBPLs was higher by 25.00 % (p=0.021) in the EH only group, by 26.53% (p=0.039) in the EH+CAD group, and by 20.00% (p=0.036) in the EH+CAD+CHF group.

Discussion

When comparing the hematological profiles of patients with EH without cardiovascular comorbidity and in combination with CAD and CHF to those of the CG, we observed several statistically significant differences. Total WBC count was reduced only in hypertensive patients with cardiovascular comorbidity. Neutrophil and eosinophil counts were elevated in all hypertensive patients, regardless of the presence of cardiovascular comorbidities. Conversely, lymphocyte and monocyte counts were decreased across all the hypertensive patients, independent on the comorbidity status. MPV and PDW were increased exclusively in hypertensive individuals with cardiovascular comorbidities. Furthermore, lymphocyte percentage was by 7.05% lower in the EH+CAD+CHF group compared to patients with EH only. Monocyte percentage was elevated by 26.09% in the EH+CAD+CHF group and 23.91% in the EH+CAD group relative to the EH only group. MPV and PDW in the EH+CAD group exceeded those in the EH only group by 12.77% and 5.66%, respectively. Analysis of potential associations between total WBC, neutrophil, lymphocyte, eosinophil, and monocyte counts, MPV, PDW and the ability to achieve TBPLs revealed significant differences only in monocyte percentage. This was consistently higher in individuals who reached TBPLs, both among patients with EH only and those with EH combined with cardiovascular comorbidities.

There is growing evidence that alterations in total WBC count and WBC differential are closely associated with EH although the exact mechanisms underlying the link between elevated WBC count and increased BP remain unclear (Tsuda 2024). Morton et al. (2008) have demonstrated a direct role of neutrophils in BP regulation showing that reducing neutrophil count in normotensive mice resulted in decreased endothelium-dependent vasoconstriction and lower systolic BP. Similarly, Sela et al. (2004) have reported an increased neutrophil count in a murine model of hypertension. Further supporting the involvement of neutrophils, Araos et al. (2020) have observed that experimental hypertension was associated with an enhanced neutrophil phagocytic activity and increased production of reactive oxygen species (ROS), alongside the activation of myeloperoxidase and nicotinamide adenine dinucleotide phosphate oxidase. These changes promoted the formation of neutrophil extracellular traps and increased neutrophil adhesion to endothelial cells, potentially compromising endothelial integrity and contributing to vascular dysfunction. Additionally, Nicholls et al. (2018) have shown that neutrophils exposed to noradrenaline released greater amounts of interleukin-6 and myeloperoxidase, suggesting a modulatory role for neutrophils influenced by sympathetic nervous system activation.

Circulating lymphocytes have been implicated in the process of microvascular remodeling in hypertension (De Ciuceis et al. 2017). At the same time, an increase in neutrophil count, in particular, reduced lymphocyte activity (Niazi et al. 2019). There is evidence that a reduced lymphocyte count may reflect immune system suppression due to chronic inflammation (Hu et al. 2025). In patients with hypertension, the NLR exceeds that of normotensive individuals. Moreover, it was found that NLR was significantly higher in individuals with a "non-dipper" pattern of circadian BP rhythm compared to those with a "dipper" profile (Kilicaslan et al. 2015; Sarejloo et al. 2023). Hu et al. (2025) have further demonstrated that NLR was significantly increased in patients with EH who also exhibited left ventricular hypertrophy (LVH), and it positively correlated with the left ventricular mass index (LVMI). Interestingly, the LVMI showed a negative correlation with lymphocyte count indicating that a lower lymphocyte count may be associated with a greater risk of developing LVH in hypertensive individuals. Additionally, the study by Siedlinski et al. (2020) have identified a potential causal relationship between total lymphocyte count and both systolic and diastolic BP, independent of the major histocompatibility complex region.

As for eosinophilia observed in all the study groups, our results are consistent with findings by Masenga

et al. (2020) who have reported that among people living with human immunodeficiency virus (HIV) (n=70), hypertensive individuals had significantly higher relative and absolute blood eosinophil counts compared to normotensive individuals. Importantly, the positive association between eosinophil levels and EH remained significant after adjusting for age, sex, and body mass index (BMI) in a multivariate analysis. To determine whether hypertension is associated with eosinophilia in HIV-negative individuals, the same researchers recruited an additional group of 50 HIV-negative participants (25 hypertensive and 25 normotensive) and found that eosinophil counts in hypertensive individuals were also significantly higher than in normotensives. However, a multivariate analysis considering sex, age, and BMI showed that eosinophil count was not associated with hypertension but was significantly correlated with BMI. In the final stage of their study, the researchers conducted a logistic regression analysis of the combined cohort (70 HIV-positive and 50 HIV-negative individuals), which, after adjusting for age, sex, and BMI, showed a persistent link between eosinophil count and hypertension, although this association did not reach statistical significance.

Circulating monocytes are not only linked to the progression of cardiovascular diseases, but are also influenced by various risk factors contributing to their development (Williams et al. 2021; Lu et al. 2024). Notably, monocytes play a crucial role in sustaining low-grade inflammation and serve as a reservoir for macrophages that infiltrate atherosclerotic plaques. The recruitment of monocytes into the vascular intima represents a key step in plaque formation (Ley et al. 2007). Loperena et al. (2018) have highlighted the central involvement of monocytes and macrophages in initiating and propagating the inflammatory cascade in hypertension. Danger-associated molecular pattern receptors detect intracellular inflammatory agents including ROS (Banoth and Cassel 2018; Shcherba et al. 2021). Activation of these pathways triggers inflammasomes, multiprotein complexes with enzymatic functions that cleave and activate pro-inflammatory cytokines IL-1β and IL-18 within innate immune cells (Patrick et al. 2021). Furthermore, a Mendelian randomization study reported a positive association between absolute monocyte count and elevated systolic and diastolic BP, as well as increased pulse pressure (Siedlinski et al. 2020).

Regarding platelets, there is evidence that increased platelet activation and increased aggregation are commonly observed in individuals with hypertension (Zhao et al. 2021; Xu and Guo 2023). This heightened platelet activity may impair vascular repair mechanisms and elevate the risk of cardiovascular complications (Vrigkou et al. 2020). MPV and PDW serve as potential indicators of platelet activation (Barrett et al. 2020). Roy et al. (2024) have reported that MPV and PDW were significantly higher in patients with T2DM, hypertension, and their comorbid course compared to practically healthy individuals. Jian et al. (2023) have investigated the clinical value of platelet parameters and inflammatory factor activation in vascular endothelial injury in hypertension and found that patients in the hypertension group exhibited higher levels of MPV, PDW, and PCT vs. control. Moreover, Spearman correlation analysis showed a significant negative correlation of MPV, PDW and PCT with reactive hyperemia index; univariate and multivariate regression analysis presented that MPV and PCT were independent risk factors for vascular endothelial dysfunction. Additionally, Mansoori et al. (2024) have used logistic regression and decision tree modelling to investigate the association between EH, demographic variables, and routine hematologic parameters. Age and total WBC count emerged as the strongest predictors of EH, followed by sex and PDW. In the decision tree model, individuals aged ≥58 years with high PDW (≥17.3) and low RDW-SD (<46) had a 98.0% probability of having EH. The study further underscored elevated WBC and PDW as the hematologic parameters most strongly associated with hypertension severity, along with female sex and older age.

Thus, our study supports the notion that different types of circulating leukocytes and platelets activation are involved in occurrence and progression of EH. We further show that the relative lymphocyte count in patients with EH+CAD+CHF was significantly lower compared to the patients with EH only; relative monocyte counts in the EH+CAD+CHF and EH+CAD groups were significantly higher compared to the patients with EH only. This findings support an assumption that a reduced lymphocyte count may reflect immune system suppression owing to chronic inflammation, which is implicated in the development of cardiovascular comorbidities in patients with EH; increased monocyte count in hypertensive patients with comorbid CAD and CHF reflected elevated secretion of pro-inflammatory cytokines and increased expression of adhesion molecules what contributes to the progression of endothelial dysfunction and oxidative stress in comorbid course

of EH. In addition, we demonstrated a previously unrecognized link between relative monocyte count (critical innate immune system cell type that serves homeostatic and immunoregulatory functions) and achieving TBPLs in hypertensive patients. This provides new insight into how the immune system can be involved in BP regulation.

Conclusion. We demonstrated that relative monocyte count, MPV and PDW were significantly higher in the patients with EH+CAD compared to the patients with EH only. Relative lymphocyte count was significantly lower and relative monocyte count was significantly higher in the patients with EH+CAD+CHF compared to the patients with EH only. Furthermore, both in hypertensive patients with cardiovascular comorbidity and in patients without cardiovascular comorbidity, relative monocyte count in individuals who achieved TBPLs was significantly higher compared to the individuals who did not achieve TBPLs, what requires further studies. Improved understanding of the cellular mechanisms connecting monocyte count to BP regulation could enhance our insight into the pathogenesis of EH and contribute to the development of more effective strategies for the prevention of hypertension incidents.

Limitations. Our study has limitations of cross-sectional type; short follow-up period; small sample size of study groups as well and control group and therefore, the significant differences were difficult to establish; we rely on a single measurement of the CBC indices, which may be affected by short-term physiological (menstrual cycle) or pathological (acute viral or bacterial infection) changes.

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