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One condition, different environments? Haematologic parameter dynamics and pulmonary embolism in urban vs. rural orthopaedic patients

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Abstract

Introduction and Objective. Pulmonary embolism (PE) remains a major cause of morbidity and mortality among orthopaedic patients. Despite documented cardiovascular disparities between urban and rural populations, data linking these environments with PE incidence and haematologic changes are scarce. The study investigates the differences in acute pulmonary embolism (APE) incidence and dynamic haematologic changes between urban and rural orthopaedic patients.

Materials and Method. A retrospective analysis included 276 orthopaedic patients hospitalized over eight years in a tertiary centre in Eastern Poland. Patients were categorized by residence (urban vs. rural). Complete blood count parameters, notably red cell distribution width (RDW), platelet indices, and erythrocyte parameters, were analyzed on admission and at clinical suspicion of APE. APE was confirmed by computed tomography pulmonary angiography. Ethical approval was obtained (KE-0254/17/2019). Standard statistical tests were used ($p<0.05$).

Results. APE incidence did not differ significantly between urban (39.1%) and rural (47.4%) patients ($p=0.181$). However, urban patients had significantly higher RDW values on admission ($p=0.037$). Additionally, females showed significantly elevated RDW, particularly in rural settings ($p=0.038$). Other haematologic parameters showed no significant differences between groups.

Conclusions. Although residence did not significantly influence APE incidence, the elevated RDW in urban patients suggests environmental or lifestyle-related haematologic modulation. Considering the limited similar studies in the literature, RDW emerges as a potential, cost-effective biomarker for early APE risk stratification in orthopaedic patients.

Key words

RDW, pulmonary embolism, red cell distribution width, venous thromboembolism, risk stratification, orthopaedic surgery, urban vs. rural health, haematologic biomarkers, environmental determinants of health

INTRODUCTION AND OBJECTIVE

Pulmonary embolism (PE) is a serious medical emergency in cardiology, requiring immediate hospitalization due to its complex pathophysiology and frequently non-specific symptoms. It represents a major manifestation of venous thromboembolism (VTE), which also includes deep vein thrombosis (DVT). Scientific reports indicate that PE ranks third worldwide among the leading causes of cardiovascular mortality, following myocardial infarction and stroke [1, 2]. Despite variations in the estimated incidence of VTE across different populations, the condition consistently correlates with high in-hospital mortality, frequent re-hospitalizations, and long-term complications [2].

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The pathophysiological mechanisms of VTE have long been described by Virchow's triad: hypercoagulability, venous stasis, and endothelial injury [3]. These factors are particularly relevant in hospitalized orthopaedic patients, who often experience significant tissue trauma, prolonged immobility, and systemic inflammatory responses due to procedures such as joint replacement or fracture repair [4, 5]. Consequently, this group is considered at high risk for thromboembolic events and is a major focus of prophylactic recommendations issued by the European Society of Cardiology (ESC), American Society of Hematology (ASH), and the American College of Chest Physicians (CHEST) [4–6].

Despite advancements in prophylaxis and peri-operative care, VTE remains a persistent complication, frequently occurring in subclinical or atypical forms [7]. Early diagnosis of PE is challenging due to the lack of specific symptoms and their overlap with post-operative changes, particularly in orthopaedic patients. Given the increasing need for

individualized risk assessment, there is growing interest in supplementary diagnostic tools beyond standard imaging (e.g., CT pulmonary angiography) and D-dimer testing [4, 8, 9].

In this context, haematological markers derived from automated complete blood count (CBC) analysis – notably red cell distribution width (RDW) – have attracted attention. RDW is a low-cost, widely available, and fully automated parameter reflecting the variation in the size of red blood cells. Elevated RDW has been associated with systemic inflammation, oxidative stress, impaired erythropoiesis, and poor prognosis in cardiovascular diseases, including PE [10–12]. Recent studies have shown correlations between RDW and right ventricular dysfunction, elevated natriuretic peptides, and increased mortality in PE patients [11]. Furthermore, RDW may arise before clinical symptoms emerge, making it a potential early warning marker in the peri-operative period when initial signs of PE may go unnoticed [10].

Given the multi-factorial etiology, non-specific clinical presentation, significant morbidity and mortality, and high treatment costs of PE, it is essential to identify new associations between disease features and clinical or demographic variables. Concurrently, there is growing evidence of the influence of environmental and socio-demographic factors on cardiovascular risk. Disparities in PE-related mortality, diagnostic access, and treatment outcomes have been documented across racial, geographic, and economic groups [13]. In particular, rural populations in Central and Eastern Europe – including Poland – exhibit higher rates of untreated hypertension, obesity, smoking, and lower utilization of preventive cardiology services [14, 15]. Conversely, urban residents are more exposed to chronic stress, air pollution (e.g., PM2.5), noise, shift work, and sedentary lifestyles – factors increasingly linked to endothelial dysfunction and prothrombotic activation [11].

Although previous studies have examined the incidence and outcomes of PE by place of residence, few have explored whether routine haematologic parameters reflect population-level differences in PE risk [16]. Moreover, there is a lack of data on whether RDW and related erythrocyte or platelet indices differ by residence, gender, or other demographic factors within surgical populations.

Considering the growing need for accessible, cost-effective, and personalized risk assessment tools for PE, blood count-derived indices such as RDW warrant further investigation – particularly in hospital systems serving both urban and rural populations. The orthopaedic cohort provides a suitable model, as these patients receive standardized peri-operative care, reducing the influence of therapeutic variability and enhancing data comparability.

OBJECTIVE

The aim of the study is to determine whether place of residence (urban vs. rural) influences the incidence of acute pulmonary embolism (APE), and to assess dynamic changes in haematologic parameters – with a focus on RDW – in high-risk orthopaedic patients. The study was framed within the context of current literature highlighting the prognostic value of RDW and the importance of environmental determinants in VTE pathogenesis. To date, no published studies have directly evaluated such correlations.

MATERIALS AND METHOD

A retrospective observational study was conducted in accordance with the Declaration of Helsinki and the principles of Good Clinical Practice (GCP). The study protocol received approval from the Bioethics Committee of the Medical University of Lublin, Poland (Approval No. KE-0254/17/2019). Anonymized data from 276 adult patients hospitalized between 2019 – 2022 in a tertiary orthopaedic department in Eastern Poland were analyzed.

The study population included patients admitted for major orthopaedic procedures (e.g., hip or knee arthroplasty, fracture repair, spinal surgery) and injuries resulting in prolonged immobility (Fig. 1 A – C). All patients met criteria for increased VTE risk due to recent surgery, current clinical status, and limited mobility. Exclusion criteria were: haematologic malignancy, ongoing chemotherapy, megaloblastic anaemia, or confirmed iron-deficiency anaemia.

Patients were classified as urban or rural residents based on official administrative definitions in Poland. Classification was verified using hospital admission forms or, when necessary, information provided by family members. Demographic data were also collected, including gender, age, and co-morbidities, such as hypertension, obesity, and cardiovascular history.

Haematological analysis was performed on venous blood samples collected in EDTA tubes at two time points: (1) upon admission to the orthopaedic department, and (2) at the time of clinical suspicion of APE. All samples were processed within 30 minutes in the hospital's diagnostic laboratory using automated haematology analyzers (Sysmex XN-Series), ensuring uniform analytical conditions.

Group characteristics and analyzed parameters. The following haematologic parameters were assessed:

- red blood cell indices: red blood cell count (RBC), haemoglobin concentration (HGB), haematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC), red cell distribution width (RDW), and haemoglobin distribution width (HDW);
- platelet indices: platelet count (PLT), mean platelet volume (MPV), plateletcrit (PCT), and platelet distribution width (PDW).

The selection of these parameters was based on previous studies suggesting their involvement in inflammatory and thrombotic processes and their potential utility in PE risk assessment [10, 12, 18].

Diagnosis of APE was confirmed or ruled-out based on clinical presentation and computed tomography pulmonary angiography (CTPA), performed in accordance with ESC guidelines [4]. Imaging studies were interpreted by experienced radiologists blinded to patients' laboratory results.

Statistical analysis was conducted using IBM SPSS Statistics version 27. To test the research hypotheses, descriptive statistics, the Kolmogorov–Smirnov normality test, chi-square tests, Mann–Whitney U tests, and Wilcoxon tests were used. A p-value of <0.05 was considered statistically significant.

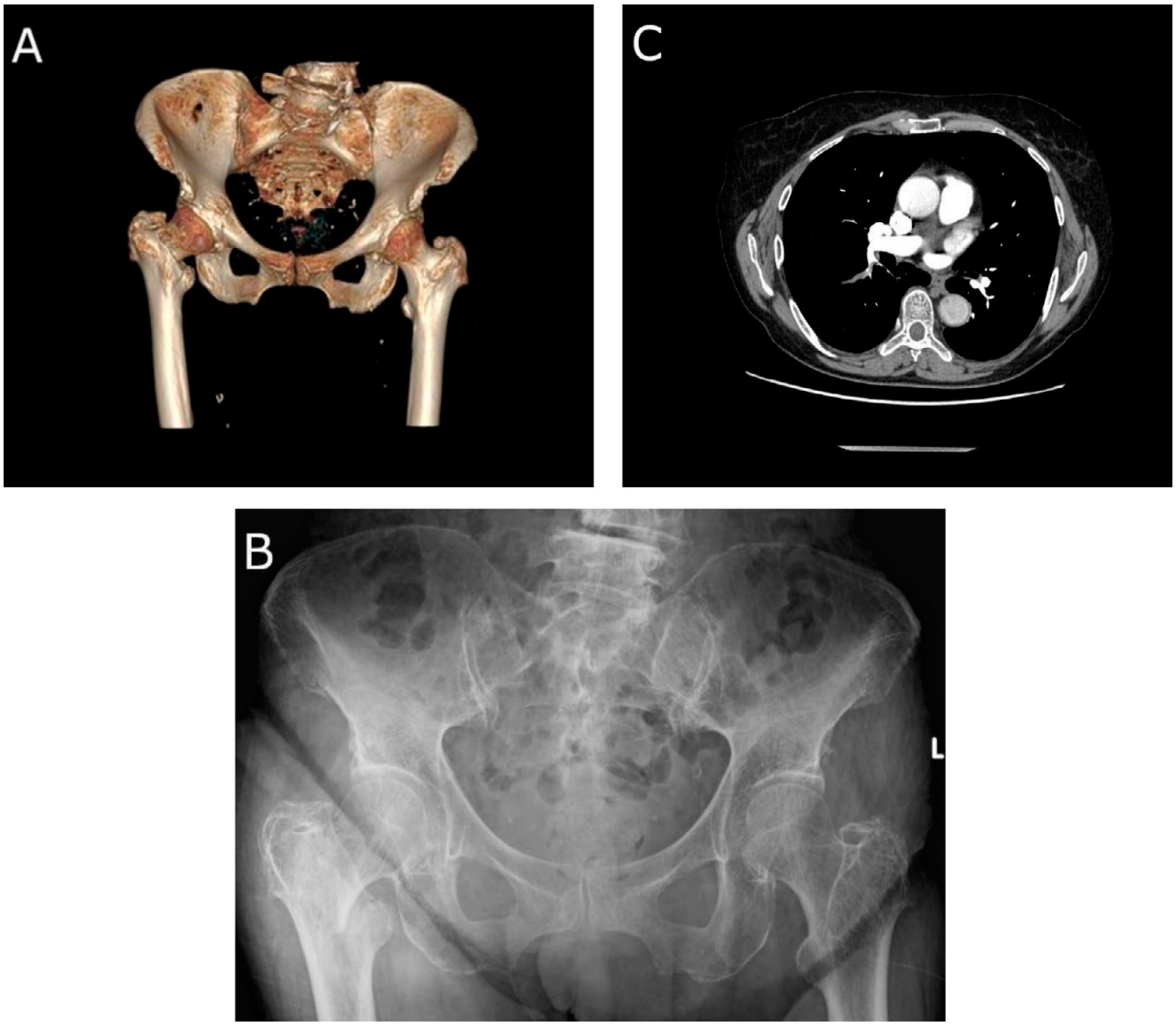

Figure 1. A-C. A 66-year-old patient with a fractured neck of right femur and pulmonary embolism. A – 3D view, B – pelvic X-ray, C – angio-CT image of pulmonary vessels

RESULTS

Two categorical variables were analyzed in this study: place of residence and confirmation or exclusion of APE. Their distribution and interrelationship are presented in Table 1. Among rural residents, APE was confirmed in 46 patients (47.4%) and excluded in 51 (52.6%); among urban residents, it was confirmed in 70 (39.1%) and excluded in 109 (60.9%). The chi-square test showed no statistically significant relationship between place of residence and APE diagnosis (p = 0.181), indicating no association between residential status and the occurrence of pulmonary embolism.

Table 1.. Distribution of pulmonary embolism diagnosis by place of residence (n = 276)

Place of residence	Total n (%)	APE confirmed n (%)	APE excluded n (%)
Village	97 (35.1%)	46 (39.7%)	51 (31.9%)
City	179 (64.9%)	70 (60.3%)	109 (68.1%)
Total	276 (100%)	116 (100%)	160 (100%)

$x^2(1) = 1.78$; p = 0.181; n – number of patients; APE – acute pulmonary embolism

The potential association between gender and APE diagnosis was then assessed within each residence group using chi-square tests (Tab. 2).

Table 2. Distribution of pulmonary embolism diagnosis by gender within residence groups (n = 276)

Residence	Gender	Total n	APE confirmed n (%)	APE excluded n (%)
Village	Female	43	19 (44.2%)	24 (55.8%)
Village	Male	54	27 (50.0%)	27 (50.0%)
City	Female	95	35 (36.8%)	60 (63.2%)
City	Male	84	35 (41.7%)	49 (58.3%)

χ^2 (village, gender) = 0.33; p = 0.683; χ^2 (city, gender) = 0.44; p = 0.542; n – number of patients; APE – acute pulmonary embolism

In both the urban and rural groups, chi-square test results were not statistically significant, indicating no association between gender and APE diagnosis in either subgroup.

Next, relationships between place of residence and haematological parameters were evaluated at two time points: (A) upon admission and (B) at the time of clinical suspicion of APE. At measurement A, red cell distribution width values

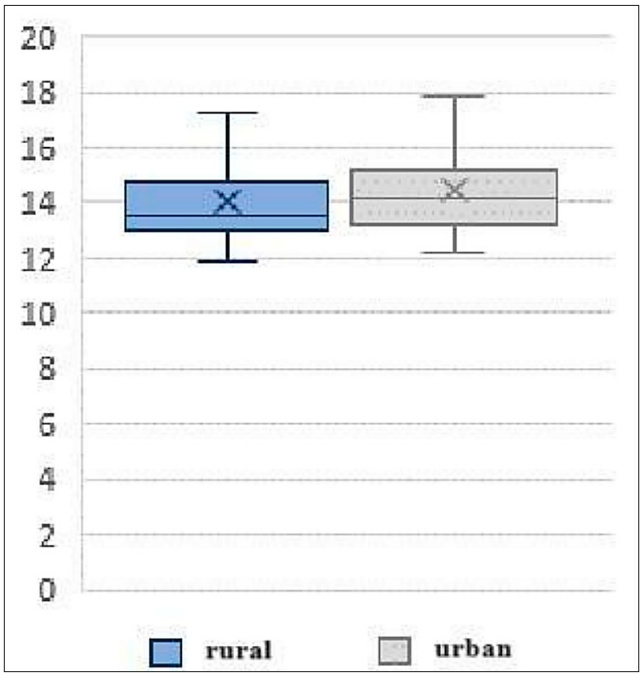

Figure 2. Distribution of RDW laboratory results in Measurement A in rural and urban residents

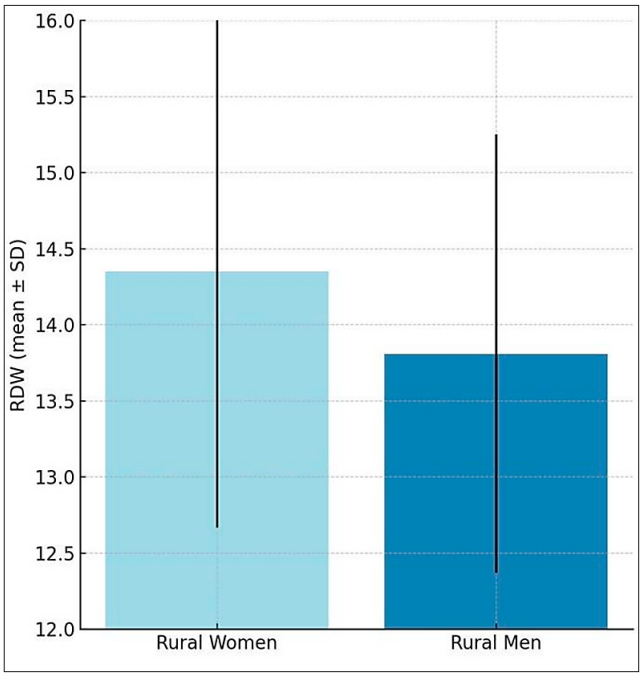

Figure 4. Distribution of RDW (Measurement A) by gender in rural residents

were significantly higher among urban patients compared to rural patients ($p = 0.037$; $\eta^2 = 0.02$) (Fig. 2).

Other parameters, including platelet count (PLT) and platelet distribution width (PDW), showed no statistically significant differences, although PDW approached significance ($p = 0.067$) (Tabl.3).

Due to the statistically significant difference in RDW values on admission (Measurement A), further analyses of this parameter were conducted. A series of Mann–Whitney U tests were performed to assess potential differences in RDW values by gender and place of residence, and additional analyses examined whether RDW levels differed between genders within each residence group (Tab. 4).

More detailed analysis revealed that RDW on admission was significantly higher in females than in males ($p = 0.040$), and also higher in urban than in rural residents ($p = 0.037$ (Fig. 3). Similar to the overall population, among rural residents, females had significantly higher RDW values than males ($p = 0.038$). In the urban subgroup, no significant gender-related difference in RDW was observed ($p = 0.370$) (Fig. 4).

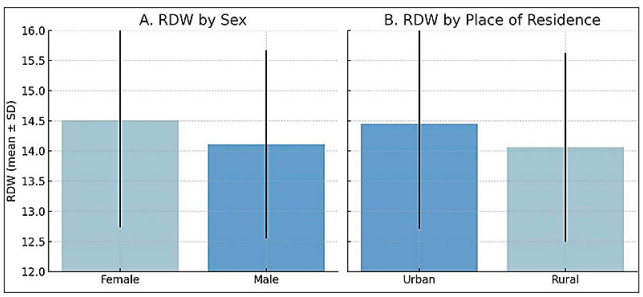

Figure 3. A-B. Grouped comparison of RDW values (Measurement A). **A** – by gender (female vs. male), **B** – by place of residence (urban vs rural).

These results indicate subtle yet statistically significant differences in red blood cell morphology parameters, which may be associated with both gender and place of residence.

DISCUSSION

The presented study sought to assess whether previously described disparities in cardiovascular health between urban and rural populations translate into differences in APE incidence among orthopaedic patients. Contrary to initial expectations, no significant association was found between place of residence and APE occurrence. As both diagnosis and suspicion of APE took place in a standardized hospital environment, the findings suggest comparable healthcare quality and accessibility in the analyzed urban and rural groups.

Venous thromboembolism imposes a substantial burden on healthcare systems, emphasizing the need for accurate yet cost-effective diagnostic methods. Effective diagnosis of APE involves significant resource allocation, both in personnel and infrastructure; therefore, efforts are ongoing to identify biomarkers that may support diagnosis in a resource-efficient manner [18].

This study focused on routine haematologic parameters measured both on hospital admission and at the time of clinical suspicion of APE. RDW was found to be significantly higher in urban patients on admission. Additionally, a clear gender-related pattern emerged: women, especially those from rural areas, had higher RDW values compared to men. These findings suggest a potential influence of demographic and environmental factors on haematological profiles, with implications for APE risk stratification in peri-operative orthopaedic populations.

Although no difference in APE diagnosis was observed between the residential groups, this contrasts with population-based data suggesting unequal distribution of cardiovascular risk factors between urban and rural residents. Numerous national and European studies have documented higher overall mortality, more untreated risk factors, and poorer access to preventive care among rural populations [14, 15]. It is plausible that such disparities are mitigated in the

Table 3. Difference in lab measurements A and B depending on place of residence

	Village (n = 97)			City (n = 179)					
	Mean rank	M	SD	Mean rank	M	SD	Z	p	η^2
Measure A - hospital admission Parameter [unit]									
PLT [thou./µL]	136.74	250.28	113.06	131.76	239.62	96.04	-0.50	0.614	0.00
MPV [fL]	133.57	8.20	1.19	133.46	8.23	1.14	-0.01	0.991	0.00
PCT [%]	134.17	0.20	0.09	131.59	0.20	0.08	-0.26	0.793	0.00
PDW [%]	145.30	54.04	7.28	127.16	51.75	9.76	-1.83	0.067	0.01
RBC [µL]	134.47	4.20	1.13	132.98	4.11	0.68	-0.15	0.880	0.00
HCT [%]	136.90	36.48	5.50	131.67	36.30	5.84	-0.53	0.597	0.00
MCV [fL]	132.59	89.12	5.74	133.99	89.14	6.86	-0.14	0.887	0.00
MCH [pg]	136.48	30.06	2.03	131.90	29.92	2.86	-0.46	0.643	0.00
MCHC [g/dL]	137.35	33.63	1.32	131.43	33.54	1.35	-0.60	0.549	0.00
HGB [g/dL]	138.90	12.56	4.10	130.60	11.98	2.28	-0.84	0.401	0.00
RDW [%]	120.08	14.06	1.57	140.72	14.45	1.74	-2.09	0.037	0.02
HDW [%]	133.33	2.64	0.33	133.59	2.65	0.37	-0.03	0.979	0.00
Measure B - suspected PE Parameter [unit]									
PLT [thou./µL]	148.69	311.35	155.15	132.98	278.89	133.02	-1.56	0.119	0.01
MPV [fL]	140.13	8.37	1.18	137.61	8.35	1.15	-0.25	0.802	0.00
PCT [%]	147.56	0.25	0.12	132.79	0.23	0.12	-1.47	0.141	0.01
PDW [%]	135.10	51.84	8.95	140.34	52.20	10.12	-0.52	0.602	0.00
RBC [µL]	136.61	3.58	0.61	139.52	3.61	0.64	-0.29	0.773	0.00
HCT [%]	135.71	32.12	7.71	140.01	32.07	5.41	-0.43	0.669	0.00
MCV [fL]	136.56	88.20	8.21	139.55	88.99	6.22	-0.30	0.766	0.00
MCH [pg]	135.95	29.75	1.76	139.88	29.92	2.70	-0.39	0.696	0.00
MCHC [g/dL]	136.96	33.49	1.18	139.34	33.45	1.37	-0.24	0.813	0.00
HGB [g/dL]	136.45	10.59	1.68	139.61	10.69	1.74	-0.31	0.753	0.00
RDW [%]	129.27	14.57	1.47	142.76	14.97	1.87	-1.34	0.179	0.01
HDW [%]	135.87	2.88	0.43	138.38	2.91	0.46	-0.25	0.802	0.00

n - number of patients; M - mean; SD - standard deviation; Z - Z-test score; p - probability of test statistic;
η^2 – effect size (potency ratio); PLT - platelets; MPV - thrombocytes; PCT - platelet haematocrit; PDW - platelet anisocytosis index; RBC - red blood cells; HCT - haematocrit; MCV - mean red blood cell volume; MCH - mean red cell haemoglobin mass; MCHC - mean corpuscular haemoglobin concentration; HGB - haemoglobin;
RDW - red cell volume distribution ratio; HDW - haemoglobin distribution ratio

Table 4. Differences in RDW laboratory measurement A by gender and place of residence (n = 276)

Comparison	Group	n	Mean rank	RDW Mean	SD	Z	p	η^2
Gender (total population)	Female	137	142.89	14.51	1.78	-2.05	0.040	0.02
	Male	129	123.53	14.11	1.56			
Residence (total population)	Village	93	120.08	14.06	1.57	-2.09	0.037	0.02
	City	173	140.72	14.45	1.74			
Gender (village only)	Female	42	53.40	14.35	1.68	-	0.038	0.05
	Male	51	41.73	13.81	1.44	2.08		
Gender (city only)	Female	95	90.09	14.58	1.83	-	0.370	0.00
	Male	78	83.23	14.30	1.62	0.90		

n – number of patients; RDW – red cell distribution width; SD – standard deviation; Z – Z-test score; p – probability of test statistic; η^2 – effect size (potency ratio)

controlled hospital environment, where uniform prophylaxis protocols and standardized clinical care are applied [4–6]. This observation warrants further investigation into the pre-hospital health status and preventive care access in different population settings.

RDW as an environmental biomarker. Elevated RDW values among urban patients may reflect underlying sub-clinical processes not yet manifesting as clinical embolism. RDW is increasingly regarded as an intermediate marker of chronic inflammation, oxidative stress, and impaired erythropoiesis [10, 12]. In PE, increased RDW correlates

with right ventricular dysfunction, elevated troponins and natriuretic peptides (BNP), and higher 30-day mortality [11, 12]. Some studies also suggest that RDW reflects embolus size and the degree of hypoxaemia, particularly in normotensive patients [19]. Environmental exposures prevalent in urban settings may contribute to these haematological differences. Particulate matter (PM2.5), nitrogen oxides, traffic noise, and circadian rhythm disruption are linked to endothelial activation, microvascular dysfunction, and chronic systemic inflammation. These mechanisms may predispose urban residents to elevated RDW even in the absence of overt clinical symptoms.

Additionally, psychosocial stress, social isolation, sedentary behaviour, and time pressure may further affect erythropoietic aging and haematologic variability [11, 13, 20].

In contrast, elevated RDW levels among rural women may result from distinct biological and systemic factors. Hormonal status, menstrual blood loss, nutritional deficiencies (e.g., iron, folate), and autoimmune disorders could partially explain the observed differences. In rural settings, these factors may be exacerbated by lower health awareness, delayed care-seeking behaviour, and limited access to diagnostics [20, 21]. The observed RDW variations by gender and residence merit further investigation in broader population cohorts.

Although platelet indices such as PDW showed only a trend toward statistical significance, their prognostic value remains debated. In the current study, PDW on admission was higher in rural residents, although not significantly ($p = 0.067$). While some studies suggest elevated PDW in confirmed PE cases, others question its diagnostic relevance [17, 22]. These findings highlight the need for larger, well-designed studies that combine haematologic data with clinical outcomes.

From a clinical perspective, obtained findings support the potential utility of RDW as an adjunctive biomarker for APE risk stratification in orthopaedic patients. As RDW is a standard component of CBC, its inclusion in early risk algorithms could be both practical and cost-effective. In resource-limited settings, or when imaging is delayed, RDW may complement D-dimer testing and guide the urgency of further diagnostic evaluation [23]. This approach aligns with contemporary PE management models emphasizing individualized, multimodal risk assessment [4, 5, 8].

It is also important to note that elevated RDW in patients without confirmed APE may reflect a chronic or predispositional inflammatory state rather than acute pathology. This distinction is essential for identifying individuals with persistent endothelial activation who may be at risk for future thrombotic or cardiovascular complications [24].

Future prospective studies should assess temporal fluctuations in RDW in relation to surgery, hospitalization, and VTE development. Integrating RDW with other parameters – such as D-dimers, cardiac biomarkers, and clinical prediction tools (e.g., Wells or Geneva scores) – may enhance risk prediction accuracy. Taking gender- and environment-specific variables into consideration could further strengthen personalized preventive strategies and early intervention models.

CONCLUSIONS

This retrospective cohort study demonstrated that, despite documented disparities in cardiovascular health and access to care, rural residents were not significantly more likely to develop APE compared to their urban counterparts. However, the elevated RDW values observed in urban patients upon admission suggest that routinely measured haematologic parameters, particularly RDW, may be useful for identifying and predicting APE risk.

These findings indicate that environmental or lifestyle factors specific to urban populations may influence haematologic profiles. In light of this, future prospective studies are warranted to evaluate RDW trends over time, explore their associations with clinical events, and integrate RDW into predictive models for personalized VTE prevention. Such an approach may improve diagnostic precision, reduce healthcare costs, and ultimately contribute to lower morbidity and mortality associated with pulmonary embolism.

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