Red Blood Cell Distribution Width Predicts Myocardial Infarction and Mortality After Vascular Surgery–A Prospective Cohort Study

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Abstract

Background This study aims to investigate the association between preoperative Red blood cell Distribution Width (RDW) and postoperative outcomes, including myocardial infarction (MI), and mortality.

Methods A prospective cohort including all patients submitted to elective vascular arterial surgery at a university hospital. The primary and secondary outcomes were 30-day mortality and 30-day MI, respectively.

Results Atrial fibrillation, chronic kidney disease (CKD), and dependent functional status were more prevalent in deceased patients. After multivariable analysis, age (adjusted OR 1.08, 95% Confidence Interval [1.01–1.15], \( p = 0.027 \)) and RDW-standard deviation (RDW-SD) (1.08 [1.01–1.16], \( p = 0.032 \)) remained independent predictors of mortality. Patients with MI had higher rates of diabetes, CKD, dependent functional status, ASA physical status IV, and insulin medication. After multivariable analysis, dependent functional status (4.8 [1.6–15.0], \( p = 0.007 \)), insulin medication (4.4 [1.5–12.6], \( p = 0.007 \)) and RDW-SD (1.10 [1.02–1.19], \( p = 0.020 \)) were independent predictors of MI.

Conclusion RDW-SD independently predicted postoperative MI and mortality, and may provide valuable information for prevention and early management of adverse outcomes.

Introduction

Cardiovascular diseases are a leading cause of morbidity and mortality worldwide [1]. The identification and strict control of cardiovascular risk factors, such as hypertension, diabetes, obesity, smoking, or dyslipidemia, play an important role in the prevention of future cardiovascular events [2]. The red blood cell distribution width (RDW) is a measure of the variability in size of circulating erythrocytes and may also be useful in risk stratification and early management of these events [3–5]. It measures the difference in size between the largest and the smallest cells,
reflecting the heterogeneity amongst these cells’ dimensions. In most automated laboratory blood counters, it is expressed as a coefficient of variation (RDW-CV), defined by the ratio between RDW standard deviation (RDW-SD) and the mean corpuscular volume [6, 7]. The term anisocytosis corresponds to an increase in the RDW, meaning that the size distribution of red blood cells has a greater variation when compared to normal RDW values. Traditionally, this blood count parameter has been exhaustively studied in hematological diseases, such as bone marrow dysfunction or anemia due to deficiencies in vitamin B12, folate, or iron [7]. Nowadays, new evidence supports a correlation between the RDW and the development of adverse cardiovascular events, such as myocardial infarction (MI), stroke, coronary disease, heart failure, or peripheral artery disease (PAD) [4, 6, 8]. Recent studies show that high RDW values are associated with all-cause mortality both in patients with and without known cardiac disease, as well as a greater mortality rate in older individuals in the presence or absence of major age-associated diseases [4]. Moreover, some reveal that the RDW baseline value is a strong and independent predictor of poor prognostic outcomes following cardiovascular interventions, such as percutaneous coronary intervention [4, 9], carotid endarterectomy [8], or percutaneous transluminal angioplasty [9].

The neutrophil–lymphocyte ratio (NLR) is another parameter that is easily accessible in a complete blood count. Recent studies have demonstrated that NLR is related to the severity and long-term prognosis of cardiovascular diseases, as in acute coronary syndrome, heart failure, or valvular heart disease [1]. It is considered an indicator to assess systemic inflammation and has been used in some studies to predict episodes of stenosis secondary to inflammation, such as ischemic heart disease [10].

Despite the evolution of anesthetic and surgical techniques in vascular surgery, along with improved perioperative planning and monitoring, postoperative mortality is still significant [11, 12]. Patients who are proposed to vascular surgery usually have multiple cardiovascular risk factors that increase the risk of major adverse cardiovascular events [13]. Previous studies have reported independent risk factors for postoperative mortality, including age, PAD, smoking status, chronic kidney disease (CKD), atrial fibrillation, and leucocyte count [11, 12]. Myocardial infarction following vascular surgery may range from 0.3 to 36% [13]. Ischemic heart disease, atrial fibrillation, and insulin-treated diabetes mellitus have been identified as independent predictors of major adverse cardiac events, including MI [13].

The aim of this study was to evaluate the potential role of preoperative hematological parameters in predicting perioperative outcomes, including MI and all-cause mortality.

**Methods**

**Study design, setting, and participants**

We designed a prospective observational cohort study to include all adult patients submitted to elective vascular arterial surgery between January and April 2015 at a university hospital with 1000 beds performing around 800 elective arterial vascular surgeries per year. The protocol was approved by the institutional ethics committee (authorization CES 04–15) and registered in ClinicalTrials.gov (NCT04051749). Patients’ consent was obtained before inclusion. This manuscript is reported according to Strengthening the Reporting of Observational Studies in Epidemiology (The STROBE Statement) [14] and Strengthening the Reporting of Cohort Studies in Surgery (The STROCSS Statement) [15].

**Data collection**

All patients were evaluated by a vascular surgeon and an anesthesiologist before the surgery. Variables were prospectively collected before and during surgery: age, gender, comorbidities (based on usual medication or follow-up by other medical specialties), vital signs parameters, analytic findings, electrocardiographic results, physical status according to the American Society of Anesthesiology (ASA), anesthetic and surgical technique and duration, drugs prescribed, blood loss and required transfusions. Preoperative cardiac evaluation was based on reported symptoms, clinical history, functional capacity (metabolic equivalents), dyspnea or orthopnea, and medication. Diabetes was based on HbA1c ≥6.5%, fasting glucose ≥126 mg/dl, random glucose ≥200 mg/dl or hypoglycemic therapy; hypertension was defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg or antihypertensive treatment; cerebrovascular disease was symptomatic or significant stenosis (>50%), history of transient ischemic attack or stroke; coronary disease were patients with angina or previous MI; congestive heart failure was based on clinical and echocardiogram findings; CKD was defined as Glomerular Filtration Rate <60 ml/min, albuminuria (albumin to creatinine ratio ≥30 mg/g), under dialysis or kidney transplant; PAD could be intermittent claudication (Fontaine IIa/b or Rutherford 1–3) or critical limb ischemia (Fontaine III/IV or Rutherford 4–6); dependent functional status were patients with limited exercise capacity (Metabolic Equivalents <4) who were not independent in...
activities of daily living. Patients with coronary artery disease or heart failure were only submitted to surgery (and included in the study) if their cardiac clinical condition was considered stable. Recent ischemic pain, higher intensity or longer than normal, occurring with less effort or at rest were sent to the Cardiology Department and additional studies (laboratory analysis, echocardiography, cardiac stress test, coronary angiography, or cardiac magnetic resonance) were requested as necessary. Surgeries were divided into intermediate or high-risk surgery according to the joint guidelines of European Society of Cardiology (ESC) and European Society of Anesthesiology (ESA) [16].

Outcomes

Postoperative assessment was performed during the hospital stay and in the outpatient clinic. We considered 30-day mortality as the primary outcome. The secondary outcome was 30-day MI, defined by chest pain, ST-segment changes in electrocardiography, or a high sensitivity myocardial Troponin levels >34 ng/L, following the ESC/American College of Cardiology criteria [17]. Information regarding other major cardiovascular events (new atrial fibrillation or heart failure, pulmonary edema requiring intervention, complete heart block, ventricular arrhythmias, or cardiac arrest) was also recorded.

Statistical analysis

Comparisons in univariate analysis were performed using Qui square or Fisher’s tests for categorical and parametric (independent samples t-test) or non-parametric (Mann–Whitney-U) tests for continuous variables. Descriptive statistics summarized the data. Since we analyzed two outcomes (mortality and MI), we used the Bonferroni correction to decrease the probability of a type I error, which resulted in a p-value <0.025. Significant variables in the univariate analysis were included in the multivariate logistic regression to determine the independent predictors, calculating the Odds Ratio (OR) and its 95% confidence interval (CI). Hemoglobin levels and surgery risk were included in the multivariate models to exclude RDW variation due to anemia and the impact of surgery type on the outcomes. The Area Under the Receiver Operating Characteristics Curve (AUROC) was analyzed to study the discrimination of laboratory results and the multivariable model. The goodness of fit and calibration of our model was assessed using the Hosmer–Lemeshow test (p >0.05 means no difference between observed data and predictive model. Stata 14 and SPSS (IBM Corp., version 26.0, Armonk, NY, USA) was used for data analysis.

Results

In this prospective cohort, 265 patients were submitted to elective arterial vascular surgery and included in the study. Table 1 shows the main features of the surgical interventions to which they were submitted. Forty-eight percent (128 out of 265) were high-risk surgery according to ESC/ESA guidelines. Table 2 shows the univariate analysis of mortality (primary outcome). Atrial fibrillation, CKD, and dependent functional status in activities of daily living were more prevalent in patients who died. These patients were more likely medicated with diuretics and less with statins. The values of RDW and urea were significantly higher in deceased patients.

We did not observe any other major cardiovascular event besides MI. The univariate analysis of MI (secondary outcome), as shown in Table 3, reveals that patients with MI had longer hospital stay (44 vs 16 days, p = 0.002) and higher mortality (20 vs 4.9%, p = 0.005) corresponding to an OR of 6.4, 95% CI [1.5–26.2], p = 0.011. Patients with postoperative MI had higher rates of diabetes, CKD, dependent functional status, ASA physical status IV, and insulin medication. The values of RDW-SD, NLR, and serum creatinine were significantly higher in patients with MI. Patients with an NLR greater than 2.9 had more MI events: 9.5 vs 3.4%, p = 0.033.

Intraoperative vital signs estimated blood loss (76 had < 500 ml, 160 had 500–1000 ml and 29 patients >1000 ml) and transfusion requirements (17 needed 1 or more units of Red Blood Cells, 4 received a unit of fresh frozen plasma and 2 patients a platelet concentrate) had the same distribution between groups (p >0.300) and did not influence mortality or MI.

After multivariable logistic regression analysis, age and RDW-SD remained independent predictors of mortality (Table 4). The increase in risk is 8% per year (adjusted OR

| Table 1 List of included procedures |
|-------------------------------------|
| **Lower extremity surgery**          |
| Femoro-popliteal bypass              | 28 |
| Femoro-distal bypass                 | 6  |
| Endovascular therapy                 | 44 |
| Major amputation                     | 45 |
| Minor amputation                     | 39 |
| Debridement                          | 29 |
| **Aortoiliac revascularization**     |
| Open                                 | 19 |
| Endovascular                         | 9  |
| **Aortoiliac aneurysm repair**       |
| Open                                 | 2  |
| Endovascular                         | 8  |
| **Carotid endarterectomy**           |
|                                      | 36 |
| **Total**                            | 265 |
Table 2 Univariate analysis of 30-day mortality

| Variables                              | Survival group (n = 254) | Mortality group (n = 11) | p value |
|----------------------------------------|--------------------------|--------------------------|---------|
| Age (years), median [IQR]              | 65 [58–74]               | 77 [65–82]               | 0.003*  |
| Male gender, n(%)                      | 203 (71.0)               | 8 (72.7)                 | 0.900†  |
| Prior medical history, n(%)            |                          |                          |         |
| Arterial hypertension                  | 186 (73.2)               | 8 (72.7)                 | 0.980†  |
| Peripheral arterial disease            | 142 (55.9)               | 7 (63.6)                 | 0.761†  |
| Diabetes                               | 137 (53.9)               | 3 (27.3)                 | 0.122†  |
| Current smoker                         | 111 (43.7)               | 6 (54.5)                 | 0.546†  |
| Chronic kidney disease                 | 80 (31.5)                | 7 (63.6)                 | 0.025†  |
| Coronary disease                       | 54 (21.3)                | 1 (9.1)                  | 0.470†  |
| Congestive heart failure               | 31 (12.2)                | 2 (18.2)                 | 0.634†  |
| Atrial fibrillation                    | 13 (5.1)                 | 3 (27.3)                 | 0.003†  |
| Dependent functional status, n(%)      | 21 (8.3)                 | 3 (27.3)                 | 0.025†  |
| ASA physical status, n(%)              |                          |                          |         |
| II/III                                 | 238 (93.7)               | 9 (81.8)                 | 0.146†  |
| IV                                     | 16 (6.3)                 | 2 (18.2)                 |         |
| Usual medication, n(%)                 |                          |                          |         |
| Antiplatelet drug                      | 161 (63.4)               | 7 (63.6)                 | 0.993†  |
| Statin                                 | 163 (64.2)               | 3 (27.3)                 | 0.013†  |
| Diuretic                               | 79 (31.1)                | 7 (63.6)                 | 0.024†  |
| Insulin                                | 67 (26.4)                | 1 (9.1)                  | 0.299†  |
| Beta-blocker                           | 64 (25.2)                | 4 (36.4)                 | 0.074†  |
| Pre-op lab results, median [IQR]:      |                          |                          |         |
| Hemoglobin (g/dL)                      | 11.9 [10.3–13.8]         | 11.3 [10.1–12.7]         | 0.456*  |
| MCV (fL)                               | 88.8 [85.0–92.5]         | 93.5 [86.3–96.9]         | 0.066*  |
| MCH (pg)                               | 29.9 [28.3–31.2]         | 31.7 [28.0–32.7]         | 0.214*  |
| MCHC (g/dL)                            | 33.5 [32.6–34.3]         | 33.3 [32.2–34.3]         | 0.715*  |
| RDW-CV (%)                             | 14.0 [13.1–15.0]         | 15.5 [14.5–16.5]         | 0.009*  |
| RDW-SD (fL)                            | 45.0 [42.7–49.1]         | 50.9 [49.5–55.7]         | < 0.001*|
| WBC (× 10^3/μL)                        | 8.4 [6.9–10.7]           | 8.8 [6.9–11.0]           | 0.882*  |
| Platelets (× 10^3/μL)                  | 249 [196–336]            | 226 [163–316]            | 0.377*  |
| Serum creatinine (mg/dL)               | 0.9 [0.7–1.5]            | 1.7 [0.9–3.0]            | 0.060*  |
| Serum urea (mg/dL)                     | 42 [31–63]               | 78 [41–123]              | 0.015*  |
| [Na⁺] (mEq/L)                          | 137 [135–140]            | 136 [133–139]            | 0.628*  |
| [K⁺] (mEq/L)                           | 4.4 [4.0–4.8]            | 4.0 [3.5–4.5]            | 0.087*  |
| [Cl⁻] (mEq/L)                          | 102 [99–105]             | 101 [97–107]             | 0.686*  |
| Blood glucose (mg/dl)                  | 113 [92–168]             | 96 [82–138]              | 0.252*  |
| Pre-op vital signs, median [IQR]:      |                          |                          |         |
| Heart rate (bpm)                       | 71 [66–80]               | 72 [64–97]               | 0.489*  |
| Systolic blood pressure (mmHg)         | 135 [118–147]            | 122 [104–144]            | 0.188*  |
| Diastolic blood pressure (mmHg)        | 68 [62–77]               | 61 [54–74]               | 0.210*  |
| Temperature (°C)                       | 36.0 [36.0–36.5]         | 36.2 [36.0–36.6]         | 0.710*  |
| Postoperative MI, n(%)                 | 14 (5.5)                 | 3 (27.3)                 | 0.004†  |

Statistically significant values are given in bold (p < 0.05)

*Mann–Whitney test, †Fisher’s-exact test. IQR Interquartile range [P25–P75]. ASA American society anesthesiology. MCV Mean corpuscular volume. MCH Mean corpuscular hemoglobin. MCHC Mean corpuscular hemoglobin concentration. RDW Red cell distribution width. CV Coefficient variation. SD Standard deviation. WBC White blood cells. MI Myocardial infarction
### Table 3: Univariate analysis of myocardial infarction (MI)

| Variables                              | Without MI (n = 246) | With MI (n = 19) | p value  |
|-----------------------------------------|----------------------|------------------|----------|
| **Age (years), median [IQR]**           | 65 [58–74]           | 66 [65–77]       | 0.135*   |
| Male gender, n(%):                      | 174 (70.7)           | 14 (73.7)        | 0.793†   |
| **Prior medical history, n(%):**        |                      |                  |          |
| Arterial hypertension                   | 179 (72.8)           | 15 (78.9)        | 0.815‡   |
| Peripheral arterial disease             | 138 (56.1)           | 12 (63.2)        | 0.540‡   |
| Diabetes                                | 126 (51.2)           | 15 (78.9)        | 0.019‡   |
| Current smoker                          | 107 (43.5)           | 11 (57.9)        | 0.216‡   |
| Chronic kidney disease                  | 77 (31.3)            | 10 (52.6)        | 0.087‡   |
| Coronary artery disease                 | 50 (20.3)            | 7 (36.8)         | 0.071‡   |
| Cerebrovascular disease                 | 48 (19.5)            | 7 (36.8)         | 0.072‡   |
| Congestive heart failure                | 29 (11.8)            | 5 (30.0)         | 0.099‡   |
| Atrial fibrillation                     | 13 (5.3)             | 3 (15.8)         |          |
| Dependent functional status, n(%)       | 17 (6.9)             | 8 (42.1)         | < 0.001† |
| **ASA physical status, n(%)**           |                      |                  |          |
| II/III                                  | 231 (93.9)           | 15 (78.9)        | 0.009‡   |
| IV                                      | 15 (6.1)             | 4 (21.1)         |          |
| **Usual medication, n(%):**             |                      |                  |          |
| Antiplatelet                            | 153 (62.2)           | 16 (84.2)        | 0.082‡   |
| Statin                                  | 154 (62.6)           | 13 (68.4)        | 0.603‡   |
| Diuretic                                | 77 (31.3)            | 9 (47.4)         | 0.151‡   |
| Beta-blocker                            | 63 (25.6)            | 4 (21.1)         | 0.790‡   |
| Insulin                                 | 52 (21.1)            | 12 (63.2)        | < 0.001† |
| **Pre-op lab results, median [IQR]:**   |                      |                  |          |
| Hemoglobin (g/dL)                       | 11.9 [10.3–13.8]     | 11.5 [9.8–12.6]  | 0.233*   |
| MCV (fL)                                | 88.7 [84.9–92.4]     | 92.9 [90.0–97.1]| 0.002*   |
| MCH (pg)                                | 29.8 [28.2–31.2]     | 31.1 [29.6–32.5]| 0.073*   |
| MCHC (g/dL)                             | 33.5 [32.7–34.3]     | 33.0 [32.2–33.7]| 0.112*   |
| RDW-CV (%)                              | 14 [13.1–15.0]       | 14.8 [13.2–15.9]| 0.134*   |
| RDW-SD (fL)                             | 45.0 [42.8–49.1]     | 50.2 [43.1–55.7]| 0.025*   |
| WBC (× 10⁹/μL)                          | 8.3 [6.8–10.7]       | 9.6 [8.0–12.0]   | 0.070*   |
| Platelets (× 10³/μL)                    | 249 [196–337]        | 211 [185–275]    | 0.116*   |
| Serum creatinine (mg/dL)                | 0.92 [0.68–1.48]     | 1.49 [0.84–3.47]| 0.010*   |
| Serum urea (mg/dL)                      | 42 [31–63]           | 58 [35–76]       | 0.090*   |
| [Na⁺] (mEq/L)                           | 137 [135–139]        | 137 [134–141]    | 0.932*   |
| [K⁺] (mEq/L)                            | 4.4 [4.0–4.8]        | 4.2 [3.6–4.7]    | 0.250*   |
| [Cl⁻] (mEq/L)                           | 102 [99–105]         | 100 [97–106]     | 0.487*   |
| Blood glucose (mg/dL)                   | 111 [92–164]         | 89 [59–208]      | 0.675*   |
| **Pre-op vital signs, median [IQR]:**   |                      |                  |          |
| Heart rate (bpm)                        | 71 [66–80]           | 84 [66–88]       | 0.111*   |
| Systolic blood pressure (mmHg)          | 136 [119–149]        | 121 [109–143]    | 0.150*   |
| Diastolic blood pressure (mmHg)         | 68 [61–77]           | 64 [59–71]       | 0.210*   |
| Temperature (°C)                        | 36.0 [36.0–36.5]     | 36.1 [36.0–36.6]| 0.512*   |
| Postoperative mortality, n(%)           | 12 (4.9)             | 5 (20.0)         | 0.005‡   |
| Length of stay (days), [IQR]            | 16 [6–37]            | 44 [24–68]       | 0.002*   |

Statistically significant values are given in bold (p < 0.05)

*Mann–Whitney test, †Chi-Square test, ‡Fisher’s-exact test, IQR Interquartile range [P25–P75], ASA American society anesthesiology, MCV Mean corpuscular volume, MCH Mean corpuscular hemoglobin, MCHC Mean corpuscular hemoglobin concentration, RDW Red cell distribution width, CV Coefficient variation, SD Standard deviation, WBC White blood cells, MI Myocardial infarction
1.08 [1.01–1.15], \( p = 0.027 \)) and 8% per unit increase in RDW-SD (1.08 [1.01–1.16], \( p = 0.032 \)). The AUROC to predict mortality was 0.81 (95% CI 0.71–0.91) for the RDW-SD alone and raised to 0.83 (95% CI 0.70–0.96) when combining age (Fig. 1).

Table 5 presents the multivariable analysis of MI that resulted in three independent predictors: dependent functional status (4.8 [1.6–15.0], \( p = 0.007 \)), insulin medication (4.4 [1.5–12.6], \( p = 0.007 \)) and RDW-SD (1.10 [1.02–1.19], \( p = 0.020 \)). The increase in risk is 10% per unit of RDW-SD. The NLR was significant in the univariate analysis (OR 1.07, \( p = 0.048 \)) but was not an independent predictor of MI in the multivariable analysis. The AUROC to predict MI was 0.66 (95% CI 0.50–0.80) for the RDW-SD, 0.71 (95% CI 0.59–0.84) for NLR, and 0.79 (95% CI 0.69–0.90) when combining the three independent predictors (Fig. 2).

**Discussion**

This prospective cohort study demonstrated that an increase in the RDW-SD value is a significant independent predictor of mortality and MI in the early postoperative period after elective arterial vascular surgery. Also, an increase in the NLR has a reasonable predictive ability for MI events. The pathophysiological mechanisms that lead to the association between RDW or NLR and adverse cardiovascular outcomes are still not fully understood. Prior studies have shown that there is a positive association between the RDW and inflammatory biomarkers, such as C-reactive protein (CRP), interleukin 6, erythrocyte sedimentation rate, soluble tumor necrosis factor, and oxidative stress [18, 19]. These play an important role in the inhibition of erythrocyte maturation at the bone marrow, which results in anisocytosis, suggesting that RDW reflects the inflammatory state required for the progression of atherosclerotic disease [2]. Moreover, some studies have demonstrated that inflammatory cytokines can suppress the synthesis of erythropoietin, causing dysregulation in the red blood cells’ maturation process [5]. Oxidative stress is strongly related to the erythrocytes’ variability in size since it shortens these cells’ lifespan and impairs iron metabolism, leading to the production and release of immature forms into the systemic circulation [3, 5]. Elevated RDW values are associated with a decrease in erythrocyte deformability, which in turn leads to a higher propensity for developing thrombotic events as well as an impaired blood flow, leading to tissue ischemia [20]. The NLR has been broadly studied as a marker of systemic inflammation and hence, of cardiovascular risk [2, 21]. It has been proven that neutrophils contribute to endothelial dysfunction along with the recruitment of monocytes to atherosclerotic lesions, leading to the disruption of atherosclerotic plaques [2]. This supports the impact that these cells have in the development of atherosclerotic disease, resulting in greater susceptibility to adverse cardiovascular outcomes.

**Table 4** Multivariate analysis of 30 day-mortality

| Variables                  | OR (95% CI) | \( p \) value | aOR (95% CI) | \( p \) value |
|----------------------------|-------------|---------------|--------------|--------------|
| Age                        | 1.10 (1.03–1.17) | 0.005         | 1.08 (1.01–1.15) | 0.027        |
| Chronic kidney disease     | 3.8 (1.1–13.3)  | 0.037         |              |              |
| Atrial fibrillation        | 6.8 (1.6–28.1)  | 0.009         |              |              |
| Statin medication          | 0.2 (0.1–0.8)   | 0.023         |              |              |
| Diuretic medication        | 3.8 (1.1–13.5)  | 0.035         |              |              |
| RDW-CV                     | 1.27 (1.02–1.59) | 0.036        |              |              |
| RDW-SD                     | 1.09 (1.02–1.16) | 0.011        | 1.08 (1.01–1.16) | 0.032        |

OR Odds ratio. CI Confidence interval. aOR Adjusted odds ratio. RDW Red cell distribution width. CV Coefficient variation. SD Standard deviation.
In this study, atrial fibrillation (AF) was more prevalent in deceased patients. Previous studies suggest that inflammation and oxidative stress take part in the primary pathways that lead to cardiac arrhythmias [1]. AF has been proven to be a strong risk factor for cerebral and cardiovascular mortality including in the postoperative period, as the main causes of death are stroke, ischemic heart disease, heart failure, and myocardial infarction [22–24]. The prevalence of CKD was higher in both the mortality and the MI group. Evidence suggests that there is a direct correlation between the prevalence of cardiovascular disease and the severity of CKD [25]. Patients with CKD have many cardiovascular comorbidities such as hypertension, diabetes mellitus, dyslipidemia, and advanced age [25]. Other risk factors, such as anemia, proteinuria, oxidative stress, and inflammation may also take part in the development of these diseases [25]. Dependent functional status was more prevalent in deceased patients and was an independent predictor of postoperative MI. Prior studies have proven that patients not independent in activities of daily living have a higher incidence of comorbid disease and exhibit more often malnutrition and cognitive dysfunction [26, 27]. Furthermore, evidence shows that these patients have a greater mortality rate when compared with functionally independent individuals [26, 27]. As such, preoperative dependent functional status could be used as an indicator of adverse outcomes following surgical interventions.

Insulin-treated diabetes was an independent predictor of postoperative MI. Diabetes is associated with an increased risk of micro and macrovascular complications [19, 28]. Hyperglycemia accelerates the development of atherosclerotic plaques and has a negative impact on the clotting mechanism, which can increase the risk of thrombosis, especially at the coronary arteries [29]. Previous studies have shown that diabetic patients treated with insulin have higher risk of developing major cardiovascular events, such as MI or stroke when compared with no insulin medication [30]. It is uncertain whether it in fact insulin increases the risk of adverse outcomes or whether it represents advanced diabetic disease that leads to a greater predisposition for worse clinical prognosis [30]. Other studies have found a correlation between the metabolic effects of insulin therapy, namely hypoglycemia and weight gain, and greater cardiovascular risk [31]. Hypoglycemia, as a result of intensive insulin treatment, has been associated with life-threatening cardiovascular complications, such as cardiac arrhythmias, prolonged QT intervals and abnormal T wave morphology, and myocardial ischemia [31].

This study has some limitations. It focuses on short-term outcomes and a major limitation is the lack of longer follow-up. The risk of a type I error is also a concern that we try to minimize by using the Bonferroni correction to adjust for multiple comparisons. Data on other factors that might influence the RDW, such as nutritional deficiencies in folate or vitamin B12, were not available for analysis. We only included patients submitted to elective surgery and more fragile individuals are less likely to be proposed to invasive procedures. This study was performed in a large

### Table 5 Multivariate analysis of myocardial infarction (MI)

| Variables          | OR (95% CI)     | p value | aOR (95% CI)     | p value |
|--------------------|-----------------|---------|------------------|---------|
| Diabetes           | 3.6 (1.2–11.0)  | 0.027   |                  |         |
| Dependent status   | 9.9 (3.6–27.5)  | <0.001  | 4.8 (1.6–15.0)   | 0.007   |
| Insulin medication | 5.7 (2.2–15.1)  | <0.001  | 4.4 (1.5–12.6)   | 0.007   |
| RDW-CV             | 1.30 (1.07–1.58)| 0.009   |                  |         |
| RDW-SD             | 1.11 (1.04–1.18)| 0.002   | 1.10 (1.02–1.19) | 0.020   |

*OR* Odds ratio. *CI* Confidence interval. *aOR* Adjusted odds ratio. *RDW* Red cell distribution width. *CV* Coefficient variation. *SD* Standard deviation

![Fig. 2 Receiver operating characteristics (ROC) curves for myocardial infarction. 453 × 329 mm (72 × 72 DPI)](image)
academic teaching institution, which might affect the external validity of the results in community hospitals.

**Conclusion**

The use of hematological parameters as prognostic biomarkers has been investigated over the years since these are inexpensive, routinely measured in clinical practice, and easily accessible in all automatic complete blood counters. Age and RDW-SD were identified as independent predictors of mortality, and dependent functional status, RDW-SD, and insulin medication as independent predictors of MI. The RDW-SD was deemed as having a better predictive capacity than the RDW-CV for the outcomes mortality and MI. The results of this prospective study suggest that the RDW may be important in risk assessment of patients scheduled for elective vascular arterial surgery and useful in the prevention of adverse events.

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**Declarations**

**Conflict of interest** The authors have no related conflicts of interest to declare.

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