



The Correlation Between RDW, MPV and Weight Indices After Metabolic Surgery in Patients with Obesity and DM/IGR: Follow-Up Observation at 12 Months

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ABSTRACT

Introduction: Red blood cell distribution width (RDW) and mean platelet volume (MPV) are both new biomarkers for the prognosis of many diseases. This study aimed to observe the predictive values of RDW and MPV for weight loss

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after different metabolic surgeries in patients with obesity and abnormal glucose metabolism [diabetes mellitus or impaired glucose regulation (DM/IGR)].

Methods: We retrospectively analyzed the body weight (BW), body mass index (BMI) and blood routine index of 98 patients with obesity and DM/IGR who underwent Roux-en-Y gastric bypass (RYGB) or sleeve gastrectomy (SG).

Results: Levels of RDW and MPV in both groups were significantly higher than before 1 month after surgery and then gradually decreased. Twelve months after surgery, the RDW level in the RYGB group was significantly lower than that before surgery. In the RYGB group, the RDW level of patients in the high-level percentage weight loss (%BW) (≥ 31.90) at 6 and 12 months after surgery decreased significantly compared to those in the corresponding low level. %BW and change in BW and BMI (Δ BW and Δ BMI) at 6 and 12 months after surgery in the high-level RDW (≥ 12.90) before surgery were significantly higher than those in the low level in the RYGB group. No significant difference in weight index was found in the high and low levels of the MPV before surgery in either group at other follow-up time points.

Conclusions: Preoperative baseline RDW and postoperative RDW levels can preliminarily predict the effect of different metabolic surgeries in patients with obesity and DM/IGR.

Keywords: Diabetes mellitus; Impaired glucose regulation; Mean platelet volume; Metabolic

surgery; Obesity; Red blood cell distribution width

Key Summary Points

Metabolic diseases threaten human health worldwide. Metabolic surgeries, especially RYGB and SG, are effective treatments for obesity and diabetes

A simple and economic indicator (such as RDW or MPV) that can accurately predict the outcome of surgery in advance may be useful to make the optimum choice of metabolic surgery

We found the higher the percentage of weight loss was 6 and 12 months after RYGB, the more significant the decrease in RDW. In addition, the higher the preoperative RDW level was, the more significant the weight loss in patients with obesity and abnormal glucose metabolism 6 and 12 months after RYGB

RDW but not MPV may have a predictive role in the effect of RYGB surgery

INTRODUCTION

Red blood cell distribution width (RDW) is a common indicator in blood routine analysis, which reflects the heterogeneity of red blood cell volume in the circulation. It is calculated as the standard deviation (SD) of the distribution of red blood cell volume divided by the mean corpuscular volume (MCV) and then multiplied by 100 [1]. In previous studies, RDW has been used for the diagnosis and differential diagnosis of erythrocyte disorders, especially anemia, and for the evaluation of nutritional status. Elevated RDW is commonly seen in iron deficiency anemia, megaloblastic anemia, etc.

Mean platelet volume (MPV) is a common indicator of platelet activity in routine blood. Increased MPV is commonly seen in primary thrombocytopenic purpura and myelodysplastic syndrome, while decreased MPV is

commonly seen in acute leukemia chemotherapy and aplastic anemia.

In the last decade, RDW and MPV have both been considered new biomarkers for the prognosis of cardiovascular disease. RDW levels were significantly higher in patients with end point events such as death, heart failure and arrhythmia than in those without end point events [2]. Cardiovascular risk score and MPV in nonalcoholic fatty liver patients can accurately predict the risk of acute cardiovascular events within 1 year [3].

Previous studies have shown a significant correlation between the two indicators and obesity. Elisia et al. [4] found that RDW was significantly higher in people with a BMI > 35 kg·m⁻² than in those with a BMI ≤ 35 kg·m⁻². In individuals with metabolic syndrome and abdominal obesity, MPV levels were positively correlated with waist circumference and were significantly higher than in those without metabolic syndrome and abdominal obesity [5].

RDW and MPV are also associated with diabetes. RDW levels in diabetic patients were significantly higher than in control subjects; also, RDW levels in diabetic patients with HbA1c > 7% were significantly higher than in those with HbA1c ≤ 7% [6]. MPV was higher in patients with type 2 diabetes mellitus (T2DM) than in those without T2DM and higher in T2DM patients with microvascular complications (retinopathy or microalbuminuria) than in those without [7].

Obesity is an independent risk factor for the development of T2DM [8]. Metabolic surgery by Roux-en-Y gastric bypass (RYGB) and sleeve gastrectomy (SG) has become the most effective treatment for patients with T2DM complicated with obesity [9]. A simple and economic indicator that can accurately predict the outcome of surgery in advance may be useful to make the optimum choice of metabolic surgery.

Previous research has found that RDW has predictive value in determining the effect of metabolic surgery [10], but there have been no reports thus far on the predictive effects of MPV on metabolic surgery. In our center, patients with simple obesity often choose SG, while those with diabetes choose either SG or RYGB. Our previous study found that RDW levels in patients with simple obesity showed no

significant change 1 month after metabolic surgery compared to before surgery, while the RDW levels in patients with obesity and abnormal glucose metabolism [diabetes mellitus or impaired glucose regulation (DM/IGR)] were significantly higher than those before surgery. In addition, the RDW and MPV levels in patients with simple obesity showed no significant changes 1 year after surgery compared to the levels before surgery. Therefore, we retrospectively studied the changes in weight indices, RDW and MPV levels after metabolic surgery in patients with obesity and DM/IGR. We also determined the predictive value of baseline RDW and MPV levels for the weight loss after a 12-month follow-up. This will help to choose more effective treatment for patients in the future.

METHODS

Study Population

Ninety-eight patients (45 male and 53 female) with obesity and DM/IGR who underwent laparoscopic weight loss surgery in the general surgery department from July 2010 to November 2016 were selected for follow-up at 1, 3, 6 and 12 months after surgery.

BMI $\geq 28 \text{ kg m}^{-2}$ is considered obesity, according to Expert Consensus on Prevention and Treatment of Obesity in Chinese Adults (2011). DM/IGR includes impaired fasting glucose [$6.1 \text{ mmol/l} \leq \text{FPG} < 7.0 \text{ mmol/l}$ and 2-h oral glucose tolerance test (OGTT) $< 7.8 \text{ mmol/l}$], impaired glucose tolerance (FPG $< 6.1 \text{ mmol/l}$ and $7.8 \text{ mmol/l} \leq 2\text{-h OGTT} < 11.1 \text{ mmol/l}$) and diabetes (FPG $\geq 7.0 \text{ mmol/l}$ and/or 2-h OGTT $\geq 11.1 \text{ mmol/l}$), according to The Chinese Guidelines for the Prevention and Treatment of Type 2 Diabetes (2017). Surgical indications were as per the 2007 guidelines for surgical treatment of bariatric diseases in China: (1) identify the presence of obesity-related metabolic disorders and predict effective treatment for weight loss; (2) steady or steady weight gain over 5 consecutive years; (3) curative effect of more than one course of medical treatment is poor or conservative treatment cannot be

tolerated; (4) there is no alcohol or drug dependence and no serious mental or intellectual impairment; (5) patients need to understand the surgical method of weight loss surgery and to understand and accept the risk of complications, the importance of postoperative lifestyle and dietary habits change for postoperative recovery and have the ability to bear and actively cooperate with postoperative follow-up). The following were excluded: (1) cases of type 1 diabetes, gestational diabetes mellitus or special types of diabetes; (2) hypercortisolism, hypothyroidism and other diseases caused by secondary obesity patients; (3) persons addicted to drugs or alcohol; (4) people with mental retardation, uncontrollable mental disorders or uncontrollable behavior; (5) people with serious systemic disease (heart, lung, liver or kidney failure) or poor general condition; (6) failure to follow postoperative dietary guidelines or to accept changes in postoperative lifestyle.

After the patient was fully informed of the surgical risks before surgery and the need for dietary changes after surgery, written informed consent was obtained from all patients and follow-up was conducted for at least 1 year after surgery. The screening process is shown in Fig. 1.

In China, before the implementation of the “Measures for the Ethical Review of Biomedical Research Involving Humans,” the collection, recording, quoting or reporting of medical records and other scientific research materials in clinical practice for > 2 years did not fall within the scope of review provided for in these measures. This study is suitable for this requirement.

Compliance with Ethics Guidelines

This article is based on previously conducted studies and does not contain any studies with human participants or animals performed by any of the authors.

Anthropometric and Laboratory Measurements

Anthropometric evaluations included body weight (BW) and height (Ht). BW was measured on an electronic scale after the patient removed all heavy clothing. Ht was recorded in patients

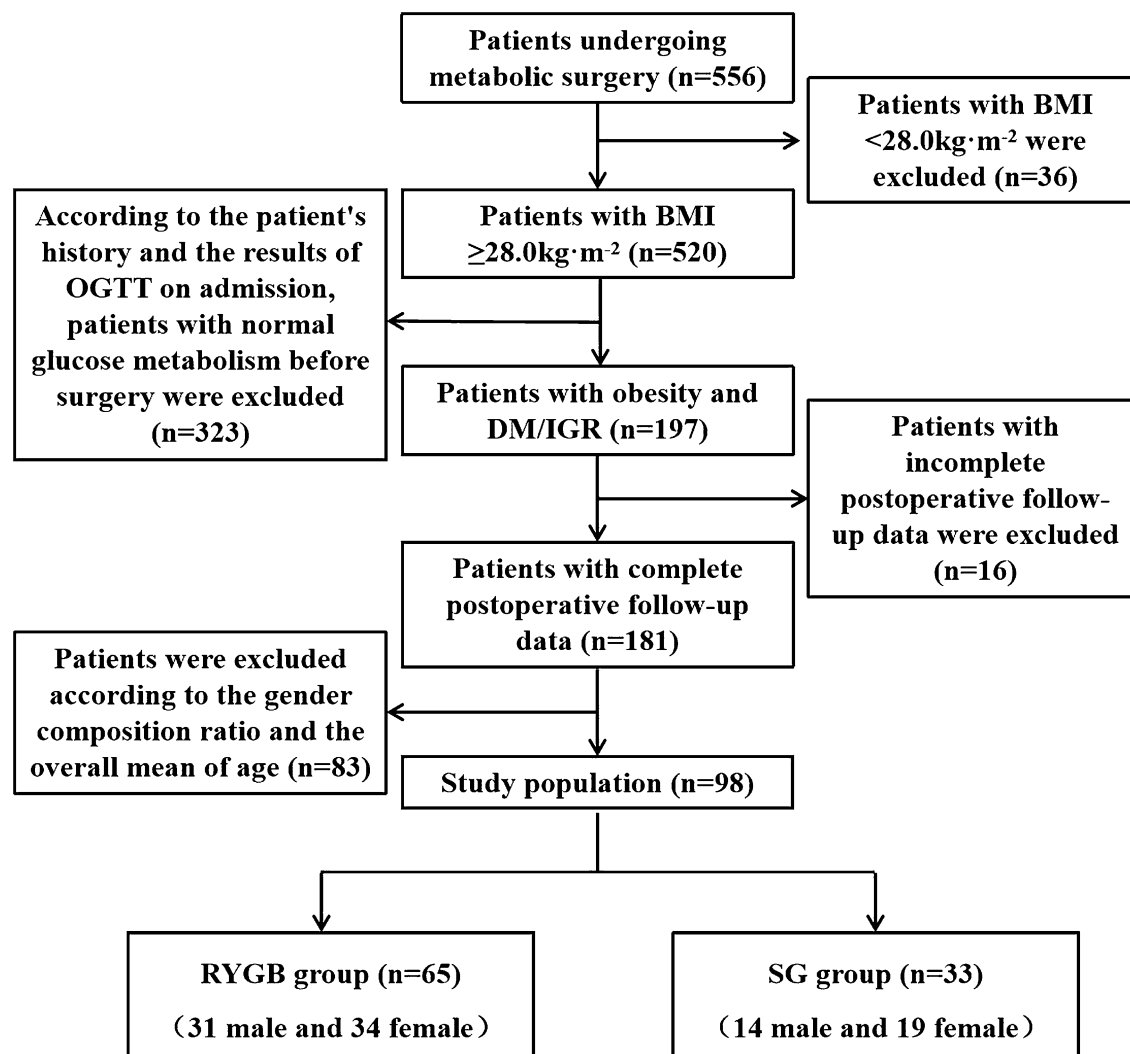


Fig. 1 Selection of the study population. *BMI* body mass index, *OGTT* oral glucose tolerance test, *DM/IGR* diabetes mellitus or impaired glucose regulation, *RYGB* Roux-en-Y gastric bypass, *SG* sleeve gastrectomy

without shoes by using a settled wall distance meter.

Serum samples were collected into dry tubes from each patient in the morning after overnight fasting. The blood routine index was detected by the sheath flow resistance method (five-category hematologic analyzer XT 2000i, SYSMEX, Japan).

Operation Methods

All patients underwent either RYGB or SG. RYGB is a procedure that alters the structure of

the gut and shuts down most stomach functions. SG is a partial gastrectomy that preserves the small curvature of the stomach and the pylorus and reduces the stomach size.

Calculation of Weight and Blood Indices

The following formulae were used:

body mass index (BMI) = BW (kg)/height (m²); change in body weight (Δ BW) = preoperative BW—a postoperative follow-up BW; percentage weight loss (%BW) = (preoperative BW—postoperative BW at a follow-up point)/

preoperative BW*100; change in BMI (Δ BMI) = preoperative BMI—a postoperative follow-up BMI; change of the RDW (Δ RDW) = preoperative RDW—a postoperative follow-up RDW; change of the MPV (Δ MPV) = preoperative MPV—a postoperative follow-up MPV.

Statistical Analysis

Data were analyzed using SPSS software version 17.0 (SPSS Inc.). Quantitative data are presented as means \pm standard deviations. Normally and non-normally distributed data were analyzed with independent-samples t-test and Kruskal-Wallis rank sum test (H test), respectively. Chi-square test (χ^2 test) was applied to compare the component ratios. Repeated measure data were analyzed by one-way repeated measure ANOVA. Differences at $P < 0.05$ were considered significant.

RESULTS

Comparison of Preoperative Baseline Data from Patients in Two Groups

There was no significant difference in sex composition ratio, age, BW, BMI, waist-hip ratio (WHR), HbA1c, FPG, FINS, RDW, MPV, MCV and hemoglobin (Hb) between the RYGB and SG groups (Table 1).

Changes and Comparison of indices in the two groups after surgery

After 1, 3, 6 and 12 months of follow-up after metabolic surgery, the BW and BMI of patients in the RYGB and SG groups decreased significantly and continuously compared with the values before surgery, and there were significant differences between each follow-up point and the previous follow-up point ($P < 0.05$). The BW at 3 months and BMI at 1 and 3 months after

Table 1 Comparison of preoperative baseline data from patients in the RYGB and SG groups ($\bar{x} \pm s$, n [%])

	Total ($n = 98$)	RYGB ($n = 65$)	SG ($n = 33$)	<i>t</i>	<i>Z</i>	χ^2	<i>P</i>
Sex, female (%)	53 (54.1%)	34 (64.2%)	19 (35.8%)			0.245	0.621
Age	36.6 \pm 10.1	37.9 \pm 8.5	34.2 \pm 12.4	1.548			0.128
BW (kg)	109.99 \pm 23.76	107.42 \pm 24.59	115.04 \pm 21.50	0.510			0.134
BMI (kg·m ⁻²)	39.01 \pm 7.19	38.06 \pm 7.01	40.87 \pm 7.28		1.887		0.059
WHR	0.99 \pm 0.07	0.98 \pm 0.07	0.99 \pm 0.07	0.602			0.549
HbA1c (%)	7.49 \pm 1.55	7.71 \pm 1.68	7.08 \pm 1.20	1.921			0.058
FPG (mmol·L ⁻¹)	7.84 \pm 2.24	8.05 \pm 2.50	7.43 \pm 1.58	1.492			0.139
FINS (mIU·L ⁻¹)	33.68 \pm 25.95	34.18 \pm 30.31	32.72 \pm 14.65		1.379		0.168
RDW	13.45 \pm 1.89	13.41 \pm 2.03	13.53 \pm 1.62		0.854		0.393
MPV (fL)	10.57 \pm 1.15	10.63 \pm 1.31	10.46 \pm 0.73	0.401			0.844
MCV (g·L ⁻¹)	86.52 \pm 4.75	87.13 \pm 3.90	85.31 \pm 5.97		0.947		0.344
Hb (g·L ⁻¹)	137.55 \pm 13.98	137.92 \pm 13.17	136.82 \pm 15.64	0.714			0.368

P value RYGB group compared to SG group

RYGB Roux-en-Y gastric bypass, *SG* sleeve gastrectomy, *BW* body weight, *BMI* body mass index, *WHR* waist-hip ratio, *HbA1c* hemoglobin a1c, *FPG* fasting plasma glucose, *FINS* fasting insulin, *RDW* red blood cell distribution width, *MPV* mean platelet volume, *MCV* mean corpuscular volume, *Hb* hemoglobin

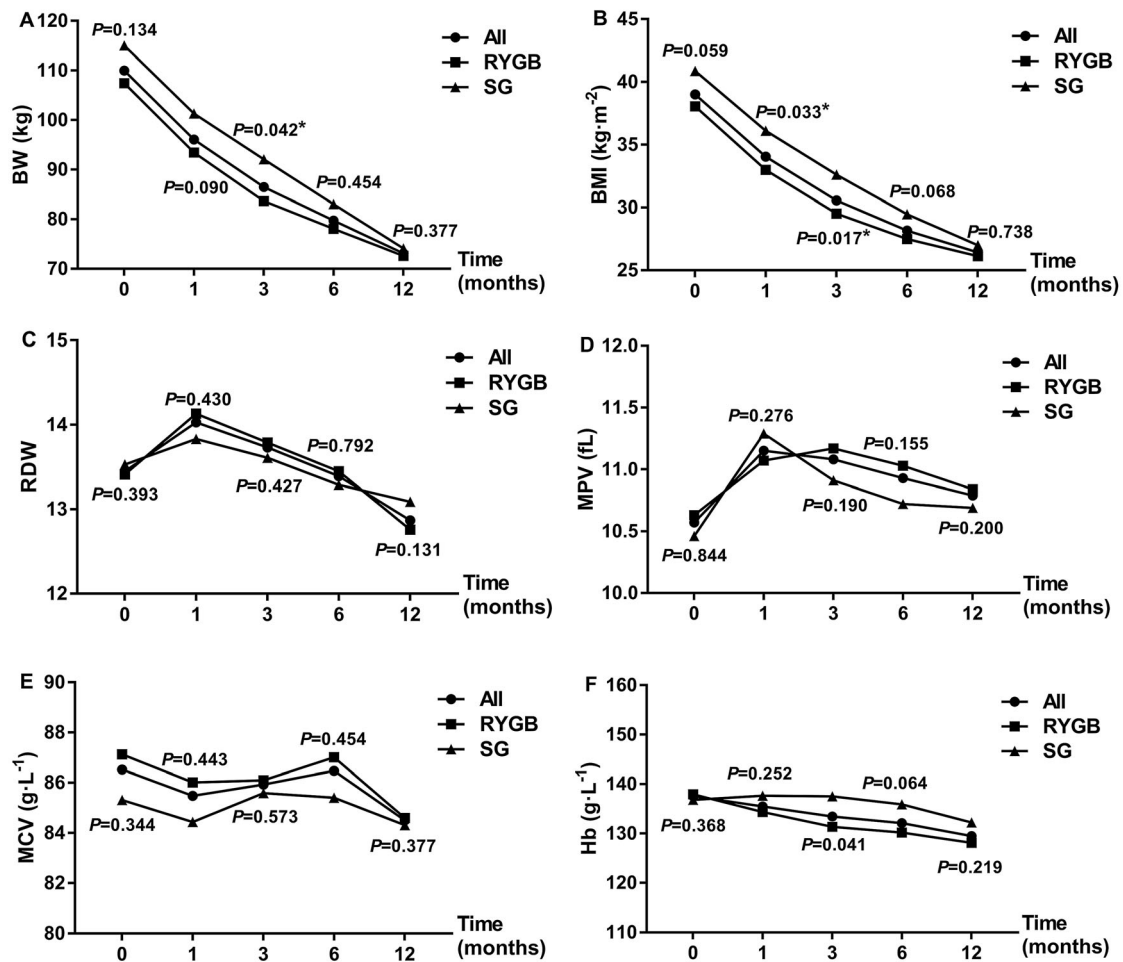


Fig. 2 Changes and comparison of indexes in the two groups after surgery. *P* value RYGB group compared to SG group. Asterisk indicates statistical significance.

a–f Respectively represent the changes of BW, BMI, RDW, MPV, MCV and Hb after 1, 3, 6 and 12 months of follow-up after metabolic surgery

surgery in the SG group were significantly higher than the corresponding values in the RYGB group ($P < 0.05$) (Fig. 2a, b).

The RDW and MPV levels in both groups were significantly higher at 1 month after surgery than before surgery ($P < 0.05$) and then gradually decreased. In the RYGB group, the RDW level at 12 months after surgery decreased significantly to a lower level than that before the operation ($P < 0.05$). However, 1 month after the surgery, the MPV level of the RYGB group and the RDW and MPV levels of the SG group decreased gradually, but there were no significant differences in the follow-up values at

3, 6 and 12 months ($P \geq 0.05$). There was no statistical difference in RDW and MPV levels between the two groups at any follow-up point ($P \geq 0.05$) (Fig. 2c, d).

In the RYGB group, the MCV at 1, 3 and 12 months after surgery was significantly lower than that before surgery, while in the SG group, the MCV at 1 month after surgery was significantly lower than that before surgery ($P < 0.05$). However, there was no significant difference in the MCV level between the two groups at any follow-up point ($P \geq 0.05$) (Fig. 2e).

The Hb concentration of the RYGB group showed a continuous postsurgical decrease, and

the Hb value at all the follow-up points showed statistical differences compared with the preoperative value ($P < 0.05$). Only 12 months after surgery, Hb of the SG group was significantly lower than that before surgery ($P < 0.05$). We found no significant difference in postoperative Hb at any other follow-up time point between the two groups ($P \geq 0.05$) (Fig. 2f).

Changes of RDW and MPV Levels Stratified According to the Weight Indexes in the Two Groups after Surgery

Patients were divided into high level and low level based on the median values of Δ BW, %BW and Δ BMI in different postoperative follow-up points in both groups. The decrease in RDW in the high level of %BW (≥ 26.67) patients in the RYGB group was significantly higher than that in the low level of %BW (< 26.67) patients 6 months after surgery ($P < 0.05$). At 12 months after the operation, the RDW level in the high level of %BW (≥ 31.90) in the RYGB group was significantly lower than that in the corresponding low level (< 31.90) ($P < 0.05$) (Fig. 3c).

However, there was no statistical difference in RDW change in the patients of the RYGB group between different levels of Δ BW and Δ BMI in different postoperative follow-up points ($P < 0.05$) (Fig. 3a, e). The change of RDW also had no significant difference in any postoperative follow-up points between the high or low levels of the three weight indices in the SG group ($P < 0.05$). (Fig. 3a–c).

There was no significant difference in the change in MPV in either group between different levels of Δ BW, %BW and Δ BMI ($P > 0.05$) in any of the postoperative follow-up time points (Fig. 3b, d, f).

Relationship Between Preoperative RDW and MPV Levels and the Changes in Postoperative Weight Indices in the Two Groups

In the RYGB group, we divided the patients into two groups according to the median RDW level before the operation. We found that Δ BW,

%BW and Δ BMI at 6 and 12 months after surgery in patients in the preoperative high-level RDW group (≥ 12.90) were significantly higher than those in patients in the low-level group (< 12.90) ($P < 0.05$). However, there was no significant difference in Δ BW, %BW and Δ BMI at 1 and 3 months after surgery and between the two levels of patients ($P > 0.05$). In addition, weight indices (Δ BW, %BW and Δ BMI) at any follow-up point after surgery showed no statistical difference between the two layers of patients that were divided into high level (≥ 13.20) and low level (< 13.20) according to the median preoperative MPV level ($P > 0.05$) (Fig. 4a, c, e).

In the SG group, we did not find significant differences in Δ BW, %BW and Δ BMI at any follow-up point after surgery between the two layers of patients that were divided into high and low levels according to the median preoperative levels of RDW or MPV levels ($P > 0.05$), unless patients with high preoperative MPV (≥ 10.60) 3 months after surgery had significantly higher %BW than those with low preoperative MPV (< 10.60) ($P < 0.05$) (Fig. 4b, d, f).

DISCUSSION

Our retrospective study found that in patients with obesity and DM/IGR, the higher the %BW after 6 and 12 months of RYGB, the more significant the decrease in RDW. In addition, the higher the preoperative RDW level, the more significant the weight loss in patients with obesity and DM/IGR 6 and 12 months after RYGB. This indicates RDW may have a predictive role for the effect of RYGB surgery.

RDW is a simple and inexpensive hematologic indicator to reflect the heterogeneity of erythrocyte volume in peripheral blood. In recent years, several studies have shown that in addition to identifying the causes of anemia, increased RDW has significant predictive value for the prognosis of many common diseases such as diabetes, cardiovascular disease and cancer.

In both short- and long-term studies, low levels of RDW are associated with a reduced risk

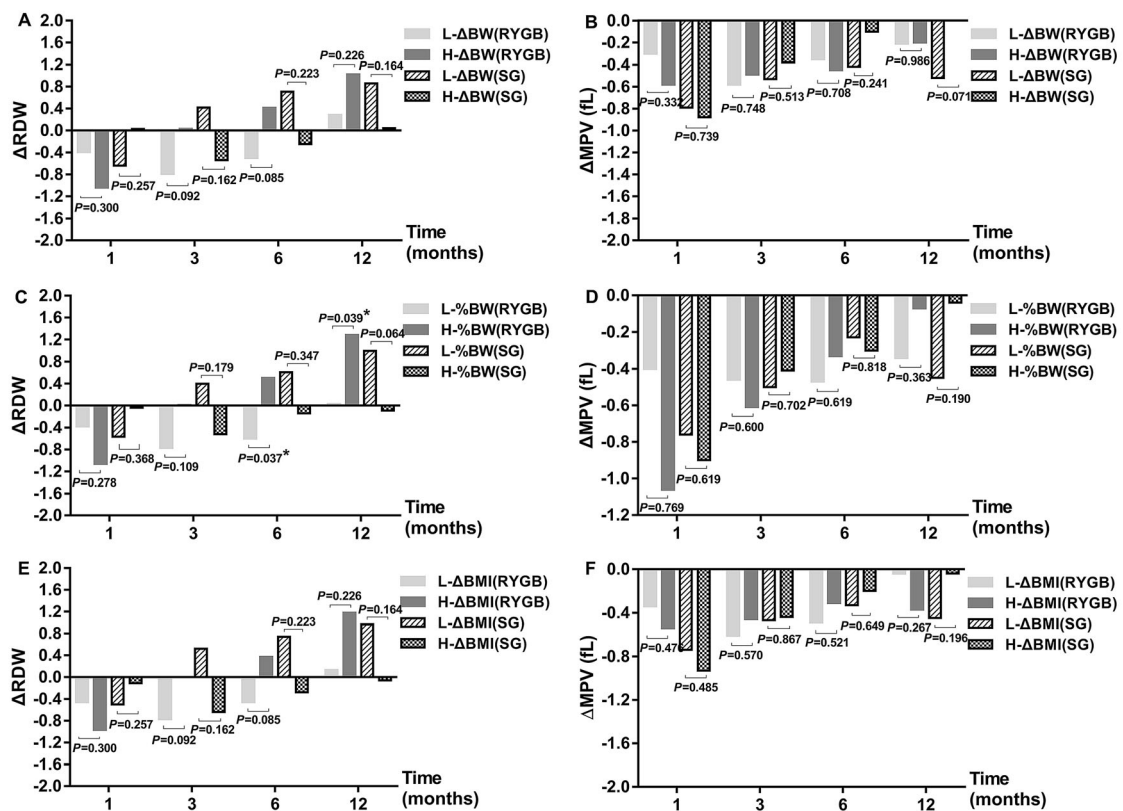


Fig. 3 Changes in RDW and MPV levels stratified according to the weight indices in the two groups after surgery. *P* value low-level group compared to the high-level group. ΔRDW change of RDW, ΔMPV change of MPV, ΔBW change of BW, %BW percentage weight loss, ΔBMI change of BMI, L- ΔBW low level ΔBW group, H- ΔBW high-level ΔBW group, L-%BW low-level %BW group, H-%BW high-level %BW group, L- ΔBMI low-level ΔBMI group, H- ΔBMI high-level ΔBMI group. **a** and **b** Respectively represent ΔRDW and ΔMPV at each follow-up

point when stratified according to the median postoperative ΔBW of patients in the RYGB group and SG group. **c** and **d** Respectively represent ΔRDW and ΔMPV at each follow-up point when stratified according to the median postoperative %BW of patients in the RYGB group and SG group. **e** and **f** Respectively represent ΔRDW and ΔMPV at each follow-up point when stratified according to the median postoperative ΔBMI of patients in the RYGB group and SG group

of major cardiovascular adverse events after acute coronary syndrome [11]. A long-term follow-up study found that higher levels of RDW were associated with coronary artery disease, heart failure, peripheral vascular disease, atrial fibrillation, stroke and cancer (especially leukemia), suggesting that RDW is both a short- and long-term predictor of disease [12].

Metabolic diseases are a threat to human health worldwide. Inflammation is the key event in the occurrence and development of metabolic diseases, and RDW, as a new

inflammatory marker, can play an important role in evaluating the severity and prognosis of metabolic diseases, especially obesity and diabetes.

A study in the USA found that white blood cell count, red blood cell count and RDW increased with waist circumference, a change that may be related to the chronic activation of the immune system and the resulting low-degree inflammatory state [13]. The increase of RDW variation rate is related to the increase of DM incidence [14].

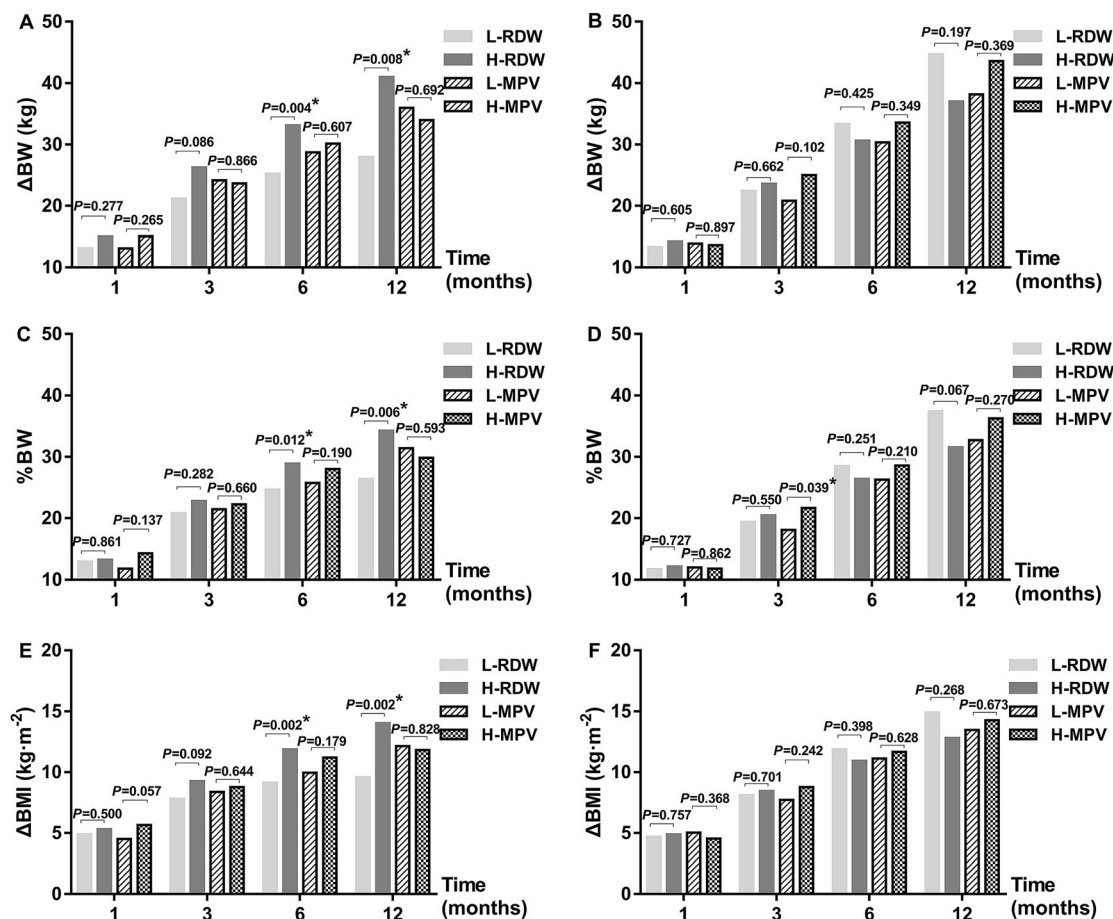


Fig. 4 Relationship between preoperative RDW and MPV levels and the changes of postoperative weight indices in the two groups. *P* value low-level group compared to high-level group. Grouping: **a**, **c**, **e** belong to the RYGB group and **b**, **d**, **f** belong to the SG group. *L-RDW* low-level RDW group, *H-RDW* high-level RDW group, *L-MPV* low-level MPV group, *H-MPV* high-level MPV group. **a**, **c** and **e** respectively represent the ΔBW ,

$\%BW$ and ΔBMI of patients in the RYGB group at each postoperative follow-up point after stratification according to the median of preoperative levels of RDW and MPV. **b**, **d** and **f** respectively represent the ΔBW , $\%BW$ and ΔBMI of patients in the SG group at each postoperative follow-up point after stratification according to the median of preoperative levels of RDW and MPV

Similar to RDW, MPV is also a common blood routine indicator with a predictive value for the prognosis of a variety of diseases [15]. However, there are still differences in the prediction of insulin resistance and prognosis of diabetes by MPV.

One study has found significant positive correlation among MPV, HOMA-IR and insulin levels in patients with gestational diabetes [16]. However, another study showed that there was no significant difference in MPV between

healthy subjects and patients at different stages of abnormal glucose metabolism [17].

Metabolic surgery is an effective treatment for obesity and diabetes [18]. At present, RYGB and SG are the most commonly used metabolic surgeries for obesity combined with diabetes [19]. RYGB is the most commonly used surgical procedure for T2DM [20]. Our study also found that Hb levels continued to decrease 1 year after RYGB, while Hb changes only showed a significant difference at 12 months after SG. This is

because RYGB rearranges the position of the patient's small intestine, alters the path of food through the digestive tract, slows gastric emptying, shortens the small intestine and thus reduces the absorption of nutrients. Therefore, in addition to anastomotic fistula, anastomotic stenosis, pulmonary embolism and other complications, deficiencies in iron, folic acid and calcium may develop during long-term follow-up [21]. However, SG is treated by reducing the stomach volume, which reduces the hormones that trigger hunger. The advantages are that it does not change the physiologic state of the gastrointestinal tract and does not interfere with the normal digestion and absorption process of food. Therefore, common postoperative complications include fistula at the closed gastric margin and blood oozing at the gastric margin [22], but nutrient deficiency is relatively rare.

Another study has found that RYGB and SG have similar effects in improving body weight [23]. Our results also showed that although the BW of the patients improved significantly 12 months after the operation, there was no significant difference between the two groups.

Previous study has confirmed that chronic systemic low-level inflammation caused by changes in cytokine levels and infiltration of adipose tissue by immune cells is an important mechanism leading to metabolic dysfunction in obese patients [24]. Metabolic surgery can effectively alleviate this inflammatory state of the body to improve metabolic disorders in patients [25]. The types of proteins significantly improved after RYGB were mainly markers of systemic inflammation and those involved in lipid metabolism [26]. After RYGB and SG surgery, some inflammatory chemokines in obese patients recovered to similar levels as in the control group [27].

As is well known, reduced MCV and increased RDW suggest iron deficiency anemia, and RYGB surgery is more likely to cause iron deficiency anemia because of its operating principle. In our study, we found that both MCV and RDW in the RYGB group decreased at 12 months after surgery compared with the presurgical levels, suggesting that other factors may inhibit the increase of RDW. Numerous

studies suggest that RDW may be a surrogate biomarker of inflammation. One study found that the RDW level was significantly higher in patients with severe autoimmune hepatitis than in those with mild liver inflammation [28]. Increased RDW was significantly associated with an increased risk of severe inflammatory response syndrome after cardiopulmonary bypass following cardiac surgery [29]. At 8 weeks after RYGB, the RDW level in obese women was significantly higher than that before RYGB [30]. Consistent with these results, our results showed that RDW and MPV levels in patients with obesity and DM/IGR showed transient increases in both RYGB and SG at 1 month after surgery. This suggested a short-term aggravation of inflammation in patients with obesity and DM/IGR after metabolic surgery, likely caused by the response to surgical traumatic stress. However, the RDW level in the RYGB group significantly decreased 1 year after surgery compared with that before surgery, while no significant change was observed in the SG group; this suggested that RYGB may be better than SG in improving the inflammatory status of patients with obesity and DM/IGR.

The Wise team found that percent excess BMI loss was significantly lower in patients with preoperative RDW > 15.0% than in those with RDW < 13.0% and with RDW between 13.0 and 15.0%, suggesting that higher preoperative RDW was associated with worse weight loss after RYGB [10]. Our results were in complete contrast to this. In the RYGB group, patients with high preoperative RDW had significantly better improvements in BW and BMI at 6 months and 1 year after surgery than those with low preoperative RDW. This may be due to RYGB improving the integrity of tight connections in the intestinal mucosa and enhancing the strength of the intestinal barrier, thereby reducing the degree of endotoxemia and inflammation in the body.

One study found no significant reduction in MPV after weight loss surgery and no significant difference in MPV between the SG and RYGB groups [31]. Similar to their results, our results also showed that although the MPV level of the RYGB and SG groups increased in the first month after surgery and then gradually

decreased, the MPV level did not change significantly in either group in the first year after surgery compared to that before surgery. In addition, no statistical difference was found in the body weight index and glucose metabolism index at each postoperative follow-up point between the patients with baseline MPV at high and low level. Therefore, MPV has no significant predictive value for the effect and prognosis of metabolic surgery. This may be due to the wide variation of MPV in real life owing to factors such as platelet count, sex, age, ethnicity and the lack of standardized methods for measuring MPV, which make it impossible to determine whether MPV is normal or slightly increased in individual patients [32].

One of the limitations of our study was that we could only analyze the existing clinical data owing to the retrospective study design. In the follow-up study, we aim to conduct prospective research, establish the exclusion criteria, obtain patient consent, additionally collect blood and tissue samples while collecting patients' clinical data, and explore the possible mechanism of the occurrence of these clinical phenomena. In addition, the evaluation of disease prognosis and treatment is a long process, and the observation time of this study was relatively short. In future studies, the observation time should be extended to explore the long-term prediction and evaluation value of RDW and MPV.

In conclusion, the improvement of BW and BMI in patients with obesity and DM/IGR after RYGB was better than that in SG in the early stage (3 months after surgery), but similar to SG in the late stage. After RYGB and SG, both the RDW and MPV of patients with obesity and DM/IGR showed a transient, short-term increases (1 month), suggesting that the inflammatory state of patients with obesity and DM/IGR after metabolic surgery may have short-term aggravation. At 12 months after RYGB surgery, the RDW level in patients with obesity and DM/IGR significantly decreased. However, the RDW level in the SG group and the MPV level in both groups remained unchanged compared with the preoperative levels, suggesting that postoperative RDW levels can better reflect the effect of RYGB surgery in patients with obesity and DM/IGR. The preoperative baseline RDW level can

preliminarily predict the effect of different metabolic surgeries in patients with obesity and DM/IGR. Preoperative baseline MPV level had no significant predictive effect on RYGB surgery in patients with obesity and DM/IGR, but may have some predictive value on weight loss in early SG surgery (3 months).

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Data Availability. The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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REFERENCES

1. Salvagno GL, Sanchis-Gomar F, Picanza A, Lippi G. Red blood cell distribution width: a simple parameter with multiple clinical applications. *Crit Rev Clin Lab Sci.* 2015;52(2):86–105.
2. Baggen VJM, van den Bosch A, van Kimmenade RR, Eindhoven JA, Witsenburg M, Cuypers JAAE, Leebeek FWG, Boersma E, Roos-Hesselink JW. Red cell distribution width in adults with congenital heart disease: a worldwide available and low-cost predictor of cardiovascular events. *Int J Cardiol.* 2018;260:6.
3. Abeles RD, Mullish BH, Forlano R, Kimhofer T, Adler M, Tzallas A, Giannakeas N, Yee M, Mayet J, Goldin RD, Thursz MR, Manousou P. Derivation and validation of a cardiovascular risk score for prediction of major acute cardiovascular events in non-alcoholic fatty liver disease; the importance of an elevated mean platelet volume. *Aliment Pharmacol Ther.* 2019;49(8):1077–85.
4. Elisia I, Lam V, Cho B, Hay M, Li MY, Kapeluto J, Elliott T, Harris D, Bu L, Jia W, Leung H, Mohn W, Krystal G. Exploratory examination of inflammation state, immune response and blood cell composition in a human obese cohort to identify potential markers predicting cancer risk. *PLoS ONE.* 2020;15(2):e0228633.
5. Furman-Niedziejko R, Golinska-Grzybala R, Wilczynska-Golonka G, Nessler J. Relationship between abdominal obesity, platelet blood count and mean platelet volume in patients with metabolic syndrome. *Folia Med Cracov.* 2014;54(2):55–64.
6. Nada AM. Red cell distribution width in type 2 diabetic patients. *Diabetes Metab Syndr Obes.* 2015;8:525–33.
7. Papanas N, Symeonidis G, Maltezos E, Mavridis G, Karavageli E, Vosnakidis T, Lakasas G. Mean platelet volume in patients with type 2 diabetes mellitus. *Platelets.* 2004;15(8):475–8.
8. Hossain P, Kavar B, El Nahas M. Obesity and diabetes in the developing world—a growing challenge. *N Engl J Med.* 2007;356(3):213–5.
9. Rubino F, Gagner M. Potential of surgery for curing type 2 diabetes mellitus. *Ann Surg.* 2002;236(5):554–9.
10. Wise ES, Hocking KM, Weltz A, Uebele A, Diaz JJ, Kavic SM, Kligman MD. Red cell distribution width is a novel biomarker that predicts excess body-mass index loss 1 year after laparoscopic Roux-en-Y gastric bypass. *Surg Endosc.* 2016;30(10):4607–12.
11. Abraham LLT, Ramos JDA, Cunanan EL, Tiongson MDA, Punzalan FER. Red cell distribution width and mortality in patients with acute coronary syndrome: a meta-analysis on prognosis. *Cardiol Res.* 2018;9(3):144–52.
12. Pilling LC, Atkins JL, Kuchel GA, Ferrucci L, Melzer D. Red cell distribution width and common disease onsets in 240,477 healthy volunteers followed for up to 9 years. *PLoS ONE.* 2018;13(9):e0203504.
13. Vuong J, Qiu Y, La M, Clarke G, Swinkels DW, Cembrowski G. Reference intervals of complete blood count constituents are highly correlated to waist circumference: should obese patients have their own “normal values?”. *Am J Hematol.* 2014;89(7):671–7.

14. Gang L, Lifang W. Association of the elevated red blood cell distribution width with the risk of developing diabetes mellitus. *Intern Med*. 2016;55(15):1959–65.
15. Moghadam RH, Shahmohammadi A, Asgari N, Azizi K, Mansour SM, Roozbahani M. Comparison of mean platelet volume levels in coronary artery ectasia and healthy people: systematic review and meta-analysis. *Blood Res*. 2018;53(4):269–75.
16. Zhou Z, Chen H, Sun M, Ju H. Mean platelet volume and gestational diabetes mellitus: a systematic review and meta-analysis. *J Diabetes Res*. 2018;2018:1985026.
17. Mertoglu C, Gunay M. Neutrophil-Lymphocyte ratio and Platelet-Lymphocyte ratio as useful predictive markers of prediabetes and diabetes mellitus. *Diabetes Metab Syndr*. 2017;11(Suppl 1):S127–S131131.
18. English WJ, Williams DB. Metabolic and bariatric surgery: an effective treatment option for obesity and cardiovascular disease. *Prog Cardiovasc Dis*. 2018;61(2):253–69.
19. Angrisani L, Santonicola A, Iovino P, Vitiello A, Zundel N, Buchwald H, Scopinaro N. Bariatric surgery and endoluminal procedures: IFSO worldwide survey 2014. *Obes Surg*. 2017;27(9):2279–89.
20. Angrisani L, Santonicola A, Iovino P, Formisano G, Buchwald H, Scopinaro N. Bariatric surgery worldwide 2013. *Obes Surg*. 2015;25(10):1822–32.
21. Engebretsen KV, Blom-Hogestol IK, Hewitt S, Ristad H, Moum B, Kristinsson JA, Mala T. Anemia following Roux-en-Y gastric bypass for morbid obesity; a 5-year follow-up study. *Scand J Gastroenterol*. 2018;53(8):917–22.
22. Giuliani A, Romano L, Papale E, Puccica I, Di Furia M, Salvatorelli A, Cianca G, Schietroma M, Amicucci G. Complications post-laparoscopic sleeve gastric resection: review of surgical technique. *Minerva Chir*. 2019;15(8):1414–9.
23. Albaugh VL, Abumrad NN. Surgical treatment of obesity. *F1000Res* 2018; 7. <https://doi.org/10.12688/f1000research.13515.1>.
24. Gregor MF, Hotamisligil GS. Inflammatory mechanisms in obesity. *Annu Rev Immunol*. 2011;29:415–45.
25. Hales CM, Fryar CD, Carroll MD, Freedman DS, Ogden CL. Trends in obesity and severe obesity prevalence in US youth and adults by sex and age, 2007–2008 to 2015–2016. *JAMA*. 2018;319(16):1723–5.
26. Wewer Albrechtsen NJ, Geyer PE, Doll S, Treit PV, Bojsen-Moller KN, Martinussen C, Jorgensen NB, Torekov SS, Meier F, Niu L, Santos A, Keilhauer EC, Holst JJ, Madsbad S, Mann M. Plasma proteome profiling reveals dynamics of inflammatory and lipid homeostasis markers after Roux-En-Y gastric bypass surgery. *Cell Syst*. 2018;7(6):601–12 (e3).
27. Wolf RM, Jaffe AE, Steele KE, Schweitzer MA, Magnuson TH, Wolfe A, Wong GW. Cytokine, chemokine, and cytokine receptor changes are associated with metabolic improvements after bariatric surgery. *J Clin Endocrinol Metab*. 2019;104(3):947–56.
28. Wang H, Wang J, Huang R, Xia J, Zuo L, Yan X, Yang Y, Wu C. Red blood cell distribution width for predicting significant liver inflammation in patients with autoimmune hepatitis. *Eur J Gastroenterol Hepatol*. 2019;31(12):1527–32.
29. Seth HS, Mishra P, Khandekar JV, Raut C, Mohapatra CKR, Ammannaya GKK, Saini JS, Shah V. Relationship between high red cell distribution width and systemic inflammatory response syndrome after extracorporeal circulation. *Braz J Cardiovasc Surg*. 2017;32(4):288–94.
30. Custodio Afonso-rocha V, Ramos de Arvelos L, Pereira Felix G, Nogueira Prado de Souza D, Bernardino Neto M, Santos Resende E, Penha-Silva N. Evolution of nutritional, hematologic and biochemical changes in obese women during 8 weeks after Roux-en-Y gastric bypass. *Nutr Hosp*. 2012;27(4):1134–40.
31. Xu H, Barnes GT, Yang Q, Tan G, Yang D, Chou CJ, Sole J, Nichols A, Ross JS, Tartaglia LA, Chen H. Chronic inflammation in fat plays a crucial role in the development of obesity-related insulin resistance. *J Clin Invest*. 2003;112(12):1821–30.
32. Noris P, Melazzini F, Balduini CL. New roles for mean platelet volume measurement in the clinical practice? *Platelets*. 2016;27(7):607–12.