

Associations of Serum Lipids and Lipoproteins with the Estimated Glomerular Filtration Rate in the Adult Chinese Population: A Cross-sectional Study

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Research

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Abstract

Background: Dyslipidemia has a critical impact on renal dysfunction, but the exact types of lipids and lipoproteins that influence the estimated glomerular filtration rate (eGFR) are under investigation. Observations from an adult Chinese population ≥ 20 years old are lacking. The present study is to investigate the associations of total cholesterol (TC), triglycerides (TG), high-density lipoprotein-cholesterol (HDL-C), and low-density lipoprotein-cholesterol (LDL-C) with eGFR, and the risks for a mildly and a moderately/severely reduced eGFR.

Methods: A total of 16,206 participants from a national representative adult population (20 years of age or older) in China were included. All calculations were weighted based on the Chinese population data and the sampling scheme.

Results: Upon stratifying the population based on lipids or lipoprotein categories, we observed a significantly lower mean eGFR as well as a higher estimated prevalence of impaired eGFR among Chinese adults with TG levels in the ranges of $1.7 \text{ mmol/L} \leq \text{TG} < 2.3 \text{ mmol/L}$ [mean eGFR: $110.99 \text{ mL/min per } 1.73 \text{ m}^2$, $P = 0.0000$; prevalence of mildly eGFR impairment: 30.92%, $P = 0.0000$; prevalence of moderately/severely eGFR impairment: 2.01%, $P = 0.1842$] and $\geq 2.3 \text{ mmol/L}$ [$111.62 \text{ mL/min per } 1.73 \text{ m}^2$, $P = 0.0000$; 27.92%, $P = 0.0000$; 2.81%, $P = 0.0174$], compared to those among individuals with normal TG [$122.03 \text{ mL/min per } 1.73 \text{ m}^2$; 19.96%; 1.20%]. Also, a higher prevalence of mildly impaired eGFR was observed with $3.4 \text{ mmol/L} \leq \text{LDL-C} < 4.1 \text{ mmol/L}$ (27.93%) compared with $\text{LDL-C} < 3.4 \text{ mmol/L}$ (22.61%, $P = 0.0092$). An elevated TG was proven to be an independent risk factor for decreased eGFR [$\beta(\text{SE}) -0.0238(0.0039)$, $P = 0.0000$], and each per mmol/L increase in TG was associated with the 1.19-fold and 1.31-fold increased risks for mildly impaired eGFR and moderately/severely impaired eGFR, respectively ($P = 0.0000$, 0.0001). A decreased HDL-C also showed a negative contribution to eGFR [$-0.0883(0.0176)$, $P = 0.0000$]. In contrast, increased TC was associated with increased eGFR [$0.0314(0.0060)$, $P = 0.0000$] and a reduction in the risk for mildly impaired eGFR by 0.91-fold ($P = 0.0302$). Increased LDL-C also contributed to an elevated eGFR [$0.0251(0.0070)$, $P = 0.0004$].

Conclusion: A decreased eGFR could be attributed independently to an elevated TG or reduced HDL-C. It emphasizes the importance of effective control of TG and HDL-C for preserving eGFR.

Introduction

Chronic kidney disease (CKD) is a growing health burden that already affects 10 ~ 15% of adults worldwide. Based on a recent nationwide survey in China, the prevalence of CKD has reached 10.8% and is still increasing(1). Epidemiological evidence revealed that CKD substantially increases the risk for end-stage renal disease (ESRD) and cardiovascular events, and, strikingly, even a mildly decreased estimated glomerular filtration rate (eGFR; $60 \sim 89 \text{ mL/min per } 1.73 \text{ m}^2$) could be associated with increased risks for renal function decline and cardiovascular morbidity(2, 3). Therefore, the exploration of risk factors for impaired eGFR in the general population is of clinical significance for the early prevention and management of renal dysfunction, which could eventually help to relieve the heavy burden of CKD.

Dyslipidemia has a critical impact on renal dysfunction. Increasing evidence indicates that dyslipidemia is not only associated with a lower eGFR and higher risk for CKD, but also contributes to the risk for a mildly reduced eGFR in the general population. In the Chinese population, the REACTION study based on individuals over 40 years old reported that dyslipidemia increases the risk for CKD by 1.43- and 1.28-fold in men and women, respectively, as well as the risk for an eGFR of $60 \sim 74 \text{ mL/min per } 1.73 \text{ m}^2$ by 1.16- and 1.06-fold, respectively(2). Clinical trials also have suggested that approaches targeting dyslipidemia (e.g., statins) could be beneficial for the prevention and management of declining renal function(4, 5).

The exact types of lipids and lipoproteins that influence the eGFR are still under investigation, separately. Previous studies established negative correlations between the eGFR and hypercholesterolemia, hypertriglyceridemia, and a reduced high-density lipoprotein-cholesterol (HDL-C) level. For example, Zheng et al. found that elevated total cholesterol (TC) and triglycerides (TG), as well as reduced HDL-C, were associated with the eGFR in participants ≥ 35 years of age from rural China(6). With adjustment for the other conventional risk factors for eGFR, Sun et al. reported that an elevated TG and a reduced HDL-C were independently associated with the increased risk for CKD defined by an eGFR $< 60 \text{ mL/min per } 1.73 \text{ m}^2$ and the presence of albuminuria in a group of patients aged ≥ 40 years from Guangzhou province in south China(7). Hou et al. reported that TC and TG showed negative contributions to eGFR, while increased TG was associated with mildly reduced eGFR ($60 \sim 90 \text{ mL/min per } 1.73 \text{ m}^2$) in another group of patients aged ≥ 40 years with normal serum lipids in China(8). Prospective studies showed that an increased TG and a lower HDL-C can serve as independent predictive factors for eGFR decline and CKD(9–11). However, other studies have yielded conflicting results. For instance, Rahman et al. reported an inverse relationship between TC and low-density lipoprotein-cholesterol (LDL-C) and renal disease outcome in CKD patients with low levels of proteinuria(12). Thus, we speculated that differences in study design and the sampling scheme could confound the associations and limit the generalization of these findings. Observations from the nationwide representative general population of Chinese adults are still lacking.

In the present study, by weighting the data from 16,206 participants recruited from a national representative population (20 years of age or older) in the China National Diabetes and Metabolism Disorders Study (DMS)(13) on the basis of the population data and sampling scheme, we estimated the mean eGFR and prevalence rates of mildly and moderately/severely impaired eGFR according to the four available measurements of lipid and lipoprotein levels (TC, TG, HDL-C and LDL-C) divided into categories and examined the associations of these lipids or lipoproteins with eGFR as well as with the risks for mildly and moderately/severely impaired eGFR. Furthermore, the interactions of these lipids and lipoproteins with conventional factors were explored to pursue a personalized risk assessment and prevention strategy for renal function decline.

Materials And Methods

Study participants

From June 2007 to May 2008, the DMS was carried out using a complex multistage, stratified sampling method, and the detailed methods were described elsewhere(13). In brief, representative regions (including 152 urban districts and 112 rural villages) were selected across China by considering the geographical distribution, economic development, and level of urbanization. Residents aged 20 years and older and who had lived locally for 5 years or more were randomly selected from each region. A total of 16,206 participants, including 6,553 men and 9,653 women, with complete data for eGFR were included in the present study.

Ethics statement

The study protocol was conducted in accordance with the Declaration of Helsinki II and approved by the ethics committee of the China-Japan Friendship Hospital (Beijing, China). Written informed consent was obtained from each participant prior to data collection.

Clinical and laboratory measurements

A standardized questionnaire was used to collect information during an interview by well-trained staff. Demographical features and anthropometric characteristics were carefully examined as previously described(13). Body mass index (BMI) was calculated as weight/height² (kg/m²). Resting blood pressure was measured twice consecutively, and the average systolic blood pressure (SBP) and average diastolic blood pressure (DBP) were calculated and used for analyses.

At enrollment, each participant completed a 75-g oral glucose tolerance test (OGTT) after overnight fasting. The concentrations of TC, TG, HDL-C, and LDL-C, as well as creatinine, in fasting serum samples were examined using an automatic biochemical analyzer (Olympus, Tokyo, Japan). The urinary albumin-creatinine ratio (UACR) was measured using a DCA Vantage™ analyzer (Siemens, Erlangen, Germany) utilizing an immunoassay method for albumin. The eGFR was calculated using the abbreviated Modification of Diet in Renal Disease (MDRD) equation for the Chinese population: $eGFR \text{ (mL/min per } 1.73 \text{ m}^2) = 186 \times [\text{serum creatine (}\mu\text{mol/L)} / 88.4]^{-1.154} \times \text{age}^{-0.203} \times 1.233 \times [0.742 \text{ for women}]$ (14).

Definitions

Normal renal function was defined by an eGFR ≥ 90 ml/min per 1.73 m². Mild eGFR impairment was defined by $60 \leq eGFR < 90$ ml/min per 1.73 m². Moderate/severe eGFR impairment was defined by eGFR < 60 ml/min per 1.73 m²(15).

The blood lipid levels were classified into categories according to the guidelines for the prevention and treatment of dyslipidemia in Chinese adults. TG was divided into three categories (normal: < 1.7 mmol/L, borderline high: ≥ 1.7 and < 2.3 mmol/L, high: ≥ 2.3 mmol/L), TC was divided into three categories (normal: < 5.2 mmol/L, borderline high: ≥ 5.2 and < 6.2 mmol/L, and high: ≥ 6.2 mmol/L), HDL-C was divided into two categories (normal: ≥ 1.0 mmol/L and low: < 1.0 mmol/L), and LDL-C was divided into three categories (normal: < 3.4 mmol/L, borderline high: ≥ 3.4 and < 4.1 mmol/L, high: ≥ 4.1 mmol/L)(16–18).

Underweight was defined by a BMI < 18.5 kg/m², normal weight was defined by a BMI $18.5 \sim 24$ kg/m², and overweight/obese was defined by a BMI ≥ 24 kg/m²(16).

Diabetes was identified according to the 1999 World Health Organization (WHO) criteria of fasting plasma glucose (FPG) ≥ 7.0 mmol/L, 2-h post-prandial plasma glucose (2-h PPG) ≥ 11.1 mmol/L, or a self-reported history of diabetes. Prediabetes was defined by FPG ≥ 6.1 mmol/L and < 7.0 mmol/L and/or 2-h PPG ≥ 7.8 mmol/L and < 11.1 mmol/L, with no previous diagnosis of diabetes.

Hypertension was defined by an SBP ≥ 140 mmHg and/or mean DBP ≥ 90 mmHg, or receiving anti-hypertension therapy. Prehypertension was defined by SBP of $120 \sim 140$ mmHg or DBP of $80 \sim 90$ mmHg with no previous diagnosis of hypertension(19).

Statistical analysis

All statistical analyses were conducted with the use of SUDAAN software (version 10; Research Triangle Institute, NC, USA). Using SUDAAN, all calculations in this study were weighted to represent the total population of Chinese adults (20 years of age or older) on the basis of Chinese population data from 2006 and the study sampling scheme as previously described(13). Oversampling of female and urban residents, non-response, economic development, and other demographic or geographic differences between the sample and the total population of the survey were taken into account. The reported *P* values were two-tailed, and *P* < 0.05 was considered as significant.

The mean values and 95% confidence intervals (CIs) for the clinical features and estimated prevalence rates of metabolic disorders were determined according to eGFR categories. The mean values of eGFR and the prevalence estimates for mildly impaired eGFR and moderately/severely impaired eGFR according to the TC, TG, HDL-C, and LDL-C categories were calculated. The differences in means and frequencies between categories were tested using the PAIRWISE procedure in SUDAAN software.

Regression analysis (REGRESS procedure) was applied to determine the effects of TC, TG, HDL-C, and LDL-C, as well as their categories, on eGFR. The beta coefficient (β) and standard error (SE) were calculated. Prior to the regression analyses, eGFR was natural logarithmically transformed. A multinomial logistic analysis (MULTILOG procedure) was used to test the associations of TC, TG, HDL-C, and LDL-C, as well as their categories, with the risks for mildly impaired eGFR and moderately/severely impaired eGFR. The odds ratio (OR) and 95% CI were calculated. For the above calculations, the conventional risk factors for eGFR, including gender, age, BMI, smoking status (no/yes), alcohol intake habit (no/yes), diabetes status (normal glycemic metabolism/prediabetes/diabetes), and hypertension status (normal tension/prehypertension/hypertension), were adjusted as confounders. To examine the interaction effects of these conventional factors on the above associations, the interaction terms were further included in these models, separately. Moreover, the association studies were also performed in subpopulations according to sex, age (< 40 , $40 \sim 60$, and ≥ 60 years), BMI (underweight, normal weight, vs. overweight/obese), smoking

status (no vs. yes), alcohol intake habit (no vs. yes), diabetes status (normal glycemic metabolism, prediabetes vs. diabetes), and hypertension status (normal tension, prehypertension vs. hypertension), separately.

Results

Clinical characteristics of study participants according to eGFR categories

The clinical characteristics of the participants in the different eGFR categories are shown in Table 1. In total, 16,206 participants were included in the present study. Among them, 13,237 had normal renal function [eGFR \geq 90 ml/min per 1.73 m²: mean (95% CI) 132.22 (127.44, 137.00) ml/min per 1.73 m²], 2,780 had a mildly impaired eGFR [eGFR between 60 to 90 ml/min per 1.73 m²: 79.42 (78.90, 79.94) ml/min per 1.73 m²], and 189 had a moderately/severely impaired eGFR [eGFR < 60 ml/min per 1.73 m²: 48.00 (44.36, 51.65) ml/min per 1.73 m²] (Table 1). The estimated prevalence rates of mildly impaired eGFR and moderately/severely impaired eGFR were 22.63% and 1.57%, respectively (Table 2).

Table 1
Clinical characteristics of the study participants according to the estimated glomerular filtration rate categories.

Traits	Normal eGFR (eGFR \geq 90 ml/min per 1.73 m ²)	Mildly impaired eGFR (eGFR 60 ~ 90 ml/min per 1.73 m ²)	Moderately/severely impaired eGFR (eGFR < 60 ml/min per 1.73 m ²)	<i>P</i> _{eGFR 60~90 vs. eGFR \geq90}	<i>P</i> _{eGFR <60 vs. eGFR \geq90}	<i>P</i> _{eGFR <60 vs. eGFR 60~90}
N	13,237	2,780	189			
N _{Male}	5,581	921	51			
Mean age (95% CI), year	42.66 (42.03, 43.30)	52.59 (51.74, 53.43) ^a	58.62 (54.59, 62.65) _{a,b}	0.0000	0.0000	0.0039
Mean BMI (95% CI), kg/m ²	23.62 (23.51, 23.74)	23.99 (23.80, 24.18) ^a	23.95 (23.21, 24.69)	0.0005	0.2759	0.9707
Prevalence of underweight (95% CI), %	4.92 (4.31, 5.63)	3.18 (2.42, 4.15) ^a	3.40 (1.20, 9.24)	0.0015	0.4001	0.9024
Prevalence of overweight/obese (95% CI), %	42.27 (40.55, 44.02)	47.59 (44.84, 50.35) ^a	43.31 (28.70, 59.19)	0.0014	0.8979	0.5998
Mean fasting plasma glucose (95% CI), mmol/L	5.10 (5.06, 5.14)	5.45 (5.37, 5.52) ^a	7.79 (4.32, 11.25)	0.0000	0.0724	0.1541
Mean 2-h OGTT glucose (95% CI), mmol/L	6.45 (6.35, 6.54)	7.60 (7.38, 7.81) ^a	11.19 (6.28, 16.10) ^a	0.0000	0.0145	0.1105
Prevalence of prediabetes (95% CI), %	13.43 (11.96, 15.05)	20.66 (18.40, 23.13) ^a	20.81 (12.08, 33.45)	0.0000	0.1805	0.9795
Prevalence of diabetes (95% CI), %	6.96 (6.22, 7.80)	13.62 (11.74, 15.76) ^a	29.14 (12.86, 53.41) ^a	0.0000	0.0401	0.1524
Mean SBP (95% CI), mmHg	119.82 (119.05, 120.59)	125.30 (123.62, 126.99) ^a	134.01 (128.51, 139.50) _{a,b}	0.0000	0.0000	0.0017
Mean DBP (95% CI), mmHg	76.53 (75.99, 77.06)	77.61 (76.57, 78.65)	82.81 (79.68, 85.95) _{a,b}	0.0978	0.0001	0.0015
Prevalence of prehypertension (95% CI), %	36.07 (34.46, 37.72)	36.81 (34.11, 39.59)	27.05 (17.45, 39.42)	0.6522	0.1148	0.0942
Prevalence of hypertension (95% CI), %	19.64 (18.09, 21.29)	29.83 (27.36, 32.42) ^a	55.00 (39.12, 69.92) _{a,b}	0.0000	0.0000	0.0022
Mean TG (95% CI), mmol/L	1.48 (1.45, 1.52)	1.73 (1.66, 1.79) ^a	1.94 (1.69, 2.20) _{a,b}	0.0000	0.0000	0.0044
Prevalence of borderline high TG (95% CI), %	12.00 (10.92, 13.17)	18.49 (16.28, 20.93) ^a	17.52 (10.08, 28.69)	0.0000	0.2451	0.8413
Prevalence of high TG (95% CI), %	14.02 (12.92, 15.19)	18.89 (16.90, 21.05) ^a	27.73 (17.25, 41.39) ^a	0.0001	0.0287	0.1625
Mean TC (95% CI), mmol/L	4.67 (4.63, 4.70)	4.81 (4.76, 4.86) ^a	5.07 (4.69, 5.44) ^a	0.0000	0.0351	0.1971
Prevalence of borderline high TC (95% CI), %	21.47 (19.86, 23.18)	23.85 (21.55, 26.32)	22.49 (13.46, 35.11)	0.1082	0.8559	0.8099
Prevalence of high TC (95% CI), %	6.02 (5.25, 6.89)	7.89 (6.53, 9.50) ^a	22.81 (7.37, 52.34)	0.0297	0.1546	0.2067
Mean HDL-C (95% CI), mmol/L	1.33 (1.32, 1.35)	1.35 (1.33, 1.37)	1.35 (1.18, 1.53)	0.2135	0.9663	0.9039
Prevalence of low HDL-C (95% CI), %	15.20 (13.95, 16.54)	13.76 (12.02, 15.71)	18.51 (10.52, 30.49)	0.2104	0.5168	0.3564

Abbreviations: BMI, body mass index; CI, confidence interval; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; OGTT, oral glucose tolerance test; SBP, systolic blood pressure; SE, standard error; TC, total cholesterol; TG, triglycerides; UACR, urinary albumin-creatinine-ratio.

For lipids and lipoprotein categories, the following definitions were used. Borderline high TG: TG \geq 1.7 and < 2.3 mmol/L. High TG: TG \geq 2.3 mmol/L). Borderline high TC: TC \geq 5.2 and < 6.2 mmol/L. High TC: TC \geq 6.2 mmol/L. Low HDL-C: HDL-C < 1.0 mmol/L. Borderline high LDL-C: LDL-C \geq 3.4 and < 4.1 mmol/L. High LDL-C: LDL-C \geq 4.1 mmol/L.

Data are shown as mean (95%CI) or prevalence (95%CI). All mean values and estimated prevalence rates were weighted to represent the total population of Chinese adults (\geq 20 years old) base on the Chinese population data from 2006. All non-Gaussian distributed quantitative traits were natural logarithmically transformed prior to the comparisons. The differences of means or prevalence rates between the eGFR categories were tested using the PAIRWISE procedure in SUDAAN software. *P* < 0.05 is considered statistically significant. ^a, significant different from eGFR \geq 90 ml/min per 1.73 m² group; ^b, eGFR < 60 ml/min per 1.73 m² group is significant different from eGFR 60 ~ 90 ml/min per 1.73 m² group.

Traits	Normal eGFR (eGFR \geq 90 ml/min per 1.73 m ²)	Mildly impaired eGFR (eGFR 60 ~ 90 ml/min per 1.73 m ²)	Moderately/severely impaired eGFR (eGFR < 60 ml/min per 1.73 m ²)	<i>P</i> _{eGFR 60~90 vs. eGFR \geq90}	<i>P</i> _{eGFR <60 vs. eGFR \geq90}	<i>P</i> _{eGFR <60 vs. eGFR 60~90}
Mean LDL-C (95% CI), mmol/L	2.72 (2.69, 2.75)	2.84 (2.80, 2.88) ^a	3.08 (2.81, 3.35) ^a	0.0000	0.0072	0.0915
Prevalence of borderline high LDL-C (95% CI), %	13.2 (11.87, 14.66)	17.02 (14.91, 19.36) ^a	24.94 (9.36, 51.66)	0.0044	0.2940	0.4803
Prevalence of high LDL-C (95% CI), %	5.51 (4.49, 6.75)	5.78 (4.70, 7.09)	10.24 (5.00, 19.83)	0.7439	0.1978	0.2256
Mean eGFR (95% CI), ml/min per 1.73 m ²	132.22 (127.44, 137.00)	79.42 (78.90, 79.94) ^a	48.00 (44.36, 51.65) _{a,b}	0.0000	0.0000	0.0000
Mean UACR (95% CI), mg/g	27.23 (25.14, 29.31)	32.19 (28.34, 36.03)	98.35 (64.01, 132.70) _{a,b}	0.1233	0.0000	0.0000
Abbreviations: BMI, body mass index; CI, confidence interval; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; OGTT, oral glucose tolerance test; SBP, systolic blood pressure; SE, standard error; TC, total cholesterol; TG, triglycerides; UACR, urinary albumin-creatinine-ratio.						
For lipids and lipoprotein categories, the following definitions were used. Borderline high TG: TG \geq 1.7 and < 2.3 mmol/L. High TG: TG \geq 2.3 mmol/L). Borderline high TC: TC \geq 5.2 and < 6.2 mmol/L. High TC: TC \geq 6.2 mmol/L. Low HDL-C: HDL-C < 1.0 mmol/L. Borderline high LDL-C: LDL-C \geq 3.4 and < 4.1 mmol/L. High LDL-C: LDL-C \geq 4.1 mmol/L.						
Data are shown as mean (95%CI) or prevalence (95%CI). All mean values and estimated prevalence rates were weighted to represent the total population of Chinese adults (\geq 20 years old) base on the Chinese population data from 2006. All non-Gaussian distributed quantitative traits were natural logarithmically transformed prior to the comparisons. The differences of means or prevalence rates between the eGFR categories were tested using the PAIRWISE procedure in SUDAAN software. <i>P</i> < 0.05 is considered statistically significant. ^a , significant different from eGFR \geq 90 ml/min per 1.73 m ² group; ^b , eGFR < 60 ml/min per 1.73 m ² group is significant different from eGFR 60 ~ 90 ml/min per 1.73 m ² group.						

Table 2

Age- and sex-standardized means of the estimated glomerular filtration rate and prevalence rates of estimated glomerular filtration rate impairment in Chinese population.

Population	Mean eGFR (95%CI), ml/min per 1.73 m ²	Mildly impaired eGFR (eGFR 60 ~ 90 ml/min per 1.73 m ²) Estimated prevalence (95% CI), %	Moderately/severely impaired eGFR (eGFR < 60 ml/min per 1.73 m ²) Estimated prevalence (95% CI), %
Overall cohort	118.95 (115.27, 122.63)	22.63 (21.53, 23.78)	1.57 (1.12, 2.19)
TC categories			
Normal: <5.2 mmol/L	118.80 (113.93, 123.68)	21.68 (20.41, 23.01)	1.17 (0.87, 1.56)
Borderline high: 5.2 ~ 6.3 mmol/L	118.08 (114.02, 122.14)	24.52 (21.94, 27.30)	1.55 (0.99, 2.43)
High: ≥6.3 mmol/L	119.96 (107.23, 132.69)	26.68 (22.07, 31.86)	5.19 (1.48, 16.65)
TG categories			
Normal: <1.7 mmol/L	122.03 (117.00, 127.07)	19.96 (18.72, 21.27)	1.20 (0.68, 2.10)
Borderline high: 1.7 ~ 2.3 mmol/L	110.99 (105.44, 116.55) ^a	30.92 (27.37, 34.70) ^a	2.01 (1.23, 3.28)
High: ≥2.3 mmol/L	111.62 (107.85, 115.39) ^a	27.92 (25.08, 30.95) ^a	2.81 (1.87, 4.21) ^a
HDL-C categories			
Normal: ≥1.0 mmol/L	118.99 (115.10, 122.88)	22.92 (21.72, 24.18)	1.48 (0.99, 2.21)
Low: <1.0 mmol/L	119.11 (108.15, 130.06)	20.85 (18.18, 23.79)	1.92 (1.14, 3.19)
LDL-C categories			
Normal: <3.4 mmol/L	118.70 (114.09, 123.31)	22.61 (21.38, 23.90)	1.32 (1.01, 1.73)
Borderline high: 3.4 ~ 4.1 mmol/L	113.12 (109.19, 117.04)	27.93 (24.31, 31.86) ^a	2.85 (0.92, 8.44)
High: ≥4.1 mmol/L	122.44 (107.34, 137.54)	24.00 (19.05, 29.76)	2.96 (1.49, 5.78)
Abbreviations: CI, confidence interval; eGFR, estimated glomerular filtration rate; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; OR, odds ratio; SE, standard error; TC, total cholesterol; TG, triglycerides.			
Data are shown as mean (95%CI) or prevalence (95%CI). All mean values and estimated prevalence rates were weighted to represent the total population of Chinese adults (≥ 20 years old) based on Chinese population data from 2006. All non-Gaussian distributed quantitative traits were natural logarithmically transformed prior to the comparisons. The differences of means or prevalence rates between the categories of TC, TG, HDL-C, and LDL-C were tested using the PAIRWISE procedure in SUDAAN software. <i>P</i> < 0.05 is considered statistically significant. ^a , significant different from the normal category. <i>P</i> values < 0.05 are shown in bold.			

Compared to patients in the normal renal function category [mean age (95% CI) 42.66 (42.03, 43.30) years], those in the mildly impaired and moderately/severely impaired renal function categories were significantly older [52.59 (51.74, 53.43) years; 58.62 (54.59, 62.65) years; both *P* = 0.0000]. Also, the mean values for BMI, fasting and 2-h post prandial glucose, SBP, and DBP, as well as the estimated prevalence rates of overweight/obesity, prediabetes and diabetes, and hypertension, showed significantly increasing trends with decreasing eGFR categories, whereas the estimated prevalence of underweight was decreased in participants with mildly impaired eGFR (Table 1).

Notably, significant increases in TG, TC, and LDL-C were accompanied by decreases in eGFR categories. In the normal, mildly impaired, and moderately/severely impaired eGFR groups, the mean TG levels were 1.48, 1.73, and 1.94 mmol/L, respectively; the mean TC levels were 4.67, 4.81, and 5.07 mmol/L, respectively; and the mean LDL-C levels were 2.72, 2.84, and 3.08 mmol/L, respectively (compared to the normal eGFR category, all *P* < 0.05). For HDL-C, no significant difference was observed among eGFR categories (Table 1).

In addition, the mean UACR was significantly higher in the moderately/severely impaired eGFR group [mean (95%CI) 98.35 (64.01, 132.70) mg/g] than in the normal eGFR group [27.23 (25.14, 29.31) mg/g, *P* = 0.0000] or the mildly impaired eGFR group [32.19 (28.34, 36.03) mg/g, *P* = 0.0000] (Table 1).

Mean values of eGFR and estimated prevalence rates of eGFR impairment according to categories of TC, TG, HDL-C, and LDL-C

When the mean value of eGFR was calculated and compared between categories, a significantly lower eGFR was observed only for the borderline high TG [1.7 ~ 2.3 mmol/L: 110.99 (105.44, 116.55) ml/min per 1.73 m², *P* = 0.0000] and the high TG categories [≥ 2.3 mmol/L: 111.62 (107.85, 115.39) ml/min per 1.73 m², *P* = 0.0000] compared with the normal TG category [< 1.7 mmol/L: 122.03 (117.00, 127.07) ml/min per 1.73 m²]. Also, the estimated prevalence of mildly impaired eGFR was significantly higher for the borderline high TG (30.92%, *P* = 0.0000) and high TG categories (27.92%, *P* = 0.0000) compared with the normal TG category (19.96%), and the estimated prevalence of moderately/severely impaired eGFR for the high TG category (2.81%) was significantly higher than that for the normal TG category (1.20%, *P* = 0.0174). Also, a higher prevalence of mildly impaired eGFR was observed with 3.4 mmol/L ≤ LDL-C <

4.1 mmol/L (27.93%) compared with LDL-C < 3.4 mmol/L (22.61%, $P=0.0092$). For the other comparisons, no statistically significant differences were observed (Table 2).

Associations of TC, TG, HDL-C, LDL-C, and their categories with eGFR

As shown in Table 3, after adjustment for the conventional confounding factors including age, gender, BMI, smoking, alcohol intake habit, diabetes, and hypertension, increased TG and decreased HDL-C levels showed independently significant associations with reduced eGFR [TG: β (SE) -0.0238 (0.0039), $P=0.0000$; HDL-C (decreased): -0.0883 (0.0176), $P=0.0000$], whereas elevated TC and LDL-C levels were associated with an increased eGFR [TC: 0.0314 (0.0060), $P=0.0000$; LDL-C: 0.0251 (0.0070), $P=0.0004$].

Table 3
Associations of total cholesterol, triglycerides, high-density lipoprotein-cholesterol, low-density lipoprotein-cholesterol or their categories with the estimated glomerular filtration rate and the risks for estimated glomerular filtration rate impairment.

Model	Regression model		Multinomial logistic model			
	Ln eGFR		Mildly impaired eGFR (eGFR 60 ~ 90 ml/min per 1.73 m ²)		Moderately/severely impaired eGFR (eGFR < 60 ml/min per 1.73 m ²)	
Independent variable	β (SE)	P	OR (95%CI)	P	OR (95%CI)	P
TC, per 1 mmol/L increase	0.0314 (0.0060)	0.0000	0.91 (0.84, 0.99)	0.0302	1.05 (0.74, 1.49)	0.7799
TC categories						
Normal: <5.2 mmol/L	As reference	—	As reference	—	As reference	—
Borderline high: 5.2 ~ 6.3 mmol/L	0.0504 (0.0114)	0.0000	0.82 (0.67, 1.02)	0.0713	0.80 (0.42, 1.51)	0.4926
High: \geq 6.3 mmol/L	0.0477 (0.0358)	0.1822	0.82 (0.62, 1.10)	0.1836	2.18 (0.76, 6.23)	0.1450
TG, per 1 mmol/L increase	-0.0238 (0.0039)	0.0000	1.19 (1.12, 1.26)	0.0000	1.31 (1.15, 1.50)	0.0001
TG categories						
Normal: <1.7 mmol/L	As reference	—	As reference	—	As reference	—
Borderline high: 1.7 ~ 2.3 mmol/L	-0.0674 (0.0148)	0.0000	1.69 (1.38, 2.08)	0.0000	1.83 (0.85, 3.97)	0.1236
High: \geq 2.3 mmol/L	-0.0674 (0.0139)	0.0000	1.65 (1.34, 2.02)	0.0000	2.52 (1.15, 5.52)	0.0209
HDL-C, per 1 mmol/L decrease	-0.0883 (0.0176)	0.0000	0.93 (0.87, 1.33)	0.4978	1.23 (0.33, 4.76)	0.7494
HDL-C categories						
Normal: \geq 1.0 mmol/L	As reference	—	As reference	—	As reference	—
Low: <1.0 mmol/L	-0.0240 (0.0122)	0.0497	0.96 (0.78, 1.19)	0.7205	1.52 (0.79, 2.95)	0.2096
LDL-C, per 1 mmol/L increase	0.0251 (0.0070)	0.0004	0.91 (0.82, 1.01)	0.0689	1.12 (0.80, 1.55)	0.5110
LDL-C categories						
Normal: <3.4 mmol/L	As reference	—	As reference	—	As reference	—
Borderline high: 3.4 ~ 4.1 mmol/L	0.0246 (0.0178)	0.1655	0.93 (0.73, 1.20)	0.5863	1.37 (0.51, 3.69)	0.5304
High: \geq 4.1 mmol/L	0.0597 (0.0291)	0.0404	0.62 (0.40, 0.96)	0.0319	0.93 (0.36, 2.36)	0.8721
Abbreviations: BMI, body mass index; CI, confidence interval; eGFR, estimated glomerular filtration rate; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; OR, odds ratio; SE, standard error; TC, total cholesterol; TG, triglycerides.						
All calculations were weighted based on the Chinese population data and the study sampling scheme. Regression models or multinomial logistic models were used to test the impact of TG, TC, HDL-C, and LDL-C and their categories on eGFR or the risks for mildly impaired eGFR (60 ~ 90 ml/min per 1.73 m ²) and moderately/severely impaired eGFR (< 60 ml/min per 1.73 m ²), respectively. EGFR were natural logarithmically transformed prior to the regression. Age, gender, BMI, smoking status, alcohol intake status, diabetes status, and hypertension status were adjusted as confounding factors in these models. P values < 0.05 are shown in bold.						

Upon stratification of the four measurements into categories, both the borderline high [1.7 ~ 2.3 mmol/L: β (SE) -0.0674 (0.0148), $P=0.0000$] and high TG categories [\geq 2.3 mmol/L: -0.0674 (0.0139), $P=0.0000$] as well as the low HDL-C category [< 1.0 mmol/L: -0.0240 (0.0122), $P=0.0497$] were significantly associated with a decreased eGFR. In contrast, the borderline high TC [5.2 ~ 6.3 mmol/L: 0.0504 (0.0114), $P=0.0000$] and the high LDL-C categories [\geq 4.1 mmol/L: 0.0597 (0.0291), $P=0.0404$] were related to an increased eGFR (Table 3).

Associations of TC, TG, HDL-C, LDL-C, and their categories with the risks for eGFR impairment

Using multinomial logistic analyses with adjustment for the conventional risk factors, we identified that each per mmol/L increase in TG increased the risks for mildly and moderately to severely impaired eGFR with ORs and 95% CIs of 1.19 (1.12, 1.26) ($P=0.0000$) and 1.31 (1.15, 1.50) ($P=0.0001$). Each per

mmol/L increase in TC was associated with a decreased risk for mildly impaired eGFR [OR (95% CI) 0.91 (0.84, 0.99), $P = 0.0302$]. However, neither HDL-C nor LDL-C was related to the risks for eGFR impairment (all $P > 0.05$; Table 3).

Moreover, in contrast to the normal TG category (< 1.7 mmol/L), the borderline high TG and high TG categories were significantly associated with 1.69-fold and 1.65-fold increased risks for mildly impaired eGFR ($P = 0.0000, 0.0000$), respectively, and the high TG category was associated with a 2.52-fold increase in the risk for moderately/severely impaired eGFR ($P = 0.0209$). The high LDL-C category was associated with a reduced risk for mildly impaired eGFR by 0.62-fold ($P = 0.0319$; Table 3).

Associations of TC, TG, HDL-C, and LDL-C with eGFR in subpopulations stratified by conventional risk factors

We identified significant interactions between HDL-C and gender ($P_{HDL-C*gender} = 0.0000$), BMI category ($P_{HDL-C*BMI\ category} = 0.0292$), smoking status ($P_{HDL-C*smoking\ status} = 0.0260$), and alcohol intake habit ($P_{HDL-C*alcohol\ intake} = 0.0001$) for the effect on eGFR. When the overall population was further stratified, significantly larger absolute effective sizes upon eGFR were identified in males [β (SE) -0.1556 (0.0246), $P = 0.0000$] versus females [-0.0288 (0.0233), $P = 0.2160$], in overweight/obese [-0.1329 (0.0246), $P = 0.0000$] versus underweight [-0.0772 (0.0478), $P = 0.1060$] or normal weight individuals [-0.0559 (0.0247), $P = 0.0236$], in smokers [-0.1380 (0.0340), $P = 0.0000$] versus non-smokers [-0.0673 (0.0202), $P = 0.0009$], and with alcohol intake habit [-0.1817 (0.0339), $P = 0.0000$] versus without [-0.0449 (0.0203), $P = 0.0272$]. However, no significant interactions of TC, TG, or LDL-C with any of the conventional risk factors for the effect on eGFR were observed (all $P > 0.05$; Table 4).

Table 4

Associations of total cholesterol, triglycerides, high-density lipoprotein-cholesterol, and low-density lipoprotein-cholesterol with the estimated glomerular filtration rate in the stratified populations.

Subpopulation	TC, per 1 mmol/L increase		TG, per 1 mmol/L increase		HDL-C, per 1 mmol/L decrease		LDL-C, per 1 mmol/L increase	
	β (SE)	P	β (SE)	P	β (SE)	P	β (SE)	P
Gender	(Age, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)							
Males	0.0339 (0.0078)	0.0000	-0.0210 (0.0051)	0.0000	-0.1556 (0.0246)	0.0000	0.0311 (0.0099)	0.0017
Females	0.0313 (0.0085)	0.0002	-0.0255 (0.0062)	0.0000	-0.0288 (0.0233)	0.2160	0.0205 (0.0095)	0.0302
$P_{\text{Gender interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C*gender)							
	$P_{TC*gender}=0.8371$		$P_{TG*gender}=0.9236$		$P_{HDL-C*gender}=0.0000$		$P_{LDL-C*gender}=0.7402$	
Age categories	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)							
< 40 years	0.0343 (0.0091)	0.0002	-0.0192 (0.0066)	0.0037	-0.1003 (0.0283)	0.0004	0.0224 (0.0126)	0.0764
40 ~ 60 years	0.0363 (0.0069)	0.0000	-0.0237 (0.0054)	0.0000	-0.0849 (0.0210)	0.0001	0.0382 (0.0076)	0.0000
≥ 60 years	0.0202 (0.0187)	0.2797	-0.0291 (0.0119)	0.0143	-0.0655 (0.0574)	0.2537	0.0047 (0.0197)	0.8123
$P_{\text{Age interaction}}$	(Age category, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C*age category)							
	$P_{TC*age\ category}=0.6567$		$P_{TG*age\ category}=0.5546$		$P_{HDL-C*age\ category}=0.5610$		$P_{LDL-C*age\ category}=0.3025$	
BMI categories	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)							
< 18.5 kg/m²	0.0541 (0.0177)	0.0022	0.0115 (0.0399)	0.7729	-0.0772 (0.0478)	0.1060	0.0286 (0.0203)	0.1591
18.5 ~ 24 kg/m²	0.0261 (0.0093)	0.0051	-0.0241 (0.0080)	0.0027	-0.0559 (0.0247)	0.0236	0.0091 (0.0104)	0.3790
≥ 24 kg/m²	0.0379 (0.0075)	0.0000	-0.0217 (0.0043)	0.0000	-0.1329 (0.0246)	0.0000	0.0422 (0.0099)	0.0000
$P_{\text{BMI interaction}}$	(Age, gender, BMI category, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C*BMI category)							
	$P_{TC*BMI\ category}=0.4094$		$P_{TG*BMI\ category}=0.6485$		$P_{HDL-C*BMI\ category}=0.0292$		$P_{LDL-C*BMI\ category}=0.0811$	
Smoking status	(Age, gender, BMI, alcohol intake status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)							
No	0.0296 (0.0071)	0.0000	-0.0280 (0.0050)	0.0000	-0.0673 (0.0202)	0.0009	0.0226 (0.0084)	0.0073
Yes	0.0397 (0.0102)	0.0001	-0.0148 (0.0061)	0.0151	-0.1380 (0.0340)	0.0000	0.0362 (0.0115)	0.0017
$P_{\text{Smoking status interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C*smoking status)							
	$P_{TC*smoking\ status}=0.7628$		$P_{TG*smoking\ status}=0.2760$		$P_{HDL-C*smoking\ status}=0.0260$		$P_{LDL-C*smoking\ status}=0.7070$	
Alcohol intake status	(Age, gender, BMI, smoking status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)							
No	0.0249 (0.0068)	0.0003	-0.0261 (0.0047)	0.0000	-0.0449 (0.0203)	0.0272	0.0253 (0.0079)	0.0013
Yes	0.0502 (0.0118)	0.0000	-0.0175 (0.0068)	0.0104	-0.1817 (0.0339)	0.0000	0.0249 (0.0142)	0.0798
$P_{\text{Alcohol intake interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C*alcohol intake status)							
	$P_{TC*alcohol\ intake}=0.0831$		$P_{TG*alcohol\ intake}=0.7387$		$P_{HDL-C*alcohol\ intake}=0.0001$		$P_{LDL-C*alcohol\ intake}=0.9220$	
Diabetes status	(Age, gender, BMI, smoking status, alcohol intake status, hypertension status, and TC/TG/HDL-C/LDL-C)							
Normal glycemic metabolism	0.0391 (0.0064)	0.0000	-0.0254 (0.0054)	0.0000	-0.0973 (0.0181)	0.0000	0.0295 (0.0082)	0.0003
Prediabetes	0.0224 (0.0137)	0.1027	-0.0135 (0.0071)	0.0586	-0.0930 (0.0333)	0.0052	0.0243 (0.0144)	0.0908
Diabetes	-0.0020 (0.0224)	0.9298	-0.0305 (0.0086)	0.0004	0.0075 (0.0965)	0.9377	-0.0013 (0.0211)	0.9497

Abbreviations: BMI, body mass index; BP, blood pressure; CI, confidence interval; eGFR, estimated glomerular filtration rate; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; SE, standard error; TC, total cholesterol; TG, triglycerides.

All calculations were weighted based on Chinese population data and the study sampling scheme. Regression models were used to test the impact of TG, TC, HDL-C, or LDL-C on eGFR in subpopulations stratified by gender, age, BMI, smoking status, alcohol intake status, diabetes status, and hypertension status, separately. In the overall cohort, the interaction terms were further included respectively to examine the interaction effects. EGFR were natural logarithmically transformed prior to the regression. Variables included in the regression models were denoted in the parentheses. *P* values < 0.05 are shown in bold.

Subpopulation	TC, per 1 mmol/L increase		TG, per 1 mmol/L increase		HDL-C, per 1 mmol/L decrease		LDL-C, per 1 mmol/L increase	
	β (SE)	P	β (SE)	P	β (SE)	P	β (SE)	P
$P_{\text{Diabetes status interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C*diabetes status)							
	$P_{TC*diabetes\ status} = 0.2330$		$P_{TG*diabetes\ status} = 0.2828$		$P_{HDL-C*diabetes\ status} = 0.3300$		$P_{LDL-C*diabetes\ status} = 0.3028$	
Hypertension status	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, and TC/TG/HDL-C/LDL-C)							
Normal tension	0.0255 (0.0097)	0.0087	-0.0288 (0.0086)	0.0008	-0.0718 (0.0259)	0.0056	0.0107 (0.0118)	0.3614
Prehypertension	0.0364 (0.0079)	0.0000	-0.0220 (0.0051)	0.0000	-0.0982 (0.0238)	0.0000	0.0341 (0.0108)	0.0016
Hypertension	0.0345 (0.0140)	0.0141	-0.0221 (0.0075)	0.0034	-0.1006 (0.0474)	0.0336	0.0319 (0.0139)	0.0217
$P_{\text{Hypertension status interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C* hypertension status)							
	$P_{TC*hypertension\ status} = 0.8402$		$P_{TG*hypertension\ status} = 0.8852$		$P_{HDL-C*hypertension\ status} = 0.7982$		$P_{LDL-C*hypertension\ status} = 0.4096$	
Abbreviations: BMI, body mass index; BP, blood pressure; CI, confidence interval; eGFR, estimated glomerular filtration rate; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; SE, standard error; TC, total cholesterol; TG, triglycerides.								
All calculations were weighted based on Chinese population data and the study sampling scheme. Regression models were used to test the impact of TG, TC, HDL-C, or LDL-C on eGFR in subpopulations stratified by gender, age, BMI, smoking status, alcohol intake status, diabetes status, and hypertension status, separately. In the overall cohort, the interaction terms were further included respectively to examine the interaction effects. EGFR were natural logarithmically transformed prior to the regression. Variables included in the regression models were denoted in the parentheses. <i>P</i> values < 0.05 are shown in bold.								

Associations of TC, TG, HDL-C, and LDL-C with the risks for eGFR impairment in subpopulations stratified by conventional risk factors

TG was found to interact with gender in affecting the risk for eGFR impairment ($P_{TG*gender} = 0.0261$). Each per mmol/L increase in TG was significantly associated with 1.16-fold and 1.27-fold increases in the risk for mildly impaired eGFR in males and females, respectively ($P = 0.0002, 0.0000$). Notably, each per mmol/L increase in TG increased the risk for moderately/severely impaired eGFR in males only (by 1.45-fold, $P = 0.0000$) and not in females ($P = 0.1185$; Table 5).

Table 5

Associations of total cholesterol, triglycerides, high-density lipoprotein-cholesterol, and low-density lipoprotein-cholesterol with the risks for estimated glomerular populations.

Subpopulation	TC, per 1 mmol/L increase				TG, per 1 mmol/L increase				HDL-C, per 1 mmol/L decrease			
	Mildly impaired eGFR		Moderately/severely impaired eGFR		Mildly impaired eGFR		Moderately/severely impaired eGFR		Mildly impaired eGFR		Moderately/severely impaired eGFR	
	(eGFR 60 ~ 90 ml/min per 1.73 m ²)		(eGFR < 60 ml/min per 1.73 m ²)		(eGFR 60 ~ 90 ml/min per 1.73 m ²)		(eGFR < 60 ml/min per 1.73 m ²)		(eGFR 60 ~ 90 ml/min per 1.73 m ²)		(eGFR < 60 ml/min per 1.73 m ²)	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
Gender	(Age, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)											
Males	0.93 (0.82, 1.06)	0.2801	0.95 (0.56, 1.6)	0.8526	1.16 (1.07, 1.25)	0.0002	1.45 (1.24, 1.69)	0.0000	1.23 (0.84, 1.79)	0.2834	20.00 (4.76, 100.00)	0.0001
Females	0.93 (0.83, 1.03)	0.1577	1.13 (0.73, 1.75)	0.5788	1.27 (1.15, 1.39)	0.0000	1.17 (0.96, 1.43)	0.1185	0.98 (0.76, 1.27)	0.8681	0.53 (0.17, 1.69)	0.2886
$P_{\text{Gender interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C)											
	$P_{TC*gender} = 0.4602$				$P_{TG*gender} = \mathbf{0.0261}$				$P_{HDL-C*gender} = \mathbf{0.0003}$			
Age categories	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)											
< 40 years	1.00 (0.87, 1.16)	0.9489	1.12 (0.47, 2.68)	0.8003	1.09 (0.96, 1.24)	0.1753	1.07 (0.79, 1.46)	0.6709	0.76 (0.52, 1.12)	0.1703	0.54 (0.06, 5.26)	0.5913
40 ~ 60 years	0.88 (0.79, 0.97)	0.0137	0.79 (0.50, 1.24)	0.3085	1.19 (1.11, 1.28)	0.0000	1.47 (1.25, 1.73)	0.0000	1.28 (0.97, 1.67)	0.0793	2.22 (0.66, 7.14)	0.2001
≥ 60 years	0.89 (0.74, 1.07)	0.2137	1.19 (0.73, 1.95)	0.4903	1.28 (1.09, 1.51)	0.0032	1.30 (0.99, 1.71)	0.0577	1.08 (0.65, 1.79)	0.7701	1.14 (0.15, 8.33)	0.9057
$P_{\text{Age interaction}}$	(Age category, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C)											
	$P_{TC*age\ category} = 0.1278$				$P_{TG*age\ category} = 0.6197$				$P_{HDL-C*age\ category} = 0.6775$			
BMI categories	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)											
< 18.5 kg/m²	0.62 (0.37, 1.03)	0.0653	0.53 (0.22, 1.27)	0.1544	0.67 (0.29, 1.53)	0.3429	2.67 (0.75, 9.56)	0.1312	1.67 (0.57, 4.76)	0.3489	4.76 (0.74, 33.33)	0.1016
18.5 ~ 24 kg/m²	0.95 (0.84, 1.07)	0.3919	1.21 (0.73, 1.99)	0.4608	1.25 (1.12, 1.39)	0.0001	1.14 (0.88, 1.47)	0.3357	0.91 (0.68, 1.22)	0.5134	0.58 (0.17, 2.00)	0.3891
≥ 24 kg/m²	0.88 (0.79, 0.98)	0.0222	0.86 (0.60, 1.23)	0.4197	1.14 (1.06, 1.22)	0.0003	1.37 (1.19, 1.57)	0.0000	1.22 (0.88, 1.69)	0.2201	4.35 (0.83, 25.00)	0.0811
$P_{\text{BMI interaction}}$	(Age, gender, BMI category, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C)											
	$P_{TC*BMI\ category} = 0.3627$				$P_{TG*BMI\ category} = 0.2939$				$P_{HDL-C*BMI\ category} = 0.1011$			
Smoking status	(Age, gender, BMI, alcohol intake status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)											
No	0.93 (0.84, 1.02)	0.1163	1.10 (0.77, 1.57)	0.5952	1.23 (1.15, 1.33)	0.0000	1.30 (1.11, 1.53)	0.0015	1.03 (0.81, 1.32)	0.8094	0.84 (0.23, 3.03)	0.7859
Yes	0.90 (0.76, 1.05)	0.1858	0.63 (0.23, 1.73)	0.3731	1.11 (1.01, 1.23)	0.0330	1.45 (1.11, 1.89)	0.0063	1.19 (0.73, 1.96)	0.4848	33.33 (3.70, 373.82)	0.0022

Abbreviations: BMI, body mass index; CI, confidence interval; eGFR, estimated glomerular filtration rate; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; TC, total cholesterol; TG, triglycerides.

All calculations were weighted based on Chinese population data and the study sampling scheme. Multinomial logistic models were used to test the impact of TC, TG, HDL-C, and LDL-C on the risk of CKD for mildly impaired eGFR (60 ~ 90 ml/min per 1.73 m²) and moderately/severely impaired eGFR (< 60 ml/min per 1.73 m²) in subpopulations stratified by gender, BMI, smoking status, alcohol intake status, diabetes status, and hypertension status, separately. In the overall cohort, the interaction terms were further included respectively to examine the impact of TC, TG, HDL-C, and LDL-C on the risk of CKD. In the multinomial logistic models were denoted in the parentheses. P values < 0.05 are shown in bold.

Subpopulation	TC, per 1 mmol/L increase				TG, per 1 mmol/L increase				HDL-C, per 1 mmol/L decrease			
	Mildly impaired eGFR (eGFR 60 ~ 90 ml/min per 1.73 m ²)		Moderately/severely impaired eGFR (eGFR < 60 ml/min per 1.73 m ²)		Mildly impaired eGFR (eGFR 60 ~ 90 ml/min per 1.73 m ²)		Moderately/severely impaired eGFR (eGFR < 60 ml/min per 1.73 m ²)		Mildly impaired eGFR (eGFR 60 ~ 90 ml/min per 1.73 m ²)		Moderately/severely impaired eGFR (eGFR < 60 ml/min per 1.73 m ²)	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
$P_{\text{Smoking status interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C)											
	$P_{TC*smoking\ status}=0.6951$				$P_{TG*smoking\ status}=0.1753$				$P_{HDL-C*smoking\ status}=0.0219$			
Alcohol intake status	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, and TC/TG/HDL-C/LDL-C)											
No	0.91 (0.83, 1.00)	0.0545	1.10 (0.77, 1.59)	0.5963	1.22 (1.14, 1.31)	0.0000	1.32 (1.14, 1.54)	0.0003	0.92 (0.72, 1.18)	0.4931	0.80 (0.22, 2.86)	0.7318
Yes	0.94 (0.79, 1.12)	0.4837	0.77 (0.35, 1.68)	0.5135	1.12 (1.00, 1.24)	0.0444	1.38 (1.04, 1.83)	0.0274	1.72 (1.05, 2.86)	0.0296	50.00 (4.00, 557.18)	0.0023
$P_{\text{Alcohol intake interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C)											
	$P_{TC*alcohol\ intake}=0.6415$				$P_{TG*alcohol\ intake}=0.4045$				$P_{HDL-C*alcohol\ intake}=0.0007$			
Diabetes status	(Age, gender, BMI, smoking status, alcohol intake status, hypertension status, and TC/TG/HDL-C/LDL-C)											
Normal glycemic metabolism	0.84 (0.76, 0.93)	0.0005	1.05 (0.72, 1.53)	0.7989	1.19 (1.10, 1.29)	0.0000	1.52 (1.35, 1.72)	0.0000	1.04 (0.82, 1.33)	0.7152	1.67 (0.57, 5.00)	0.3456
Prediabetes	1.17 (0.96, 1.43)	0.1139	0.63 (0.39, 1.02)	0.0587	1.15 (1.03, 1.29)	0.0170	0.64 (0.36, 1.14)	0.1295	1.20 (0.70, 2.08)	0.4889	3.13 (0.79, 12.50)	0.1060
Diabetes	0.86 (0.71, 1.04)	0.1125	1.64 (0.86, 3.13)	0.1318	1.19 (1.04, 1.35)	0.0090	1.48 (1.21, 1.80)	0.0001	1.05 (0.56, 1.96)	0.8730	0.59 (0.05, 6.67)	0.6724
$P_{\text{Diabetes status interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C)											
	$P_{TC*diabetes\ status}=0.0027$				$P_{TG*diabetes\ status}=0.0972$				$P_{HDL-C*diabetes\ status}=0.5666$			
Hypertension status	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, and TC/TG/HDL-C/LDL-C)											
Normal tension	1.05 (0.93, 1.19)	0.4355	1.30 (0.65, 2.58)	0.4553	1.26 (1.11, 1.43)	0.0003	1.38 (1.00, 1.90)	0.0480	0.78 (0.56, 1.09)	0.1467	0.65 (0.11, 3.85)	0.6314
Prehypertension	0.84 (0.74, 0.95)	0.0059	0.78 (0.51, 1.19)	0.2477	1.18 (1.08, 1.28)	0.0001	1.20 (1.00, 1.43)	0.0481	1.16 (0.82, 1.67)	0.4006	1.72 (0.54, 5.56)	0.3531
Hypertension	0.86 (0.72, 1.02)	0.0743	1.06 (0.64, 1.76)	0.8329	1.12 (1.01, 1.24)	0.0262	1.33 (1.08, 1.65)	0.0088	1.35 (0.85, 2.17)	0.1950	1.33 (0.15, 12.50)	0.7970
$P_{\text{Hypertension status interaction}}$	(Age, gender, BMI, smoking status, alcohol intake status, diabetes status, hypertension status, TC/TG/HDL-C/LDL-C, and TC/TG/HDL-C/LDL-C)											
	$P_{TC*hypertension\ status}=0.1081$				$P_{TG*hypertension\ status}=0.4163$				$P_{HDL-C*hypertension\ status}=0.1343$			
Abbreviations: BMI, body mass index; CI, confidence interval; eGFR, estimated glomerular filtration rate; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; TC, total cholesterol; TG, triglycerides.												
All calculations were weighted based on Chinese population data and the study sampling scheme. Multinomial logistic models were used to test the impact of eGFR impairment on the risk for cardiovascular events in subpopulations stratified by gender, alcohol intake status, diabetes status, and hypertension status, separately. In the overall cohort, the interaction terms were further included respectively to examine their impact on the risk for cardiovascular events. The interaction terms in the multinomial logistic models were denoted in the parentheses. <i>P</i> values < 0.05 are shown in bold.												

Significant interactions were observed between HDL-C and gender ($P_{HDL-C*gender}=0.0003$), smoking status ($P_{HDL-C*smoking\ status}=0.0219$), and alcohol intake habit ($P_{HDL-C*alcohol\ intake}=0.0007$) for the effect on the risk for eGFR impairment. We then found that each per mmol/L decrease in HDL-C specifically

increased the risk for moderately/severely impaired eGFR by 20-fold in males ($P=0.0001$) and by 33.33-fold in smokers ($P=0.0022$), but these associations were not identified in females ($P=0.2886$) or those without a smoking habit ($P=0.7859$). In individuals with an alcohol intake habit, each per mmol/L decrease in HDL-C was associated with 1.72-fold and 50.00-fold increases in the risks for mildly impaired and moderately/severely impaired eGFR, respectively ($P=0.0296, 0.0023$), and these associations were not observed in individuals without an alcohol intake habit ($P=0.4931, 0.7318$; Table 5).

TC and diabetes status showed a significant interaction also ($P_{TC*diabetes\ status}=0.0027$). The association of elevated TC with a decreased risk for mildly impaired eGFR was only observed in individuals with normal glycemic metabolism [OR (95%CI) 0.84 (0.76, 0.93), $P=0.0005$], and not in those with prediabetes ($P=0.1139$) or diabetes ($P=0.1125$). Moreover, TC did not show any association with the risk for moderately/severely eGFR impairment in individuals with normal glycemic metabolism ($P=0.7989$), prediabetes ($P=0.0587$), or diabetes ($P=0.1318$; Table 5).

LDL-C and age showed significant interactions ($P_{LDL-C*age}=0.0076$). In those aged 40 ~ 60 years, each per mmol/L increase in LDL-C was associated with decreased risks for mildly impaired eGFR [0.84 (0.75, 0.94), $P=0.0032$] and moderately/severely impaired eGFR [0.69 (0.49, 0.98), $P=0.0382$], but these associations were not observed in the participants aged < 40 years ($P=0.1393, 0.7755$) or ≥ 60 years ($P=0.2850, 0.1833$; Table 5).

Discussion

Epidemiological studies have suggested that dyslipidemia is associated with a reduced eGFR, but the specific types of lipids or lipoproteins that contribute to eGFR remained unclear for the general Chinese population. Based on the weighted data from a national representative population of 16,206 Chinese individuals, we found that the estimated mean eGFR values were significantly lower with TG levels in the abnormally high categories, and the prevalence rates of mildly impaired eGFR and moderately/severely impaired eGFR were significantly higher with TG levels in the abnormal categories (1.7 ~ 2.3, ≥ 2.3 mmol/L). The estimated prevalence of mildly impaired eGFR was also higher with LDL-C levels in the borderline high category (≥ 4.1 mmol/L). The results further indicate that high TG and low HDL-C were independently associated with a lower eGFR, whereas high TC and LDL-C were independently associated with a higher eGFR after adjustment for age, gender, BMI, smoking, alcohol intake, diabetes, and hypertension. Using multinomial logistic analyses, the TG level significantly contributed to the elevated risks for impaired eGFR. Moreover, a reduced HDL-C had a significantly stronger impact on eGFR in males, overweight/obese individuals, and those with smoking or alcohol intake habit. The findings of the present study highlight the importance of lipid and lipoprotein measurement in the risk assessment and prevention of impaired renal function in the general Chinese population, independent of the other conventional risk factors. A personalized management strategy for the at-risk population with recognition of the other conventional risk factors must be emphasized.

CKD is well known to be associated with an increased risk for cardiovascular events. In fact, previous studies indicated that a mild reduction in eGFR increases the risks for cardiovascular morbidity and mortality. For example, an observational study suggested that the risks for cardiovascular events and all-cause mortality increased in participants with an eGFR of 60 ~ 89 mL/min per 1.73 m² compared to those with an eGFR ≥ 90 mL/min per 1.73 m²(20). In the Chinese population, the REACTION study reported that even a mildly reduced eGFR (< 90 mL/min per 1.73 m²) is associated with an elevated 10-year Framingham risk for coronary heart disease and an elevated 10-year atherosclerotic cardiovascular disease risk among Chinese adults(2). At the same time, several studies established that monitoring of eGFR at a normal or milder stage is of clinical importance. In a community-based Chinese population aged over 40 years with normal or mildly impaired renal function, 12.3% of the participants developed renal function decline during a 4-year follow-up with a median change in the eGFR of ~ 20 mL/min per 1.73 m²(21). Sumida et al. reported that 12% of the participants in a nationwide cohort of 56,946 United States veterans with an eGFR ≥ 60 mL/min per 1.73 m² showed rapid eGFR decline (≥ 5 mL/min per 1.73 m²/year)(22). Interestingly, another study conducted in a US population found that 348 of 2,219 individuals with an eGFR of 60 ~ 119 mL/min per 1.73 m² showed rapid renal function decline (≥ 5 mL/min per 1.73 m²/year) in an 8-year follow-up, and a greater percentage experienced rapid renal function decline among individuals with a baseline eGFR of 60 ~ 89 mL/min per 1.73 m² versus a baseline eGFR of 90 ~ 119 mL/min per 1.73 m²(23). These facts also support that individuals with mildly impaired renal function will experience more rapid renal function decline, making them major candidates for CKD in the future. In the present study, the estimated prevalence rates of both mildly impaired eGFR (60 ~ 90 mL/min per 1.73 m²) and moderately/severely impaired eGFR (< 60 mL/min per 1.73 m²) were reported, and both outcomes were considered in the analyses applying the multinomial logistic procedure in SUDAAN software. Thus, the findings of the current study provide valuable information for the prevention of CKD in the general Chinese population aged 20 years and older.

Lipid disorder is proposed to be an essential cause of renal dysfunction, and patients with renal dysfunction usually have concomitant dyslipidemia. However, the link between lipid metabolism and the GFR have not been fully elucidated. Experimental data show that dyslipidemia can affect renal function and accelerate the progression of renal injury(24). Altered fatty acid and cholesterol metabolism are known as the key mediators of renal lipid accumulation, resulting in renal inflammation, oxidative stress, and fibrosis(25). Clinical studies showed that lipids or lipoproteins have discordant contributions to the GFR. Previous studies frequently showed that an increased TG level and a decreased HDL-C level were associated with a decreased eGFR, as well as the risk for renal dysfunction, in several different populations(6, 7, 9–11). However, there has been a lack of research based on nationally representative general populations. In the current study, we estimated the prevalence rates and investigated the contributions of lipids and lipoproteins to eGFR and the risks for eGFR impairment in a nationally representative Chinese population with a large sample size, which was also weighted to represent the total population of Chinese adults on the basis of population data and sampling scheme. Thus, the results from this study can be reliably generalized to the general population of Chinese ancestry.

Our results demonstrated significant contributions of abnormal TG and HDL-C levels to decreased eGFR, as well as the contribution of high TG to elevated risks for both mildly impaired eGFR and moderately/severely impaired eGFR. The present study also emphasizes the importance of reducing TG and raising HDL-C for renal function protection in the general population. In this respect, drugs targeting TG or HDL-C, such as fibrate compounds, niacin, and inhibitors of cholesteryl ester transfer protein, might be beneficial theoretically. Evidence of their impacts on kidney function is still lacking. In current clinical practice,

fibrate and niacin are only recommended for the treatment of patients with TG \geq 5.7 mmol/L to prevent pancreatitis, and for the treatment patients who were previously treated the maximum tolerable doses of statins and continued to have TG \geq 2.6 mmol/L(18, 26). However, in the FIELD Helsinki study, even concomitant decreases in creatinine clearance and eGFR in type 2 diabetes patients were revealed after long-term fenofibrate treatment for 5 years(27). Similar findings were also reported in outpatients not restricted to those with diabetes(28). In the future, clinical trials focusing on renal outcomes of drugs targeting TG or HDL-C are highly anticipated.

We previously reported that BMI, waist circumference, blood pressure, and fasting and post-prandial glucose levels are associated with TG in the Chinese population, whereas BMI, waist circumference, and glucose levels are associated with the HDL-C level(29). Interventions treating metabolic disorders are also well-known to be beneficial for the protection of renal function in Chinese populations. However, the findings of the present study indicate that TG and HDL-C influence renal function independent of the conventional risk factors including age, smoking and drink habits, as well as metabolic-related disorders, such as obesity, abnormal glycemic metabolism and hypertension. Thus, the present study highlights the critical impacts of TG and HDL-C on renal function beyond those conventional risk factors, indicating that these levels should be closely monitored and controlled.

Elevated TC and LDL-C levels are the predominant features of lipid disorder in patients with nephrotic syndrome. However, the exact influences of TC and LDL-C on the eGFR continue to be debated. The conflicting results from different studies could have resulted from the differential adjustment for confounding factors or differences in the study populations. For instance, without controlling for the other conventional factors, negative correlations were observed between TC or LDL-C and eGFR in a Chinese population aged 40 years or older(7). In another study based on middle-aged and elder Chinese population, TC was associated with a decreased eGFR before and after adjustment for the conventional risk factors, and LDL-C was only associated with a decreased eGFR in the crude model(8). Moreover, other studies failed to identify any associations of TC or LDL-C with a decreased eGFR(9, 10). Notably, the CRIC study reported that a 1-standard deviation (SD) higher TC or LDL-C was associated with a 26% or 23% lower risk, respectively, of the renal end point after adjustment the other risk factors in patients with low levels of proteinuria (12). In the current study, among those with an abnormally high TC or LDL-C, the prevalence of eGFR impairment tended to be increased, suggesting that eGFR should be carefully monitored in individuals with abnormally high TC or LDL-C in clinical practice. On the other hand, after adjustment for the conventional risk factors, both elevated TC and LDL-C levels were independently associated with an increased eGFR, as well as lower risks for eGFR impairment. Although it cannot be determined whether causal relationships exist between TC or LDL-C and eGFR in the Chinese population via this cross-sectional study, it can be speculated that metabolic factors, such as BMI, diabetes status, and hypertension, have strong interplay with TC or LDL-C, leading to conflicting findings with or without adjustment for these factors. Moreover, the absolute roles of elevated TC and LDL-C independent of the other comorbid metabolic disorders may be protective of eGFR. In addition, statins, which are widely used to lower cholesterol levels by inhibiting the enzyme HMG-CoA reductase, have long been speculated to protect kidney function(4, 5). A recent meta-analysis conducted in 2016 reported that statin therapy does not reduce the risk for kidney failure events in adults not receiving dialysis, but may modestly reduce proteinuria and the rate of eGFR decline(30). Thus, the exact biological effects of TC and LDL-C on the eGFR remain incompletely understood.

Using interaction and subpopulation analyses, a decreased HDL-C was observed to have significantly stronger influences on the reduction of eGFR and elevated risks for impaired eGFR in males and individuals with smoking or alcohol intake habit, as well as a stronger influence on the reduction of eGFR in overweight/obese individuals. These results suggest that the disturbance of HDL-C can be more harmful, especially for these patient groups. In the Chinese population, the majority of the individuals with smoking or alcohol intake habits are men, which may partly explain the similar patterns of the interacting effects of these factors. Notably, because smoking and alcohol intake are modifiable factors, lifestyle intervention, such as smoking cessation and alcohol avoidance, might reduce an individual's risk for renal dysfunction through the interaction with HDL-C. Based on the observation that the eGFR of overweight or obese individuals was more susceptible to the reduction of HDL-C, these patients may also benefit from weight loss intervention. Moreover, each per mmol/L TG increase significantly increased the risk for moderately/severely impaired eGFR by 45% specifically in males, but not in females, suggesting that males were more susceptible to the effects of increased TG. We also found that the protective role of TC against mildly impaired eGFR did not exist among individuals with prediabetes or diabetes. Also, the protective effect of LDL-C was observed only in the middle-aged population (40 ~ 60 years old). Overall, the interaction data highlight the necessity of personalized management of the eGFR for the prevention of CKD.

The current study has the following strengths. The present study was based on a relatively large nationally representative survey in China, and the data were weighted on basis of the population data and sampling strategy, so that the results could be well-generalized to the Chinese population. Second, the mild eGFR impairment was taken into consideration by applying a multinomial logistic regression analysis, which provided valuable data for the early prevention and intervention of renal function decline. Finally, the elucidation of interaction effects of conventional factors can be applied to achieve precise risk assessment and improve intervention strategies. However, this study also has limitations. As a cross-sectional survey, it could not elucidate the sequential effects of the onset of dyslipidemia and eGFR impairment. Therefore, longitudinal studies are required to test the robustness of the findings of this study. Moreover, accumulating data for the involvement of lipid composites besides TC, TG, HDL-C, and LDL-C are found in the literatures(31, 32), suggesting that novel lipid biomarkers for eGFR not covered in the present study still need to be investigated.

In summary, we investigated the contributions of the four clinical measurements of lipids and lipoproteins on eGFR, as well as the risks for mild eGFR reduction and moderate/severe eGFR reduction based on weighted data from a nationally representative general population of Chinese ancestry. Significant increases in TG, TC, and LDL-C were accompanied by a decrease in the eGFR. With adjustment for the conventional risk factors, elevated TG and reduced HDL-C were independently associated with impaired eGFR outcomes, whereas TC and LDL-C levels were positively associated with the eGFR. Moreover, the effects of a lower HDL-C on eGFR reduction were significantly stronger in males, those with smoking or alcohol intake habits, and overweight/obese individuals, while males were more susceptible to the effect of increased TG on the risk for a moderately/severely impaired eGFR. These findings emphasize the importance of effective control of TG and HDL-C levels for protecting renal function in Chinese adults aged 20 years and above, and the need for the development of a personalized management strategy for the at-risk population. In this respect, individuals with abnormal TG or HDL-C levels require close monitoring of the eGFR and should receive effective interventions to reduce TG and increase HDL-C.

List Of Abbreviations

2-h PPG, 2-h post-prandial plasma glucose; β , beta coefficient; CI, confidence interval; CKD, chronic kidney disease; DBP, diastolic blood pressure; DMS, the China National Diabetes and Metabolism Disorders Study; eGFR, estimated glomerular filtration rate; ESRD, end-stage renal disease; FPG, fasting plasma glucose; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; MDRD, Modification of Diet in Renal Disease; OGTT, oral glucose tolerance test; OR, odds ratio; SBP, systolic blood pressure; SE, standard error; TC, total cholesterol; TG, triglycerides; UACR, urinary albumin-creatinine ratio; WHO, World Health Organization.

Declarations

Ethics approval and consent to participate

The study protocol was conducted in accordance with the Declaration of Helsinki II and approved by the ethics committee of the China-Japan Friendship Hospital (Beijing, China). Written informed consent was obtained from each participant prior to data collection.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Competing interests

We also have following competing interest to disclose. Outside the submitted work, WY has attended the advisory board of Novo Nordisk, received investigator-initiated trial research funds from AstraZeneca, and been a speaker for Novo Nordisk, Bayer, Sanofi Aventis, Merck Sharp & Dohme China, AstraZeneca, Eli Lilly, Boehringer-Ingelheim, and Servier; received honorarium and travel support as the advisory boards' member from Merck & Co., Inc. These do not alter our adherence to all the journal policies on sharing data and materials, as detailed online in the guide for authors.

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Authors' contributions

All authors contributed significantly and met the criteria of authorship. XC and XK generated the study hypothesis, and developed the study design. BZ, XC, XX, HZ, and XK collected the data. XK, XC, ZY, LY, and WY analyzed and interpreted the data. XK drafted the manuscript. All of the authors critically revised the manuscript and contributed to the discussion. XC completed the final version of manuscript. All authors are in agreement with the content of the manuscript, and agree to submit for consideration for publication in the journal. There are no any ethical/legal conflicts involved in the article. As the corresponding author, XC have had full access to the data in the study and final responsibility for the decision to submit for publication.

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