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Association of erythrocyte parameters with metabolic syndrome in the Pearl River Delta region of China: a cross sectional study

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ABSTRACT

Objective Increasing studies have reported that erythrocyte parameters, including red blood cells (RBCs), haematocrit (HCT), haemoglobin (Hb) and red blood cell distribution width (RDW), are associated with metabolic syndrome (MetS) in adults worldwide. However, the association, stratified by sex, remains to be elucidated, particularly in the Pearl River Delta region of China. Therefore, our aim was to explore the association of erythrocyte parameters with MetS, stratified by sex, in the Pearl River Delta region of China.

Methods In this cross sectional study, 2161 men and 2511 women were enrolled. MetS was diagnosed using a modified version of the Adult Treatment Panel III criteria. Logistic regression analyses were performed to calculate adjusted ORs of erythrocyte parameters associated with MetS stratified by sex.

Results The prevalence of MetS was higher in women than in men (35.2%vs26.7%). RBC, HCT, Hb and RDW values increased linearly with the number of MetS components from 0 to 5 identified in both men and women. Among men, the ORs of MetS risk increased across the tertiles of Hb (Q2: OR=1.921, 95% CI=1.170 to 3.151; Q3: OR=1.992, 95%CI=1.198 to 3.312). Men in the highest tertiles of RDW had a 2.752-fold increased risk of suffering from MetS compared with those in the reference group. Among women, the ORs of MetS risk also increased across the tertiles of Hb (Q2: OR=1.538, 95%CI=1.008 to 2.348; Q3: OR=1.665, 95%CI=1.075 to 2.578). Women in the highest tertiles of RBC had a 1.718-fold increased risk of experiencing MetS compared with those in the reference group.

Conclusions MetS was more prevalent in women than in men. The association between erythrocyte parameters and MetS differed between the sexes. RBC and Hb were identified as risk factors for MetS in women and Hb and RDW as risk factors in men.

Strengths and limitations of this study

- A large sample of subjects were enrolled in our survey.
- To the best of our knowledge, this is the first study to report the association of erythrocyte parameters with MetS, stratified by sex, in the Pearl River Delta region of China.
- The present study was designed as a cross sectional study; therefore, direct causation may not be concluded from the results.
- Supplementary information about the lifestyle of the subjects was not collected; therefore, these factors could not be included in the adjustments of our multivariate logistic regression analyses.

INTRODUCTION

Metabolic syndrome (MetS) is defined as a cluster of multiple correlated metabolic features, including abdominal obesity, hypertension, elevated triglyceride (TG) levels, decreased high density lipoprotein cholesterol (HDL-C) levels and hyperglycaemia.[1] It is known to be strongly associated with an increased risk of type 2 diabetes,[2] cardiovascular disease[2–4] and all cause mortality.[4] In recent years, MetS has emerged as a global public health issue owing to its increased prevalence around the world, affecting nearly 20–30% of adults in many countries.[5–7] Hence early identification of individuals at high risk of MetS is essential for the prevention of MetS.

Currently, the pathogenesis of MetS is not clearly understood. Generally, MetS is accompanied by insulin resistance and/or chronic low grade inflammation.[8 9]Numerous investigators previously reported that erythrocyte parameters, including red blood cell (RBC) count, haematocrit (HCT), haemoglobin (Hb) and red blood cell distribution width (RDW) were positively associated with insulin resistance and chronic low grade inflammation.[10–14] In fact, RBC,[14–16] HCT,[15 16] Hb[14 15 17] and RDW[18] were demonstrated in several studies worldwide to correlate with MetS in adults. However, the association between erythrocyte parameters and MetS

remains controversial, because the results reported are inconsistent depending on the different ethnic populations studied. In addition, discrepancies in the results may be partly attributed to differences between the sexes. Many studies simply applied sex as an adjustment variable to investigate the relationship between erythrocyte parameters and MetS, and no studies were conducted in the Pearl River Delta region of China. Therefore, the aim of this study was to explore the association between erythrocyte parameters and MetS, stratified by sex, in the Pearl River Delta region of China.

MATERIALS AND METHODS

Study participants

This cross sectional study involved participants who underwent a general health examination at the Community Health Service Agencies in the Pearl River Delta region of China in 2015. The health examination included recording of medical history, anthropometric measurements and laboratory tests. Participants with a history of cardiovascular diseases, severe liver or kidney dysfunction, tumours or severe inflammatory diseases were excluded. In addition, participants who did not have complete data on their MetS components and erythrocyte parameters were excluded. A total of 4672 subjects (2161 men and 2511 women) were enrolled in the study. The study was approved by the ethics committee of Guangdong Sociological Society. Written informed consent was obtained from all participants.

Data collection and measurements

Medical histories of subjects were obtained by review of self-reported questionnaires. Anthropometric parameters were measured by trained staff, following a standardised protocol. Height, weight, waist circumference (WC), systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured several times, and all mean values of the above indexes were calculated. Body mass index (BMI) was calculated as weight (kg) divided by height (m^2). After an overnight fast, venous blood samples from participants were obtained and analysed for TG, total cholesterol (TC), HDL-C, low density lipoprotein cholesterol (LDL-C), fasting plasma glucose (FPG), uric acid (UA), white blood cell (WBC) count, platelets (PLT), RBC count, HCT, Hb, RDW, alanine transaminase (ALT), aspartate aminotransferase (AST), γ-glutamyl transferase (GGT), albumin (ALB) and glycated haemoglobin A1c (HbAIc).

Quality control

All data were collected by trained doctors or nurses who checked the data from every participant. In addition, several supervisors verified the authenticity of the data.

Tertiles of erythrocyte parameters levels

Erythrocyte parameter levels were categorised into tertiles on the basis of individual distributions, for men and women (in men: RBC, Q1 <4.37 $\times10^{12}$/L, Q2=4.37~4,75$\times10^{12}$/L, Q3 ≥4.76 $\times10^{12}$/L; HCT, Q1 <39.8%, Q2=39.8~42.4%, Q3 ≥42.5%; Hb, Q1 <137 g/L, Q2=137~146 g/L, Q3 ≥147 g/L; RDW, Q1 <12.5%, Q2=12.5~13.1%, Q3 ≥13.2%; in women: RBC, Q1 <3.96$\times10^{12}$/L, Q2=3.96~4.27$\times10^{12}$/L, Q3 ≥4.28$\times10^{12}$/L; HCT, Q1 <35.2%, Q2=35.2~37.3%, Q3 ≥37.4%; Hb, Q1 <120 g/L, Q2=120~127 g/L, Q3 ≥128 g/L; RDW, Q1 <12.3%, Q2=12.3~12.8%, Q3 ≥12.9%).

Definition of metabolic syndrome

MetS was diagnosed using a modified version of the Adult Treatment Panel III (ATP III) criteria,[1] which included at least three of the following five components: (1) WC ≥90 cm in men and WC ≥80 cm in women; (2) SBP ≥130 mm Hg or DBP ≥85 mm Hg; (3) TG ≥1.70 mmol/L; (4) HDL-C <1.03 mmol/L in men and HDL-C <1.29 mmol/L in women; and (5) FPG ≥5.6 mmol/L.

Statistical analysis

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) V.21.0 (SPSS Inc, Chicago, Illinois, USA). Data are presented as mean±SD or frequency (percentage). The t test was used to evaluate differences in characteristics of the study subjects with and without MetS stratified by sex. The χ^2 test was performed to compare the proportion of MetS components, from 0 to 5, between men and women, and to compare the prevalence of MetS dependent on the tertiles for RBC count, HCT, Hb and RDW between men and women. A one way ANOVA was conducted to test mean levels for erythrocyte parameters according to the number of MetS components in men and women separately. Multivariate logistic regression analyses (the enter selection procedure) were performed to calculate adjusted ORs for the erythrocyte parameters associated with MetS, stratified by sex, with adjustments for potential confounders (the statistically significant variables in table 1—men: adjusted for age, WC, SBP, DBP, TG, HDL-C, FPG, ALT, AST, GGT, BMI, UA, WBC, PLT and HbAIc; women: adjusted for age, WC, SBP, DBP, TG, HDL-C, FPG, ALT, GGT, BMI, TC, LDL-C, UA, WBC, PLT and HbAIc). A P value <0.05 was considered to be statistically significant.

RESULTS

Prevalence of MetS

In total, there were 2161 men and 2511 women enrolled in the study, of whom 576 men (26.7%) and 885 women (35.2%) were diagnosed with MetS.

Characteristics of the study subjects

In this study, among men, the mean age of the MetS group was significantly lower than that of the non-MetS group, whereas the opposite trend was observed among women (P<0.001). In the cluster of MetS components, WC, SBP, DBP, TG and FPG levels were much greater in the MetS group than in the non-MetS group in both

Table 1 Characteristics of the study subjects with and without metabolic syndrome, stratified by sex

	Men (n=2161)			Women (n=2511)		
Variable	MetS	Non-MetS	P value	MetS	Non-MetS	P value
MetS status (n (%))	576 (26.7)	1585 (73.3)		885 (35.2)	885 (35.2)	
Age (years)	51.39±12.21	54.61±13.79	<0.001	59.78±12.34	55.70±12.97	<0.001
Components of MetS						
WC (cm)	89.98±6.79	82.40±7.76	<0.001	85.94±7.21	77.59±8.56	<0.001
SBP (mm Hg)	134.93±15.20	127.57±16.32	<0.001	136.49±16.42	124.74±18.39	<0.001
DBP (mm Hg)	89.24±10.47	82.93±11.09	<0.001	84.13±10.25	78.51±10.53	<0.001
TG (mmol/L)	2.76±1.77	1.29±0.91	<0.001	2.15±1.41	1.20±1.87	<0.001
HDL-C (mmol/L)	1.00±0.47	1.28±0.44	<0.001	1.17±0.22	1.50±0.34	<0.001
FPG (mmol/L)	5.53±2.01	4.87±1.40	<0.001	5.38±1.86	4.71±0.97	<0.001
Erythrocyte parameters						
RBC ($\times10^{12}$/L)	4.99±0.80	4.53±0.51	<0.001	4.55±0.84	4.10±0.57	<0.001
HCT (%)	42.27±4.09	40.68±3.63	<0.001	37.35±2.80	35.58±2.83	<0.001
Hb (g/L)	147.11±12.57	139.02±12.68	<0.001	129.68±14.45	121.50±11.82	<0.001
RDW (%)	13.33±0.96	12.87±1.21	<0.001	13.18±1.90	12.88±2.27	<0.001
Liver function parameters						
ALT (u/L)	31.44±18.35	26.31±15.52	<0.001	24.09±13.81	21.14±11.79	<0.001
AST (u/L)	26.37±15.87	24.80±10.00	0.026	23.82±8.90	23.27±8.63	0.129
GGT (u/L)	48.73±39.88	36.04±26.83	<0.001	32.00±22.79	26.12±26.03	<0.001
ALB (g/L)	47.36±3.23	47.32±4.07	0.820	47.48±4.32	47.77±12.28	0.484
Other clinical characteristics						
BMI (kg/m^2)	25.90±2.67	23.61±3.04	<0.001	25.21±3.05	22.85±3.17	<0.001
TC (mmol/L)	4.81±0.95	4.73±0.94	0.059	5.26±1.08	5.08±1.02	<0.001
LDL-C (mmol/L)	2.65±0.70	2.66±2.06	0.885	2.95±1.48	2.75±1.03	<0.001
UA (umol/L)	415.45±143.27	382.19±84.92	<0.001	340.60±83.08	306.95±101.63	<0.001
WBC ($\times10^9$/L)	6.95±1.40	6.43±1.40	<0.001	6.41±1.35	5.84±1.31	<0.001
PLT ($\times10^9$/L)	214.70±49.89	201.57±52.17	<0.001	224.04±53.55	216.73±52.14	0.001
HbAlc (%)	5.79±1.37	5.42±0.97	<0.001	5.64±1.22	5.33±0.67	<0.001

Data are presented as mean±SD or n (%).
ALB, albumin; ALT, alanine transaminase; AST, aspartate aminotransferase; BMI, body mass index ; DBP, diastolic blood pressure ; FPG, fasting plasma glucose; GGT, γ-glutamyl transferase; Hb, haemoglobin; HbAlc, glycated haemoglobin A1c; HCT, haematocrit; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; MetS, metabolic syndrome; PLT, platelet; RBC, red blood cell; RDW, red blood cell distribution width; SBP, systolic blood pressure; TC, total cholesterol; TG, triglyceride; UA, uric acid; WBC, white blood cell; WC, waist circumference.

men and women, but HDL-C levels were significantly lower in the MetS group than that those in the non-MetS group in both men and women (P<0.001). In the cluster of erythrocyte parameters, we found that RBC, HCT, Hb and RDW were significantly higher in the MetS group than in the non-MetS group in both men and women (P<0.001). Additional information on the characteristics of study subjects with and without MetS, stratified by sex, are presented in table 1.

Proportion of MetS components

Our results revealed that most men experienced one metabolic disorder, and most women suffered from two metabolic disorders. In addition, the proportion of MetS components from 2 to 5 was significantly lower in men than that in women (25.5% vs 27.8%, 18% vs 21.3%, 7.5% vs 11.3% and 1.1% vs 2.6, respectively). Additional information is shown in figure 1.

Association of erythrocyte parameters with MetS

The study showed that the levels of RBC, HCT, Hb and RDW clearly increased with the number of MetS components from 0 to 5 identified in both men and women (P<0.001, shown in table 2). Figure 2 shows that the prevalence of MetS increased in a dose dependent manner as the tertiles for RBC, HCT, Hb and RDW levels increased in both men and women. Furthermore, at each tertile for the above mentioned parameters, the prevalence of MetS was lower in men than in women, except at the highest tertiles for RDW levels (figure 2).

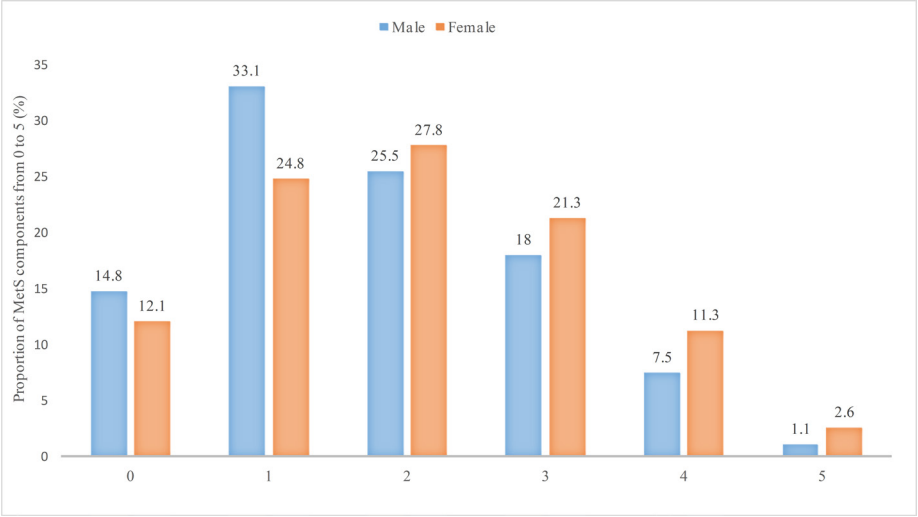

Figure 1 Proportion of metabolic syndrome (MetS) components from 0 to 5 between men and women.

Multivariate logistic regression analysis model

Adjusted ORs of MetS risk associated with each tertile of RBC, HCT, Hb and RDW are listed in table 3. After adjusting for potential confounders (the statistically significant variables in table 1—men: adjusted for age, WC, SBP, DBP, TG, HDL-C, FPG, ALT, AST, GGT, BMI, UA, WBC, PLT and HbAIc; women: adjusted for age, WC, SBP, DBP, TG, HDL-C, FPG, ALT, GGT, BMI, TC, LDL-C, UA, WBC, PLT and HbAIc). A significant association of Hb and RDW with MetS was observed in men, but this was not the same for RBC and HCT. The ORs of MetS risk increased across the tertiles of Hb (Q2: OR=1.921, 95% CI=1.170 to 3.151; Q3: OR=1.992, 95%CI=1.198~3.312). Men in the highest tertiles of RDW had a 2.752-fold increased risk of suffering from MetS compared with those in the reference group. Only RBC and Hb levels were observed to be associated with MetS in women. The ORs of MetS risk also increased across the tertiles of Hb (Q2: OR=1.538, 95%CI=1.008 to 2.348; Q3: OR=1.665, 95%CI=1.075 to 2.578). Women in the highest tertiles of RBC had a 1.718-fold increased risk of experiencing MetS in comparison with those in the reference group.

DISCUSSION

Main findings

The prevalence of MetS was higher in women than in men (35.2% vs 26.7%). Levels of RBC, HCT, Hb and RDW increased linearly with the number of MetS components from 0 to 5, identified in both men and women. The association between erythrocyte parameters and MetS differed between the sexes: Hb and RDW were identified as risk factors for MetS in men and RBC and Hb as risk factors in women.

Comparisons with previous studies

Sex has been demonstrated to be a predictive factor for MetS development. Several studies have shown that women have a higher prevalence of MetS than men.[19 20] A large scale study conducted in Russia reported that the

Table 2 Levels of erythrocyte parameters in the study subjects according to the number of metabolic syndrome components (from 0 to 5) in men and women

Variable	0	1	2	3	4	5	F	P value
Men								
RBC	4.44±0.53	4.55±0.50	4.55±0.52	4.80±0.54	5.31±0.86	5.95±1.23	87.448	<0.001
HCT	39.96±3.39	40.76±3.88	41.00±3.38	42.12±4.10	42.33±4.14	44.21±3.01	19.799	<0.001
Hb	131.60±12.35	138.81±12.86	140.71±12.41	144.51±11.65	151.28±12.87	160.04±9.19	52.445	<0.001
RDW	12.75±0.82	12.83±1.55	13.00±0.80	13.24±0.86	13.41±1.07	14.33±1.13	20.264	<0.001
Women								
RBC	4.03±0.39	4.07±0.52	4.16±0.54	4.45±0.82	4.67±0.88	4.83±0.78	66.453	<0.001
HCT	35.16±2.65	35.43±2.78	35.91±2.91	37.07±2.81	37.74±2.79	37.96±2.36	52.237	<0.001
Hb	119.70±11.54	121.28±11.79	122.49±11.88	128.26±14.04	130.04±14.35	139.61±14.46	59.262	<0.001
RDW	12.71±2.10	12.74±1.40	13.07±2.87	13.11±1.39	13.25±2.70	13.38±1.13	4.493	<0.001

Hb, haemoglobin; HCT, haematocrit; RBC, red blood cell; RDW, red blood cell distribution width.

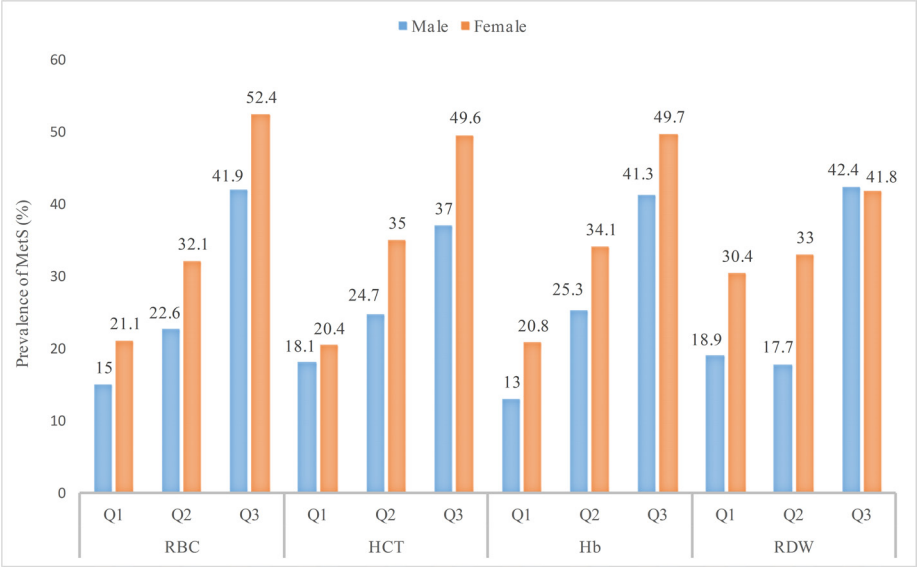

Figure 2 Prevalence of metabolic syndrome (MetS) in association with the tertiles for red blood cell (RBC) count, haematocrit (HCT), haemoglobin (Hb) and red blood cell distribution width (RDW), in men and women separately.

prevalence of MetS diagnosed using the ATP III criteria was 9.5% in men and 23.5% in women.[19] Another study performed in the seven geographical regions of Turkey showed that the prevalence of MetS, as determined by the ATP III criteria, was 28% in men and 39.6% in women.[20] Our study outcomes are in accordance with these reports. However, other studies have reported that men have a higher prevalence of MetS than women. For example, Tao *et al* found that the 5 year cumulative incidence of MetS in Beijing adults was 14.22% for men and 7.59% for women.[21] Yang *et al* revealed that the 5 year cumulative incidence of MetS in Taiwanese adults was 14.95% for men and 9.89% for women.[22] Differences in the findings might be due to different study designs and/or the selected populations.

It is well known that MetS represents a cluster of simultaneously occurring metabolic abnormalities. In fact, previous studies demonstrated that RBC and Hb levels clearly increased with the number of MetS components,[16 23] and this is demonstrated in our outcomes. It has also been shown that a higher number of MetS components is associated with insulin resistance. Based on the facts that levels of RBC, HCT and Hb are significantly associated with insulin resistance,[10 12 24] we hypothesised that increased levels of erythrocyte parameters tested in this study may be indicative of the development of insulin resistance.

Several studies have demonstrated an association between RBC levels and MetS, indicating that the RBC variable is a potential haematological marker for early detection of MetS.[14–16] Our results revealed that the highest tertiles of RBC were associated with MetS in women, consistent with a recent study.[25] The pathogenesis of insulin resistance may, in part, be causative of the association between RBC levels and MetS. Aoki *et al* reported that insulin can stimulate the proliferation and differentiation of erythropoietic cells by binding receptors on the cell surface.[26] It was suggested that insulin and insulin growth factors I and II can promote the proliferation and differentiation of erythroid progenitors in human bone marrow and the circulation.[27–29] Alternatively, the relationship between RBC levels and MetS may be a result of iron overload. It was reported that iron overload was associated with insulin resistance,[30] and excessive body iron storage interfered with insulin mediated effects, while bloodletting improved insulin sensitivity.[31] Bozzini *et al* found that iron overload was strongly associated with obesity and dyslipidaemia, and serum ferritin tests would help identify a subgroup of individuals at risk for insulin resistance associated with hepatic iron overload.[32] Additionally, erythrocyte fatty acids may be another linking factor between RBC levels and MetS. Novgorodtseva *et al* found that the development of MetS was accompanied by changes to the composition of erythrocyte fatty acids.[33] Zong *et al* also demonstrated that erythrocyte fatty acids in the de novo lipogenesis pathway were independently associated with an elevated risk of MetS.[34] Fatty acid composition in erythrocytes may affect insulin sensitivity in individuals with MetS. This may be the underlying mechanism linking insulin resistance to changes in fatty acid composition of RBCs in individuals with MetS.[35]

Hb, another important erythrocyte parameter, has been reported to be associated with MetS in both cross sectional and cohort studies.[14 16 17 36] An 8 year follow-up cohort study conducted in Japan detected that the highest and third quartiles of Hb concentration were associated with an increased risk of MetS incidence compared with the lowest quartiles of Hb concentration in men, but there was no association observed in women.[17] In general, our findings are consistent with those of previous reports. In our study, the ORs for MetS increased across the

Table 3 OR of erythrocyte parameters associated with metabolic syndrome stratified by sex

	Men		Women	
Variable	OR (95% CI)	P value	OR (95% CI)	P value
Age	0.999 (0.986 to 1.013)	0.930	1.012 (0.998 to 1.025)	0.088
WC	1.157 (1.121 to 1.194)	<0.001	1.130 (1.103 to 1.158)	<0.001
SBP	1.025 (1.012 to 1.039)	<0.001	1.041 (1.031 to 1.051)	<0.001
DBP	1.025 (1.006 to 1.045)	0.011	1.030 (1.013 to 1.047)	0.001
TG	3.240 (2.697 to 3.893)	<0.001	1.518 (1.269 to 1.817)	<0.001
HDL-C	0.026 (0.012 to 0.054)	<0.001	0.001 (0.001 to 0.003)	<0.001
FPG	1.725 (1.410 to 2.111)	<0.001	2.221 (1.836 to 2.687)	<0.001
ALT	0.996 (0.980 to 1.012)	0.620	1.002 (0.990 to 1.014)	0.757
AST	1.016 (0.988 to 1.045)	0.260		
GGT	1.001 (0.997 to 1.006)	0.492	1.005 (1.000 to 1.010)	**0.064**
BMI	0.976 (0.907 to 1.049)	0.506	1.015 (0.958 to 1.076)	0.620
TC			1.243 (1.061 to 1.455)	**0.007**
LDL-C			0.992 (0.903 to 1.090)	0.867
UA	1.001 (0.999 to 1.003)	0.291	1.001 (0.999 to 1.002)	0.303
WBC	1.044 (0.935 to 1.165)	0.447	1.063 (0.959 to 1.178)	0.248
PLT	1.002 (0.999 to 1.005)	0.202	1.001 (0.998 to 1.003)	0.639
HbAlc	0.856 (0.649 to 1.130)	0.273	0.747 (0.572 to 0.976)	0.032
RBC				
Q1	Reference		Reference	
Q2	0.940 (0.613 to 1.443)	0.779	1.070 (0.743 to 1.541)	0.716
Q3	1.207 (0.771 to 1.889)	0.410	1.718 (1.173 to 2.515)	0.005
HCT				
Q1	Reference		Reference	
Q2	0.771 (0.482 to 1.234)	0.279	1.419 (0.933 to 2.159)	0.102
Q3	0.968 (0.606 to 1.547)	0.893	1.407 (0.896 to 2.208)	0.138
Hb				
Q1	Reference		Reference	
Q2	1.921 (1.170 to 3.151)	0.010	1.538 (1.008 to 2.348)	0.046
Q3	1.992 (1.198 to 3.312)	0.008	1.665 (1.075 to 2.578)	0.022
RDW				
Q1	Reference		Reference	
Q2	1.114 (0.757 to 1.639)	0.583	0.787 (0.571 to 1.085)	0.144
Q3	2.725 (1.915 to 3.878)	**<0.001**	1.057 (0.753 to 1.484)	0.750

The bolded values represented P value <0.05.
Statistical analysis by binary logistic regression with adjustments for potential confounders (the statistically significant variables in table 1). Men: adjusted for age, WC, SBP, DBP, TG, HDL-C, FPG, ALT, AST, GGT, BMI, UA, WBC, PLT and HbAlc. Women: adjusted for age, WC, SBP, DBP, TG, HDL-C, FPG, ALT, GGT, BMI, TC, LDL-C, UA, WBC, PLT and HbAlc.
ALT, alanine transaminase; AST, aspartate aminotransferase; BMI, body mass index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; GGT, γ-glutamyl transferase; Hb, haemoglobin; HbAlc, glycated haemoglobin A1c; HCT, haematocrit; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; PLT, platelets; RBC, red blood cell; RDW, red blood cell distribution width; SBP, systolic blood pressure; TC, total cholesterol; TG, triglyceride; UA, uric acid; WBC, white blood cell; WC, waist circumference.

successive tertiles of Hb among men; however, no similar trend was observed in women. The following mechanisms may be regarded as the causes of the association between Hb and MetS: Hb is a well known carrier and buffer of nitric oxide (NO), and can regulate the endothelial function of blood vessels by modulating NO levels in blood.[37] Furthermore, Hb and various compounds of NO modulate the affinity between Hb and oxygen in blood, which can lead to vascular endothelial dysfunction.[38] It has been found that vascular endothelial dysfunction was associated with MetS.[39 40] In addition, Hb plays a key role in regulating sCD40L levels,[41] and sCD40L has been shown

to participate in thrombus formation and inflammation, which is an independent risk factor for atherosclerosis and MetS.[42] Another possibility linking Hb and MetS may be adiponectin. Previous studies showed that higher Hb levels were closely related to lower adiponectin levels,[43 44] and lower levels of adiponectin significantly increased the risk for MetS, respectively. Finally, insulin resistance may also be involved in the association between Hb and MetS.[8 12]

RDW, a common index of routine blood examinations, represents a measure of heterogeneity in the size of circulating erythrocytes. A high RDW index indicates greater heterogeneity in the size of circulating erythrocytes in a subject. In this study, men in the highest tertiles of RDW (>13.2%) had a 2.75-fold increased risk for MetS. Multiple groups previously showed that elevated RDW was associated with MetS.[45 46] For instance, Laufer *et al* demonstrated that RDW ≥14% was independently associated with an increased risk for MetS development[45]; Sanchez-Chaparro *et al* reported that the highest quartile of RDW (>14%) was linked with MetS after adjusting for potential confounders.[46] Moreover, a recent study showed that RDW is a potential metabolic marker for the detection of metabolic diseases.[47] To date, the mechanism for the association between RDW and MetS remains unknown; however, chronic inflammation linked to RDW may play an important role. MetS has previously been associated with chronic inflammation,[9] and RDW reflects an underlying inflammatory state.[13] Pierce *et al* have proved that proinflammatory cytokines can inhibit erythropoietin induced erythrocyte maturation, which may lead to an elevation in RDW.[48]

Our study was conducted in the Pearl River Delta region of China, and it may imply that the generalisability of our results is limited to this region. Additionally, participants with a history of cardiovascular diseases, severe liver or kidney dysfunction, tumours or severe inflammatory diseases were excluded, so our results are not applicable to these subjects.

There were several limitations in this study. First, the present study was designed as a cross sectional study; therefore, direct causation cannot be concluded from the results. Supplementary information about the lifestyle of the subjects was not collected and hence factors such as smoking, physical exercise and dietary could not be included in the adjustments of our multivariate logistic regression analyses.

CONCLUSIONS

In our study, MetS was more prevalent in women than in males. The association between erythrocyte parameters and MetS differed between the sexes: RBC and Hb were identified as risk factors for MetS in women and Hb and RDW as risk factors in men. This has important clinical implications for health professionals. Erythrocyte parameters may serve as effective indices for the early detection of the risk and treatment of MetS on a sex dependent basis.

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