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Distribution of serum transferrin, and its associations with metabolic disorders among Chinese: A nation-wide, health and nutrition survey

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Abstract

Scope: This study examined the associations of serum transferrin and metabolic disorders among Chinese population.

Methods and results: This study is based on nation-wide, population-based China Health and Nutrition survey including 8564 men and women aged 18 years or older. Anthropometric and fasting blood glucose, insulin, lipids, and transferrin data were collected. Elevated transferrin concentrations associated with higher body mass index, waist circumference, lipids, insulin, glucose (all $p < 0.0001$). Serum transferrin concentrations increased gradually with increasing numbers of metabolic syndrome (MetS) components among men and women ($p = 0.0003$). Elevated concentrations of transferrin were significantly related with higher risk of MetS ($p = 0.0006$), obesity ($p = 0.0089$), overweight ($p < 0.0001$). No associations between transferrin concentrations and risk of diabetes and high blood pressure were observed in both men and women.

Conclusion: Elevated transferrin concentrations were positively associated with risk of MetS and obesity, but not with risk of diabetes among Chinese.

Keywords

China Health and Nutrition Survey; Diabetes; Metabolic disorders; Obesity; Transferrin

1 Introduction

Compelling evidences have shown that elevated body iron stores may adversely affect health outcomes. Elevated iron stores were positively associated with body fat distribution and

obesity in Mexican American men aged 20–49 years [1], prevalence of the metabolic syndrome (MetS), and insulin resistance in US adults [2].

Epidemiological studies among Chinese population reported an association between elevated iron stores and metabolic disorders [3–5]. For example, iron status and iron intake have shown a positive association with risk of diabetes among Chinese women [3]. Elevated circulating ferritin concentration was positively related to type 2 diabetes and MetS in middle-aged and elderly Chinese [4], and in north Chinese adults [5]. Furthermore, a general South Korean population study found that lower transferrin saturations might increase risk of impaired fasting glucose and insulin resistance [6]. While, elevated transferrin associated with high risk of MetS in French population [7]. However, to date, no data reported the relationship between circulating transferrin levels and metabolic disorders among Chinese population.

We hypothesized that serum transferrin might associate with metabolic disorders among Chinese. To test this hypothesis, we conducted a cross-sectional analysis using representative data from China Health and Nutrition Survey.

2 Materials and methods

The China Health and Nutrition Survey (CHNS) is a longitudinal survey examining a series of economic, sociological, demographic, and health questions [8]. The CHNS collected health data throughout China from 1989 to 2009 in 228 communities in nine diverse provinces (Guangxi, Guizhou, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Liaoning, and Shandong). The surveyed provinces represent 56% of the Chinese population. The detailed information on sampling methods was previously described [9]. A total of 8564 subjects were included in the present study. All participants gave informed consent. The study was approved by the Institutional Review Board at Ministry of Health and the Institute of Nutrition and Food Safety, China Centers for Disease Control and Prevention, the China-Japan Friendship Hospital, and the University of North Carolina at Chapel Hill, USA.

2.1 Anthropometric measurements

Height was measured without shoes to the nearest 0.2 cm using a portable SECA stadiometer and weight was measured without shoes and in light clothing to the nearest 0.1 kg on a calibrated beam scale. Body-mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters. Information regarding age, sex, lifestyle factors, medical history, and current medication was collected using self-report questionnaires.

2.2 Fasting blood collection and laboratory tests

Fasting blood was collected for the first time in the 2009 survey. Blood was collected by venipuncture (12 mL) after an overnight fast. Whole blood was centrifuged. All samples were analyzed in a national central lab in Beijing (medical laboratory accreditation certificate ISO 15189:2007) with strict quality control. Total cholesterol (TC), high- and low-density lipoprotein cholesterol (HDL-C and LDL-C) were measured using determiner reagents [Kyowa Medex Co., Ltd, Tokyo, Japan] and triglycerides (TG) using determiner

regents [Kyowa Medex Co., Ltd]) on the Hitachi 7600 automated analyzer (Hitachi Inc., Tokyo, Japan). The serum glucose was measured using a glucose oxidase phenol 4-aminoantipyrine peroxidase kit (GOD-PAP; Randox, Crumlin, UK) on a Hitachi 7600 analyser. The β -cell function was estimated by homeostasis model assessment of β -cell function (HOMA- β): $(20 \times \text{fasting insulin } [\mu\text{U/mL}] / [(\text{fasting glucose } [\text{mg/dL}]/18.01) - 3.5])$; and insulin resistance was estimated by homeostasis model assessment of insulin resistance (HOMA-IR): $(\text{fasting insulin } [\mu\text{U/mL}] \times [\text{fasting glucose } [\text{mg/dL}]/18.01])/22.5$ [10].

2.3 Definition of diseases

Overweight was defined as a BMI of 25.0 kg/m² or greater, according to WHO definitions [11, 12]. Diabetes was defined as answering 'yes' to the question 'has a doctor ever told you that you suffer from diabetes?' or having a fasting blood glucose (FBG) measurement ≥ 7.0 mmol/L according to the WHO 2006 guidelines. According to the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III; ATP III) [13] criteria, the metabolic syndrome was defined as the presence of three or more of the following risk factors: (i) serum triglyceride concentration of 1.7 mmol/L or greater; (ii) HDL-cholesterol concentration of less than 1.0 mmol/L in men or less than 1.3 mmol/L in women; (iii) waist circumference greater than 102 cm in men or greater than 88 cm in women; (iv) blood pressure $\geq 130/85$ mmHg or greater; or (v) serum glucose concentration of 6.1 mmol/L or greater [14].

2.4 Statistical analyses

Participants were classified into four groups according to their serum transferrin quartiles. Analysis of covariance was used to compare biomarkers between quartiles of transferrin concentrations. Multivariate logistic regression models were used to estimate the odds ratio (ORs) for MetS, obesity, overweight, and diabetes for the comparison across transferrin quartiles. Potential confounding variables included age, sex, BMI, geographic location, smoking, alcohol drinking, education level, and dietary factors, including total energy intake, dietary protein, and dietary fat. Statistical analyses were performed using SAS 9.2 (SAS Institute Inc., Cary, NC). Statistical tests were two sided and $p < 0.05$ was considered statistically significant.

3 Results

Transferrin concentrations were lower among men than women (2.80 ± 0.01 versus 2.95 ± 0.01 g/L, $p < 0.01$). There were no significant differences in fasting insulin, the homeostatic model assessment-insulin resistance (Homa-IR) and Homa- β between men and women (data not shown). Serum transferrin concentrations increased gradually with increasing numbers of MetS components among men and women after controlling age, sex, BMI, region, smoking, alcohol drinking, dietary factors (total energy intake, fat intake, and protein) ($p = 0.0003$) (Fig. 1). Subjects with higher transferrin concentrations have higher BMI, waist circumference (WC), total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-c), insulin, glucose, Homa-IR, and high-density lipoprotein

cholesterol (HDL-c). We did not observe the association between transferrin and Homa- β (Table 1).

The odds ratio (OR) for MetS ($p = 0.0006$), obesity ($p = 0.0089$), overweight ($p < 0.0001$), high TG ($p < 0.0001$), high WC ($p < 0.0001$), high glucose ($p < 0.0001$), and low HDL-c ($p < 0.0001$) increased progressively across the transferrin quartiles after controlling age, sex, BMI, region, smoking, alcohol drinking, dietary factors (total energy intake, fat intake, and protein) (Table 2). We further found similar results among men and women. Interestingly, we did not observe the significant associations between transferrin concentrations and risk of diabetes and high blood pressure among both men and women (Fig. 2).

4 Discussion

In the China Health and Nutrition Survey, we first found strong associations between transferrin and higher risk of MetS, obesity and overweight among Chinese population. However, we did not observe the significant associations between transferrin concentrations and risk of diabetes and high blood pressure among both men and women.

Iron is a transitional metal and a potential catalyst in many cellular reactions that produce reactive oxygen species (Supporting Information Fig. 1), which contribute to tissue damage [15]. It was suggested that there is a possible link between high body iron stores and serum insulin [16], and glucose [17]. Be in line with previous studies, our finding in the present study showed that older subjects have lower transferrin concentrations; subjects with elevated transferrin concentration exhibited higher lipids, insulin, and glucose levels. However, another study among general South Korean population reported that lower transferrin saturations might associate with an increased risk of impaired fasting glucose and insulin resistance [6]. The diet is the major source of body iron, which exists as either heme or nonheme iron in human body. Prospective cohort studies reported that intake of total or nonheme iron was not associated with the risk of type 2 diabetes, but heme iron was associated with elevated risk [18,19]. Therefore, different dietary patterns may account for these discrepancies, as the difference in iron status is attributable to dietary pattern [20].

Previous findings on the relationship between transferrin and diabetes were conflicting among Chinese [3,5]. Similarly, results on association of dietary iron with diabetes are inconclusive. For example, total iron intake, heme-iron intake from nonred meat sources, and blood donations are not related to the risk of type 2 diabetes [18]. In addition, previous study also did not observe significant association among total iron intake, nonheme iron intake, and diabetes risk [5]. While, large cohort study suggests that higher heme iron intake is associated with a significantly increased risk of type 2 diabetes [21]. A cross-sectional household survey carried out in 2002 in Jiangsu, China showed that iron status and iron intake was independently associated with risk of diabetes in Chinese women, but not in men [3]. Interestingly, in the present study, we did not observe the significant associations between transferrin concentrations and risk of diabetes in both men and women. The reason for this non-significant result is unclear. However, we speculate that serum transferrin concentration may be affected by diurnal variation, recent dietary iron intake, the presence of inflammatory conditions which might modulate the association of elevated transferrin

with risk of diabetes. Unfortunately, these factors are not available in the present study. Therefore, further studies are required to examine the possible reasons explaining the discrepancies. The mechanisms behind the observed associations are not fully understood. However, elevated iron stores may interfere with hepatic insulin extraction leading to peripheral hyperinsulinemia [22]. Iron modulates insulin action [23]. For example, iron depletion is beneficial for insulin secretion, insulin action, and metabolic control [23]. Experimental studies demonstrated that elevated body iron enhances free fatty acids oxidation through accelerated production of free radicals [24]. Elevated free fatty acids damage pancreatic β -cells [25, 26]. Furthermore, increased iron content was found in peripheral muscle [27], which is the major site of glucose disposal. Higher iron accumulation may cause derangement of muscle glucose uptake because of muscle damage [28]. It is also possible that higher hepatic iron overload interferes with the relationship between serum transferrin and insulin resistance [29]. In addition, Hepcidin, a bioactive peptide originally identified in plasma and urine and subsequently in the liver, is also expressed in the pancreas. Body iron uptake in the intestine is regulated by hepcidin. The localization of this peptide to β -cells suggests that pancreatic β -cells may be involved in iron metabolism in addition to their genuine function in blood glucose regulation [30] (Supporting Information Fig. 1). However, further experimental study is required to elucidate the potential mechanisms. Importantly, several limitations need to be considered. We acknowledge the fact that serum transferrin may be affected by diurnal variation, the presence of infection or inflammatory conditions, and recent dietary iron intake. In addition, we restricted analysis to Chinese population; therefore, further studies are needed to determine whether our findings are generalizable to other ethnic groups. We acknowledge that replication in diverse populations is required to verify our findings.

In conclusion, our findings suggest that elevated transferrin is associated with higher risk of metabolic syndrome, obesity and overweight, but not associated with diabetes among Chinese population. Further on these associations are warranted to understand the potential mechanisms.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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5 References

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Figure 1.

Distribution of serum transferrin, and its associations with metabolic disorders among Chinese: A nation-wide, health and nutrition survey

Serum transferrin concentrations according to the number of MetS components. Data are shown as means $\pm$ SE after adjustment for age, sex, BMI, geographic location, smoking, alcohol drinking, education level, and dietary factors, including total energy intake, dietary protein, and dietary fat. $p = 0.0003$ for trend.

Figure 2.

Distribution of serum transferrin, and its associations with metabolic disorders among

Chinese: A nation-wide, health and nutrition survey

Adjusted ORs and 95% CIs for metabolic syndrome, obesity, overweight, and diabetes according to quartiles of transferrin after controlling age, sex, BMI, geographic location, smoking, alcohol drinking, ferritin, education level, and dietary factors, including total energy intake, dietary protein, and dietary fat.

Table 1.

Sample characteristic across transferrin categories in Chinese adults (n = 8564)

Transferrin ^{a)}	Q1 (low)	Q 2	Q3	Q4 (high)	p for trend ^{b)}
Participants (n)	2141	2142	2142	2139	
Age (year) ^{c)}	54.49 ± 0.3 2	51.60 ± 0.33	49.51 ± 0.32	47.14 ± 0.32	<0.0001
Men (n, (%))	985 (46.1)	964 (45.7)	985 (46.2)	981 (45.9)	0.12
Transferrin (mcg/dL)	162.95 ± 3.98	145.03 ± 4.02	132.71 ± 4.00	108.35 ± 4.01	<0.0001
BMI (kg/m2) ^{c)}	22.67 ± 0.08	23.33 ± 0.08	23.53 ± 0.08	23.90 ± 0.08	<0.0001
WC (cm)	81.54 ± 0.23	82.59 ± 0.23	83.11 ± 0.23	83.61 ± 0.23	<0.0001
TG (mmol/L)	1.33 ± 0.03	1.48 ± 0.03	1.63 ± 0.03	1.90 ± 0.03	<0.0001
TC (mmol/L)	4.72 ± 0.02	4.82 ± 0.02	4.89 ± 0.02	5.02 ± 0.02	<0.0001
LDL-c (mmol/L)	2.90 ± 0.02	2.97 ± 0.02	3.00 ± 0.02	3.02 ± 0.02	0.002
HDL-c (mmol/L)	1.43 ± 0.01	1.43 ± 0.01	1.43 ± 0.01	1.47 ± 0.01	0.006
Insulin (uIU/mL)	13.28 ± 0.48	14.26 ± 0.48	14.74 ± 0.48	15.43 ± 0.48	0.014
Glucose (mmol/L)	5.35 ± 0.03	5.35 ± 0.03	5.44 ± 0.03	5.47 ± 0.03	0.009
Homa-IR	3.46 ± 0.15	3.70 ± 0.15	3.88 ± 0.15	4.02 ± 0.15	0.04
Homa- β	178.06 ± 70.57	299.34 ± 71.17	237.30 ± 70.83	160.58 ± 70.91	0.5

^{a)}Data are means ± SE.^{b)}p values were calculated after adjustment for age, sex, BMI, region, smoking, alcohol drinking, dietary factors (total energy intake, fat intake, and protein).^{c)}Not adjusted for itself.

BMI, body mass index; HDL-c, high-density lipoprotein cholesterol; Homa-β, the homeostatic model assessment-β-cell function; Homa-IR, the homeostatic model assessment-insulin resistance; LDL-c, low-density lipoprotein cholesterol; MetS: metabolic syndrome; TC, total cholesterol; TG, triglycerides; WC, waist circumference.

Table 2.

OR (95% CI) for metabolic syndrome according to quartiles of serum transferrin in Chinese adults (n = 8564)

		Q1(low)	Q2	Q3	Q4 (high)	p for trend
Mena)						
MetS	1	2.08 (0.60, 7.23)	3.68 (1.12, 6.06)	7.51 (2.34, 12.12)	<0.0001	
Obesity	1	1.55 (0.51, 4.69)	1.30 (0.44, 3.84)	3.02 (1.08, 8.46)	0.0008	
Overweight	1	0.99 (0.62, 1.57)	1.15 (0.74, 1.78)	2.37 (1.55, 3.63)	<0.0001	
Diabetes	1	0.88 (0.26, 2.94)	0.72 (0.23, 2.31)	1.36 (0.46, 4.05)	0.3	
High TG	1	0.90 (0.56, 1.45)	1.63 (1.05, 2.54)	3.32 (2.17, 5.10)	<0.0001	
High WC	1	2.97 (0.67, 13.11)	1.87 (0.43, 8.22)	6.42 (1.55, 10.69)	<0.0001	
High BP	1	0.70 (0.45, 1.09)	0.86 (0.56, 1.30)	0.89 (0.59, 1.34)	0.29	
High Glucose	1	0.98 (0.57, 1.69)	1.09 (0.65, 1.81)	1.83 (1.11, 3.00)	<0.0001	
Low HDL-c	1	1.08 (0.50, 2.34)	2.00 (0.98, 4.10)	3.35 (1.66, 6.75)	<0.0001	
Women ^{a)}						
MetS	1	1.32 (0.57, 3.02)	1.32 (0.91, 3.42)	2.26 (1.81, 6.27)	0.02	
Obesity	1	1.96 (0.54, 7.20)	1.81 (0.41, 8.11)	5.38 (1.21, 13.98)	0.015	
Overweight	1	1.39 (0.79, 2.45)	1.33 (0.67, 2.64)	2.78 (1.24, 6.25)	0.01	
Diabetes	1	0.68 (0.02, 19.36)	2.21 (0.07, 9.94)	3.06 (0.08, 13.84)	0.89	
High TG	1	1.53 (0.80, 2.93)	2.46 (1.19, 5.09)	5.05 (2.16, 11.82)	0.001	
High WC	1	1.23 (0.66, 2.28)	1.60 (0.78, 3.25)	2.96 (1.84, 4.59)	0.03	
High BP	1	1.01 (0.47, 2.19)	0.85 (0.35, 2.09)	0.24 (0.06, 0.98)	0.2	
High Glucose	1	2.25 (0.98, 5.18)	2.13 (0.83, 5.46)	3.20 (1.12, 9.11)	0.01	
Low HDL-c	1	0.87 (0.50, 1.53)	1.35 (0.70, 2.59)	2.95 (1.87, 4.39)	0.001	
Both ^{b)}						
High TG	1	1.21 (0.83, 1.76)	2.11 (1.47, 3.02)	4.28 (3.00, 6.11)	<0.0001	
High WC	1	1.61 (0.94, 2.74)	1.43 (0.81, 2.52)	3.61 (2.07, 6.30)	<0.0001	
High BP	1	0.78 (0.53, 1.14)	0.90 (0.63, 1.29)	0.90 (0.63, 1.29)	0.54	
High Glucose	1	1.29 (0.82, 2.04)	1.36 (0.87, 2.12)	2.27 (1.48, 3.49)	<0.0001	
Low HDL-c	1	0.97 (0.63, 1.49)	1.69 (1.11, 2.58)	2.84 (1.87, 4.31)	<0.0001	

^{a)} Adjusted for age, BMI, geographic location, smoking, alcohol drinking, education level, and dietary factors, including total energy intake, dietary protein, and dietary fat.

^{b)} Adjusted for age, sex, BMI, geographic location, smoking, alcohol drinking, education level, and dietary factors, including total energy intake, dietary protein, and dietary fat.

BP, blood pressure; MetS, Metabolic syndrome.