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Association between lifestyle and hematological parameters: A study of Chinese male steelworkers

Mei-Chu Yen Jean[1] | Chia-Chang Hsu[2] | Wei-Chin Hung[3] | Yung-Chuan Lu[4,5] | Chao-Ping Wang[3,5] | I-Ting Tsai[6] | I-Cheng Lu[1] | Yi-Hsin Hung[7] | Fu-Mei Chung[3] | Yau-Jiunn Lee[8] | Teng-Hung Yu[3]

[1]Department of Occupational Medicine, E-Da Hospital, I-Shou University, Kaohsiung, Taiwan

[2]Division of Gastroenterology and Hepatology, E-Da Hospital, I-Shou University, Kaohsiung, Taiwan

[3]Division of Cardiology, E-Da Hospital, I-Shou University, Kaohsiung, Taiwan

[4]Division of Endocrinologic, Department of Internal Medicine, E-Da Hospital, I-Shou University, Kaohsiung, Taiwan

[5]School of Medicine for International Students, I-Shou University, Kaohsiung, Taiwan

[6]Department of Emergency, E-Da Hospital, I-Shou University, Kaohsiung, Taiwan

[7]Faculty of Medicine, National Yang Ming University, Taipei, Taiwan

[8]Lee's Endocrinologic Clinic, Pingtung, Taiwan

Correspondence
Teng-Hung Yu, Division of Cardiology, E-Da Hospital, I-Shou University, Kaohsiung 82445, Taiwan.
Email: tenghungy@gmail.com

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Abstract

Background: Increasing evidence suggests an association between lifestyle and white blood cell (WBC) count; however, no study has examined the effects of lifestyle associations on hematological parameters. The aim of this study was to examine the association between lifestyle factors and hematological parameters in a large population-based sample of Chinese male steelworkers.

Methods: This study included 3189 male workers at a steel plant who responded to a cross-sectional questionnaire on basic attributes, lifestyle, and sleep. All workers in the plant underwent periodic health checkups. Hematological parameters were also examined at the checkup.

Results: Stepwise linear regression analyses showed that smoking, poor sleep, shift work, and obesity were all significant factors associated with WBC count. Obesity was independently associated with RBC count. Furthermore, smoking and obesity were associated with hemoglobin, and smoking, poor sleep, and obesity were independently associated with hematocrit. Moreover, smoking was the main factor associated with MCV and MCH. When the subjects were divided into quartiles according to WBC count, RBC count, hemoglobin, hematocrit, MCV, MCH, and increased WBC count were associated with smoking, poor sleep, shift work, and obesity. Increased hemoglobin was associated with smoking and obesity. Furthermore, an increased RBC count was associated with obesity, and increased hematocrit was associated with smoking, poor sleep, and obesity. Similarly, increased MCV and MCH were also associated with smoking.

Conclusion: This study indicates that lifestyle factors may exert an important effect on hematological parameters (eg, WBC count, RBC count, hemoglobin, hematocrit, MCV, and MCH).

KEYWORDS
Chinese male, hematological parameters, lifestyle, steelworkers

Yen Jean and Hsu equally contributed to this work.

1 | INTRODUCTION

Oxygen, nutrients, and waste products are exchanged via the blood, including plasma and blood cells (red blood cells (RBCs) and white blood cells (WBCs)), WBCs are responsible for inflammation, and RBCs carry oxygen and nutrients to all tissues of the body and waste products away from the organs. Hematological abnormalities have been associated with coronary heart disease (CHD), oxidative damage, and other health problems.[1-4] Epidemiological studies have reported associations between an increased WBC count and the risk of CHD and subclinical atherosclerosis.[5,6] A high RBC count may be a symptom of a disease or disorder, although it does not always indicate a health problem, and health or lifestyle factors can also cause a high RBC count.[7] Furthermore, a high hemoglobin count in the absence of any other abnormalities is unlikely to be related to any condition of concern. Specific disorders such as chronic obstructive pulmonary disease,[8] heart failure,[9] liver cancer,[10] and kidney cancer[9] or lifestyle factors such as smoking and living at a high altitude[7] may affect the hemoglobin level. In addition, Braekkan et al[11] suggested that hematocrit and related hematological variables such as hemoglobin and RBC count are risk factors for venous thromboembolism in the general population. Moreover, Emamian et al[12] demonstrated that hematocrit was an independent risk factor for hypertension in the general population. In addition, previous studies have shown that high mean corpuscular volume (MCV) is a prognostic indicator for acute decompensated heart failure[13] and that it is associated with all-cause mortality, cardiovascular disease mortality, and infection-associated mortality in patients with chronic kidney disease stages 3-5,[14] and that mean corpuscular hemoglobin (MCH) is a predictor of iron deficiency.[15]

Although numerous studies have indicated that lifestyle factors such as smoking, alcohol consumption, shift work, and exercise may exert an important effect on WBC count,[16-19] little is known about the association between hematological parameters and lifestyle factors. To promote primary prevention of CHD and other diseases at the workplace, the evaluation of lifestyle factors related to hematological parameters is considered to be important. As hematological parameters are commonly measured in clinical laboratory tests, we examined the associations between lifestyle factors (alcohol consumption, smoking, physical exercise, poor sleep, shift work, and obesity) and hematological parameters in a large population-based sample of Chinese male steelworkers.

2 | MATERIALS AND METHODS

2.1 | Study population

A total of 3189 male steelworkers, all >20 years of age, were enrolled in this study. The subjects were recruited from the Occupational Clinic of E-Da Hospital. Each subject gave informed consent, and the study protocol was approved by the Human Research Ethics Committee of Kaohsiung E-Da Hospital. None of the subjects included in this study had a history or manifestations of acute or chronic inflammatory disease, cancer, active liver or kidney disease, chronic pancreatitis, history of ischemic heart disease, infection, and hormonal therapy. In addition, subjects with incomplete demographic, occupational history, or sleep quality data were excluded. Details of the study design and population characteristics are available in an earlier report.[17]

2.2 | Data collection and definitions

Data on basic demographic characteristics and lifestyle, such as age, sex, job type, sleep quality, health condition, physical exercise, smoking habits, and alcohol consumption, were collected through a self-administered questionnaire. Measurements of height and weight were taken with the participants wearing no shoes and very light clothing. Height was measured to the nearest 0.5 cm using a standard physician's height stadiometer. Body weight was measured to the nearest 0.1 kg using a portable balance scale. Body mass index (BMI; kg/m^2) was calculated as weight (in kilograms) divided by the square of the height (in meters). Obesity was defined according to the Department of Health, Taiwan, as a BMI of ≥27 kg/m^2.

Lifestyle factors were identified based on the participants' answers to five questions on a self-reported questionnaire. All questions had three possible answers, except for job schedule, which had two. The questions and their possible responses were as follows. Physical exercise was assessed using the question "How often did you exercise during the past month?" Response options were hardly ever, once, and twice or more. For job schedules, the participants were asked whether they were daytime workers (8:00-17:00) or shift workers who worked rotating shifts comprising morning (07:00-15:00), afternoon (15:00-23:00), and night (23:00-07:00) shifts. Sleep quality was assessed using the question "How often did you have poor sleep during the past month?" Response options were almost never, sometimes, and often and almost always.

The subjects' smoking status was classified as never having smoked, former smoker (quit smoking for at least 1 year), or current smoker. Alcohol consumption status was classified as never having drunk, former drinker (quit drinking for at least 1 year), or current drinker. In this study, former and current drinkers were analyzed as a single group.[20]

2.3 | Laboratory measurements

On the morning of the procedure and after fasting for at least 8 hours, blood samples were collected, stored, and analyzed by one single laboratory. Serum levels of triglycerides, total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, and glucose were measured using standard commercial methods on a parallel, multichannel analyzer (Hitachi 7170A) as in our previous reports.[17] Total leukocyte count, RBC, hemoglobin, hematocrit, MCV, and MCH were measured using an automatic hematological analyzer (XE-2100 Hematology Alpha Transportation System; Sysmex Corporation). To minimize the confounding effect of infection, subjects with a WBC count below 4.0×10^9/L or greater than

10.0×10^9/L were rechecked and examined extensively for possible occult or chronic infections. Any specimen with abnormal or atypical leukocytes were re-analyzed and excluded.

2.4 | Statistical analysis

Data are presented as the mean ± SD. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 12.0, SPSS Inc). Statistical differences were compared using unpaired Student's *t* tests and one-way analysis of variance (ANOVA) for normally distributed variables. Simple and multiple linear stepwise regression analyses were used to examine associations and independence between hematological parameters and other parameters. The prevalence of smoking, poor sleep, shift work, and obesity categorized by quartile of hematological parameters (WBC, RBC, hemoglobin, hematocrit, MCV, and MCH) were tested for trends. All statistical analyses were two-sided, and a P value < 0.05 was considered to be statistically significant.

3 | RESULTS

The subjects' characteristics are shown in Table 1. The mean ± SD age of the subjects was 42.9 ± 7.4 years. Of the 3189 participants, 1415 (44.4%) had engaged in shift work for at least 1 year. The prevalence rates of obesity, alcohol consumption, current smokers, hardly ever partaking in physical exercise, and often or almost always having poor sleep were 752 (23.6%), 1602 (50.2%), 1184 (37.1%), 839 (26.3%), and 309 (9.7%), respectively.

Table 2 shows comparisons of hematological parameters of the study subjects grouped by age, alcohol consumption status, smoking status, physical exercise, poor sleep, shift work, and obesity. There were statistically significant increases in WBC count in the subjects who were <45 years old, were current smokers, were hardly ever exercised, often or almost always had poor sleep, worked shifts, and were obese (all P < 0.01). RBC count was elevated in the subjects who were <45 years old, were never smokers, worked shifts, and were obese, and decreased in those who had exercised two or more times in the past month (all P < 0.05). In addition, there were significant increases in hemoglobin and hematocrit in the subjects who were <45 years old, were current smokers, hardly ever exercised, often or almost always had poor sleep, worked shifts, and were obese (all P < 0.05). Moreover, MCV and MCH were elevated in the subjects ≥45 years old, alcohol drinkers, and current smokers (all P < 0.05). There were no significant differences in WBC count, RBC count, hemoglobin, and hematocrit between drinkers and non-drinkers, and there was no significant difference in RBC count with regard to sleep status. There were no significant differences in physical exercise (hardly ever, once, and twice or more in the past month), poor sleep (almost never, sometimes, and often or almost always in the past month), shift work (yes, no), and obesity (yes, no) among MCV and MCH values (all P > 0.05) (Table 2).

Univariate analysis revealed that WBC count was positively associated with smoking, poor sleep, hypertension, hyperlipidemia, shift work, and obesity and that RBC count was positively associated with hyperlipidemia, shift work, and obesity. Furthermore, hemoglobin was positively associated with smoking, poor sleep, hyperlipidemia, shift work, and obesity, and hematocrit was positively associated with smoking, poor sleep, hyperlipidemia, shift work, and obesity. Moreover, MCV was positively associated with age, drinking, and smoking, and MCH was positively associated with age, drinking, smoking, and hyperlipidemia. In addition, age was negatively associated with levels of WBC, RBC, hemoglobin, and hematocrit. Physical

TABLE 1 Clinical and biochemical characteristics of the study population

Variable	Total (N = 3189)
Age (years)	42.9 ± 7.4
Hypertension (n, %)	270 (8.5)
Hyperlipidemia (n, %)	1058 (33.2)
Diabetes mellitus (n, %)	64 (2.0)
Obesity (n, %)	752 (23.6)
Alcohol consumption (n, %)	1602 (50.2)
Shift work (n, %)	1415 (44.4)
Smoking (n, %)	
Never	1584 (49.7)
Former	421 (13.2)
Current	1184 (37.1)
Physical exercise in the past month (n, %)	
Hardly ever	839 (26.3)
Once	1758 (55.1)
Twice or more	592 (18.6)
Poor sleep in the past month (n, %)	
Almost never	2291 (71.8)
Sometimes	589 (18.5)
Often or almost always	309 (9.7)
BMI (kg/m^2)	25.0 ± 3.5
Systolic blood pressure (mm Hg)	124 ± 16
Diastolic blood pressure (mm Hg)	79 ± 11
Fasting glucose (mmol/L)	5.6 ± 1.2
T-cholesterol (mmol/L)	5.0 ± 0.9
Triglyceride (mmol/L)	1.3 (0.9-1.9)
High-density lipoprotein cholesterol (mmol/L)	1.2 ± 0.3
Low-density lipoprotein cholesterol (mmol/L)	2.9 ± 0.8
White blood cell count (10^9/L)	6.306 ± 1.617
Red blood cell count ($10^6/\mu L$)	5.204 ± 0.469
Hemoglobin (g/L)	153 ± 11
Hematocrit (%)	44.9 ± 2.7
Mean corpuscular volume (fL)	86.7 ± 6.5
Mean corpuscular hemoglobin (pg/cell)	29.5 ± 2.5

Data are expressed as mean ± SD, number (percentage), or median (interquartile range).

TABLE 2 Hematological parameters of the study subjects by age and lifestyle factors

Parameter	WBC count (10^9/L)	Red blood cell (10^6/μL)	Hemoglobin (g/dL)	Hematocrit (%)	MCV (fL)	MCH (pg/cell)
Age (years)						
<45 (n = 1982)	6.367 ± 1.642	5.249 ± 0.469	15.3 ± 1.1	45.1 ± 2.7	86.3 ± 6.5	29.4 ± 2.6
≥45 (n = 1207)	6.205 ± 1.571	5.131 ± 0.461	15.2 ± 1.1	44.6 ± 2.8	87.4 ± 6.3	29.7 ± 2.5
P value	0.006	<0.0001	0.001	<0.0001	<0.0001	<0.0001
Alcohol use						
Yes (n = 1745)	6.326 ± 1.624	5.191 ± 0.474	15.3 ± 1.1	45.0 ± 2.8	87.1 ± 6.7	29.6 ± 2.6
No (n = 1444)	6.275 ± 1.590	5.222 ± 0.474	15.3 ± 1.1	44.8 ± 2.7	86.3 ± 6.3	29.4 ± 2.5
P value	0.398	0.076	0.599	0.204	0.001	0.016
Smoking						
Never (n = 1584)	5.940 ± 1.401	5.223 ± 0.451	15.2 ± 1.0	44.7 ± 2.6	86.0 ± 5.9	29.2 ± 2.4
Former (n = 421)	6.182 ± 1.632	5.160 ± 0.450	15.2 ± 1.1	44.5 ± 2.9	86.6 ± 6.1	29.6 ± 2.4
Current (n = 1184)	6.830 ± 1.735	5.187 ± 0.506	15.4 ± 1.1	45.3 ± 2.8	87.8 ± 7.1	29.9 ± 2.8
P value	<0.0001	0.036	<0.0001	<0.0001	<0.0001	<0.0001
Physical exercise in the past month						
Hardly ever (n = 839)	6.475 ± 1.603	5.227 ± 0.473	15.4 ± 1.1	45.2 ± 2.8	86.9 ± 6.6	29.6 ± 2.6
Once (n = 1758)	6.273 ± 1.584	5.208 ± 0.477	15.3 ± 1.1	44.8 ± 2.7	86.5 ± 6.5	29.4 ± 2.6
Twice or more (n = 592)	6.137 ± 1.710	5.149 ± 0.460	15.2 ± 1.0	44.6 ± 2.6	87.0 ± 6.0	29.6 ± 2.3
P value	0.001	0.011	0.001	0.0002	0.261	0.273
Poor sleep in the past month						
Almost never (n = 2291)	6.261 ± 1.554	5.204 ± 0.469	15.2 ± 1.0	44.8 ± 2.7	86.5 ± 6.4	29.5 ± 2.5
Sometimes (n = 589)	6.233 ± 1.696	5.177 ± 0.488	15.3 ± 1.2	44.9 ± 3.0	87.1 ± 6.3	29.7 ± 2.5
Often or almost always (n = 309)	6.782 ± 1.923	5.255 ± 0.496	15.5 ± 1.2	45.5 ± 2.9	87.1 ± 6.9	29.6 ± 2.7
P value	<0.0001	0.126	0.021	0.001	0.100	0.235
Shift work						
Yes (n = 1554)	6.483 ± 1.698	5.227 ± 0.491	15.3 ± 1.1	45.0 ± 2.7	86.7 ± 6.8	29.5 ± 2.7
No (n = 1635)	6.114 ± 1.474	5.185 ± 0.451	15.2 ± 1.1	44.7 ± 2.7	86.7 ± 6.1	29.5 ± 2.4
P value	<0.0001	0.016	0.001	0.004	0.903	0.615
Obesity						
Yes (n = 752)	6.746 ± 1.649	5.268 ± 0.478	15.4 ± 1.1	45.3 ± 2.8	86.3 ± 6.2	29.4 ± 2.5
No (n = 2437)	6.169 ± 1.583	5.185 ± 0.465	15.2 ± 1.1	44.8 ± 2.7	86.8 ± 6.5	29.5 ± 2.5
P value	<0.0001	<0.0001	<0.0001	<0.0001	0.071	0.257

Data are mean ± SD.
MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; WBC, white blood cell.

exercise was negatively associated with levels of RBC and hematocrit (Table 3).

Multiple linear stepwise regression analysis showed that the significant independent factors for total WBC count were age (β = −0.047, *P* = 0.023), smoking (β = 0.211, *P* < 0.0001), poor sleep (β = 0.051, *P* = 0.011), hypertension (β = 0.056, *P* = 0.007), hyperlipidemia (β = 0.132, *P* < 0.0001), shift work (β = 0.054, *P* = 0.008), and obesity (β = 0.112, *P* < 0.0001); for RBC count were age (β = −0.133, *P* < 0.0001), hyperlipidemia (β = 0.062, *P* = 0.004), and obesity (β = 0.063, *P* = 0.003); for hemoglobin were age (β = −0.102, *P* < 0.0001), smoking (β = 0.050, *P* = 0.016), hyperlipidemia (β = 0.134, *P* < 0.0001), diabetes mellitus (β = 0.056, *P* = 0.008), and obesity (β = 0.052, *P* = 0.015); and for hematocrit were age (β = −0.102, *P* < 0.0001), smoking (β = 0.078, *P* < 0.0001), poor sleep (β = 0.048, *P* = 0.022), hyperlipidemia (β = 0.116, *P* < 0.0001), diabetes mellitus (β = 0.043, *P* = 0.037), and obesity (β = 0.055, *P* = 0.010). For MCV,

TABLE 3 Association of covariates with hematological parameters

	WBC count		Red blood cell		Hemoglobin		Hematocrit		MCV		MCH	
Factor	β	*P* value	β	*P* value	β	*P* value	β	*P* value	β	*P* value	β	*P* value
Age	−0.042	0.017	−0.136	<0.0001	−0.089	<0.0001	−0.094	<0.0001	0.086	<0.0001	0.069	<0.0001
Alcohol consumption	0.016	0.398	−0.033	0.076	0.010	0.599	0.024	0.204	0.062	0.001	0.045	0.016
Smoking	0.254	<0.0001	−0.025	0.170	0.088	<0.0001	0.107	<0.0001	0.130	<0.0001	0.109	<0.0001
Physical exercise	−0.035	0.085	−0.054	0.007	−0.035	0.082	−0.046	0.023	0.026	0.201	0.025	0.208
Poor sleep	0.086	<0.0001	0.031	0.093	0.050	0.007	0.069	<0.0001	0.020	0.280	0.031	0.090
Hypertension	0.039	0.028	−0.031	0.075	−0.005	0.790	−0.030	0.094	0.013	0.466	0.029	0.107
Diabetes mellitus	0.022	0.207	−0.018	0.317	−0.001	0.954	−0.015	0.399	0.004	0.808	0.013	0.476
Hyperlipidemia	0.189	<0.0001	0.075	<0.0001	0.149	<0.0001	0.129	<0.0001	0.014	0.428	0.042	0.017
Shift work	0.115	<0.0001	0.045	0.016	0.059	0.001	0.053	0.004	−0.002	0.902	0.009	0.615
Obesity	0.152	<0.0001	0.075	<0.0001	0.073	<0.0001	0.074	<0.0001	−0.032	0.071	−0.020	0.257

MCH, mean corpuscular hemoglobin; MCV, mean corpuscular volume.

TABLE 4 Stepwise linear regression analysis of covariates associated with hematological parameters

	WBC count		Red blood cell		Hemoglobin		Hematocrit		MCV		MCH	
Factor	β	*P* value	β	*P* value	β	*P* value	β	*P* value	β	*P* value	β	*P* value
Age	−0.047	0.023	−0.133	<0.0001	−0.102	<0.0001	−0.102	<0.0001	0.088	<0.0001	0.067	0.001
Alcohol consumption	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Smoking	0.211	<0.0001	NA	NA	0.050	0.016	0.078	<0.0001	0.116	<0.0001	0.087	<0.0001
Physical exercise	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Poor sleep	0.051	0.011	NA	NA	NA	NA	0.048	0.022	NA	NA	NA	NA
Hypertension	0.056	0.007	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hyperlipidemia	0.132	<0.0001	0.062	0.004	0.134	<0.0001	0.116	<0.0001	NA	NA	NA	NA
Diabetes mellitus	NA	NA	NA	NA	0.056	0.008	0.043	0.037	NA	NA	NA	NA
Shift work	0.054	0.008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Obesity	0.112	<0.0001	0.063	0.003	0.052	0.015	0.055	0.010	NA	NA	NA	NA

MCH, mean corpuscular hemoglobin; MCV, mean corpuscular volume; NA, not applicable.

the significant independent factors were age (β = 0.088, $P < 0.0001$) and smoking (β = 0.116, $P < 0.0001$), and for MCH were also age (β = 0.067, $P = 0.001$) and smoking (β = 0.087, $P < 0.0001$) (Table 4).

The prevalence rates of smoking, poor sleep, shift work, and obesity stratified by quartiles of total WBC count, RBC count, hemoglobin, hematocrit, MCV, and MCH levels are shown in Figures 1 and 2. The frequency of smoking differed among quartiles of total WBC count, hemoglobin, hematocrit, MCV, and MCH levels. The frequency of poor sleep also differed among quartiles of total WBC count and hematocrit concentrations. Furthermore, the frequency of shift work differed among quartiles of total WBC count. Moreover, the frequency of obesity differed among quartiles of total WBC count, RBC count, hemoglobin, and hematocrit levels (all $P < 0.001$), and the trends were all significantly linear (all $P < 0.001$) (Figures 1 and 2).

4 | DISCUSSION

In the present study, we found independent positive associations between total WBC count and cigarette smoking, poor sleep, shift work, and obesity. Furthermore, hemoglobin and hematocrit were positively associated with smoking and obesity, and MCV and MCH were positively associated with smoking. Moreover, RBC count and

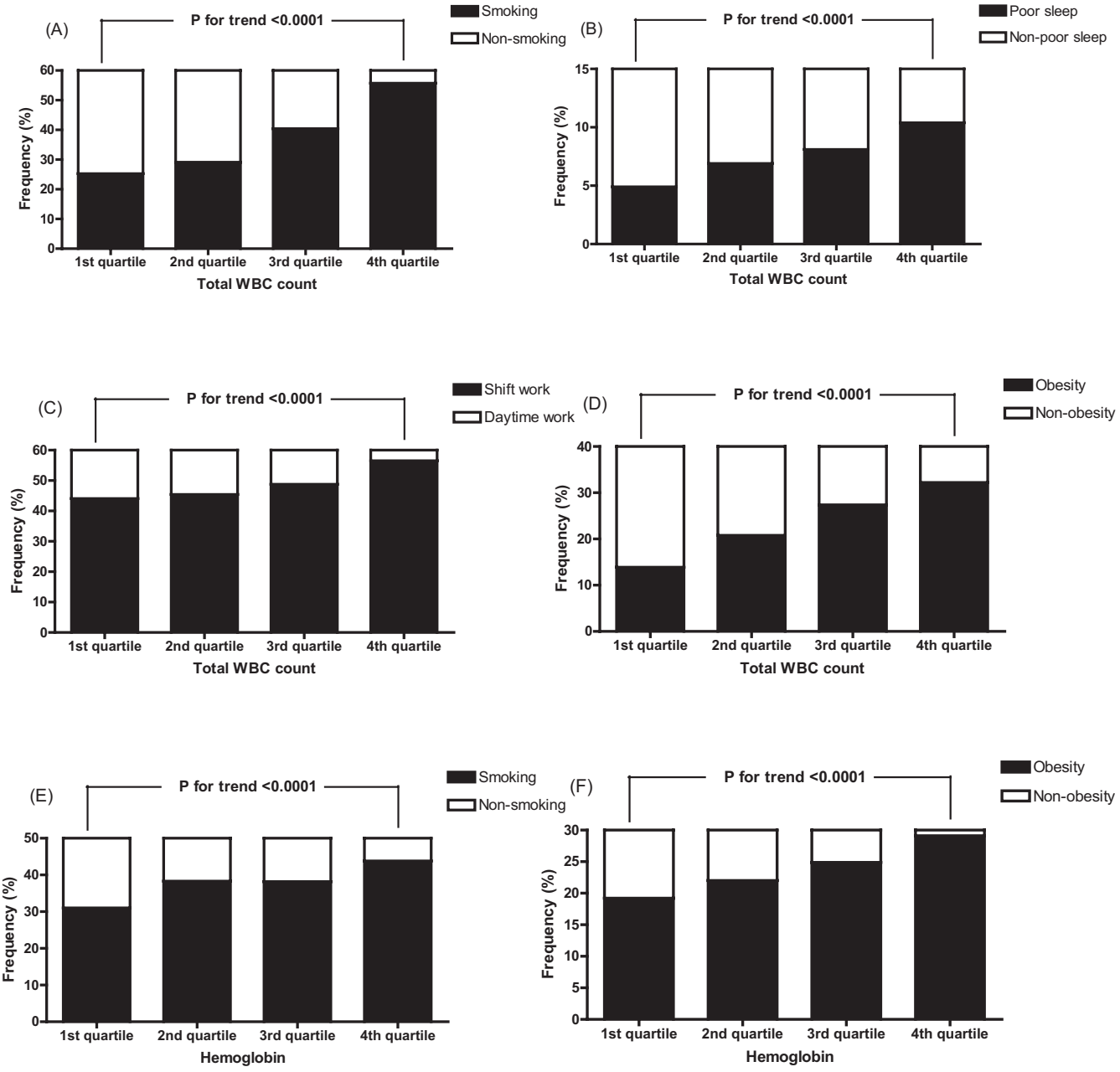

FIGURE 1 The prevalence of smoking, poor sleep, shift work, and obesity stratified by total white blood cell (WBC) count and hemoglobin. The frequencies of smoking, poor sleep, shift work, and obesity differed among quartiles of WBC count (all $P < 0.0001$, A-D), and smoking and obesity differed among quartiles of hemoglobin (all $P < 0.0001$, E, F), and the trend was significantly linear (all $P < 0.0001$)

hematocrit were also positively associated with obesity and poor sleep, respectively. Our results demonstrate that lifestyle factors may exert an important effect on hematological parameters (eg, WBC count, RBC count, hemoglobin, hematocrit, MCV, and MCH).

In this study, WBC count, hemoglobin, hematocrit, MCV, and MCH were significantly higher in current smokers than in former and/or never smokers. The significant increases in WBC count, hemoglobin, hematocrit, MCV, and MCH in those who smoked are consistent with previous studies.[7,21,22] Smith et al reported that total WBC count and its components were strongly associated with cigarette smoking and that smoking cessation may have an almost immediate impact on pathophysiologic processes such as inflammation that may be indicated by WBC count.[21] Malenica et al showed that continuous cigarette smoking had severe adverse effects on hematological parameters (eg, hemoglobin, WBC count, MCV, RBC count, hematocrit) and that these alterations might be associated with a greater risk of developing atherosclerosis, polycythemia vera, chronic obstructive pulmonary disease, and cardiovascular diseases.[7] Some studies have suggested that an increase in hemoglobin level in the blood of smokers could be a compensatory mechanism

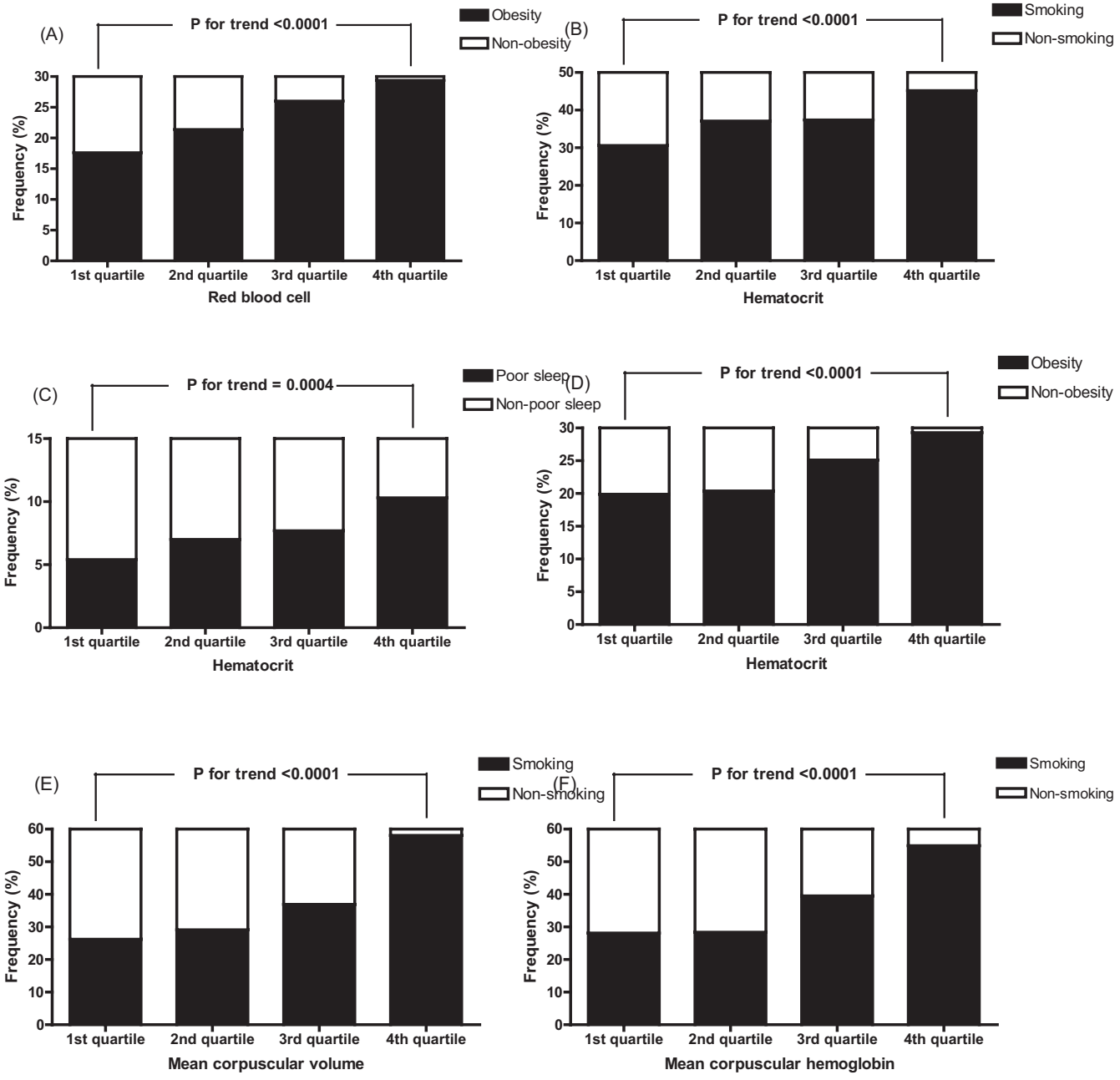

FIGURE 2 The prevalence rates of obesity, smoking, and poor sleep stratified by red blood cell (RBC) count, hematocrit, mean corpuscular volume (MCV), and mean corpuscular hemoglobin (MCH). The frequencies of obesity differed among quartiles of RBC count ($P < 0.0001$, A); smoking, poor sleep, and obesity differed among quartiles of hematocrit (all $P < 0.001$, B-D); and smoking differed among quartiles of MCV and MCH (all $P < 0.0001$, E, F), and the trends were significantly linear (all $P < 0.001$)

mediated by exposure to carbon monoxide.[23] Carbon monoxide from cigarette smoke has also been reported to lead to an increase in permeability of the capillaries, which decreases the plasma volume and mimics the condition of polycythemia, characterized by an increased percentage of erythrocytes in the blood volume, which is then reflected in increased values of hematocrit.[24] Furthermore, we found significantly higher values of MCV and MCH among the smokers. MCV and MCH are two main RBC indices that help in measuring the average size and hemoglobin composition of RBCs. Higher values of MCV and MCH in smokers in relation to non-smokers have been confirmed in previous studies.[25,26] Kung et al demonstrated that the values of these parameters exceeded the values of the reference range and were characteristic findings for diseases such as kidney dysfunction, hyperuricemia, hypertension, and hypercholesterolemia.[25] However, these results are in contrast to those of Pankaj et al who did not find any significant changes in MCV and MCH between smokers and non-smokers.[27]

The present study showed that shift work was associated with a higher WBC count. Increasing evidence has demonstrated an association between elevations of inflammatory markers and the risk of medical conditions, including cardiovascular disease, arthritis, diabetes mellitus, and certain cancers, which have also been reported in shift workers. The significant increase in WBC count in shift workers is consistent with previous studies.[17,28] In studies by Lu et al and Puttonen et al, peripheral total and differential leukocyte counts were significantly higher in shift workers,[17] and 2- and 3-shift work was associated with increased systemic inflammation,[28] suggesting that shift work may be a risk factor for cardiovascular disease.

Higher WBC count, RBC count, hemoglobin, and hematocrit were associated with obesity. The significant increase in WBC count in the obese subjects is consistent with previous studies.[29,30] Some studies have reported a significant association between obesity and WBC count in healthy individuals[29] and also a significant correlation between body weight and total leukocyte count. Morbid obesity has also been reported to be a cause of physiologic leukocytosis.[30] The cause of the higher RBC count, hemoglobin, and hematocrit in obesity is unclear. Iron deficiency is common in overweight and obese individuals, and the greater blood volume in these individuals may increase hemoglobin mass and iron requirements. A recent study showed that total circulating masses of interleukin-6 (IL-6), hepcidin, hemoglobin, and soluble transferrin receptor (sTfR) were higher in overweight/obese women compared to normal weight women and that there was an increase in hemoglobin mass that likely increased iron requirement for erythropoiesis and circulating TfR mass in overweight/obese women.[31] Obesity is a risk factor for many diseases including type 2 diabetes, hypertension, heart disease, stroke, dyslipidemia, osteoarthritis, gynecological problems, sleep apnea, and respiratory problems. Barazzoni et al[32] reported that positive associations among BMI and RBC count, hemoglobin, and hematocrit were dependent on abdominal fat distribution and insulin resistance markers and that obesity per se was not associated with altered hematological parameters. In addition, Sinnapah et al[33] reported that increased RBC aggregation in patients with sleep apnea is caused by being overweight. In addition, in the present study, more of the obese subjects smoked than the non-obese subjects (40.1% vs 36.6%, $P = 0.048$). To compensate for decreased oxygen delivery capacity, smokers have a higher hemoglobin level than non-smokers.[23] Whitehead et al observed that hemoglobin and hematocrit levels were significantly increased in subjects smoking more than 10 cigarettes per day.[34] Taken together, smoking may have played a role in the higher hemoglobin and hematocrit levels in the obesity subjects in the current study.

Our findings regarding poor sleep and higher WBC count are consistent with those of previous studies.[35,36] Sleep deprivation has been shown to be associated with inflammatory responses such as interleukin-6,[37] high-sensitive C-reactive protein,[38] and WBC count.[35] Thus, sleep disturbances may activate inflammatory responses, which may contribute to cardiovascular disturbances. In addition, poor sleep was significantly associated with hematocrit concentration in the present study. Moreover, the subjects with poor sleep had higher rates of smoking than the subjects who did not have poor sleep (58.0% vs 35.4%, $P < 0.0001$) in the present study. Eisenga et al[39] identified that hematocrit levels were higher in current smokers than in non-smokers, and in multivariate linear regression analysis, currently smoking was independently positively associated with hematocrit and hemoglobin levels compared to never having smoked, which is similar to the current study. It is also presumed that poor sleep can cause smoking, which may have contributed to the higher hematocrit concentration among the workers with poor sleep in this study.

In conclusion, our data indicated that cigarette smoking, poor sleep, shift work, and obesity increased hematological parameters (eg, WBC count, RBC count, hemoglobin, hematocrit, MCV, and MCH) in the Chinese male steelworkers. Although the cross-sectional study design does not permit identification of causal relationships, our results may provide an explanation for the association between lifestyle and the risk of atherosclerosis, polycythemia vera, chronic obstructive pulmonary disease, and/or cardiovascular diseases.

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ORCID

Mei-Chu Yen Jean https://orcid.org/0000-0002-8264-2191
Teng-Hung Yu https://orcid.org/0000-0002-6764-0374

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