Green tea consumption and incidence Of cardiovascular disease in type 2 Diabetic patients with overweight/obesity:A community-based cohort study

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Abstract

Background: Previous research suggests that green tea may offer protective effects against cardiovascular disease (CVD). This study explored the relationship between green tea intake and the development of CVD among overweight or obese individuals with type 2 diabetes (T2D).

Methods: A total of 4,756 Chinese adults diagnosed with T2D and classified as overweight or obese were followed for an average of 6.27 years. Data on green tea consumption were collected at baseline through interviewer-based questionnaires. The Cox proportional hazards model was applied to estimate

hazard ratios (HRs) and 95% confidence intervals (Cis) for CVD incidence based on tea consumption levels.

Results: Compared to those who rarely drank green tea, participants consuming more than 5 g of tea leaves per day had a 29% lower risk of CVD (95% CI: 0.55–0.92), a 30% reduction in stroke risk (95% CI: 0.51–0.95), and a 40% lower risk of coronary heart disease (CHD) (95% CI: 0.40–0.89). Similarly, individuals who had consumed green tea for 40 years or more showed a 31% lower risk of CVD (95% CI: 0.54–0.88), a 33% reduction in stroke risk (95% CI: 0.50–0.90), and a 39% decrease in CHD risk (95% CI: 0.42–0.88). Among participants with a T2D duration of less than five years, drinking more than 5 g/day or consuming green tea for over 40 years was linked to a 59% (95% CI: 0.23–0.72) and 57% (95% CI: 0.26–0.74) lower stroke risk, respectively. In contrast, among those with diabetes for five years or longer, these same levels of tea consumption were associated with a 50% (95% CI: 0.30–0.82) and 46% (95% CI: 0.35–0.85) reduction in CHD risk.

Conclusions: Regular green tea intake appears to be linked with a significantly lower likelihood of developing CVD, stroke, and CHD among overweight or obese individuals with type 2 diabetes.

Keywords Diabetes, Green tea, Cardiovascular diseases, Coronary heart disease, Stroke

Text box 1. Contributions to the literature

1. Regular green tea intake shows a significant inverse association with the occurrence of overall cardiovascular disease, coronary heart disease, and stroke among overweight or obese individuals with type 2 diabetes.
2. In patients with type 2 diabetes of less than five years' duration, frequent green tea consumption appears to markedly lower the likelihood of developing stroke
3. Among overweight or obese type 2 diabetes patients with a disease duration of five years or more, habitual green tea intake is strongly linked to a reduced risk of coronary heart disease.
4. The combined influence of both the quantity and duration of green tea consumption does not demonstrate a significant interaction effect on the incidence of total cardiovascular disease, coronary heart disease, or stroke in this population.

Introduction

Cardiovascular disease (CVD) remains the primary cause of death in China. Over the past few decades, numerous genetic, behavioral, nutritional, and environmental determinants have been implicated in CVD pathogenesis, such as single nucleotide polymorphisms, obesity, smoking, alcohol use, physical inactivity, and exposure to heavy metals [1]. The coexistence of diabetes and obesity, commonly referred to as diabesity, represents a major public health challenge due to its adverse effects on metabolic and cardiovascular health [2–4]. In a large-scale Chinese cohort involving 8,006 participants, Kong et al. demonstrated that non-obese individuals with diabetes had a 42% higher risk of CVD compared to healthy subjects, while diabetic participants with obesity exhibited a 78% higher risk—indicating a synergistic effect between diabetes and obesity in accelerating cardiovascular risk [5].

Green tea is rich in bioactive antioxidants, including amino acids, caffeine, and polyphenolic compounds. Several epidemiological studies have suggested that green tea consumption contributes to improved cardiovascular outcomes, particularly in lowering the risks of stroke and coronary heart disease (CHD) [6–8]. For instance, a meta-analysis encompassing nine studies and 259,267 participants found that individuals who did not consume green tea had a 19% greater risk of CVD than those who drank at least one cup daily [9]. Similarly, Zhao et al., in two Shanghai-based cohort studies involving 6,517 adults, observed that green tea intake was inversely correlated with CVD-related and all-cause mortality [10].

Nevertheless, the long-term impact of habitual green tea consumption on diabetes and its related complications remains inconclusive. For example, Nie et al., analyzing data from half a million Chinese adults, found a significant reduction in type 2 diabetes (T2D) risk among daily green tea consumers, but no association with diabetic microvascular complications [11]. Conversely, a Mendelian randomization analysis by Chen et al. revealed no causal link between green tea consumption and T2D or glycemic indices [12]. Another cohort study conducted by Liu et al. reported an opposite trend, where frequent green tea intake was associated with a higher T2D risk after adjusting for confounders such as age, sex, education, smoking, alcohol use, physical activity, BMI, and hypertension [13].

Given that individuals with T2D who are overweight or obese face an elevated risk of CVD, exploring effective preventive strategies in this group is essential. However, current evidence on the relationship

between green tea intake and CVD risk in overweight or obese T2D patients remains limited. Therefore, the present study was designed to evaluate the association between green tea consumption and the incidence of CVD and its subtypes—CHD and stroke—in this specific population. The underlying hypothesis is that regular green tea consumption may offer a protective effect against the development of CVD, CHD, and stroke among overweight and obese individuals with type 2 diabetes.

Methods:

Study Population

This investigation was derived from the Comprehensive Research on the Prevention and Control of Diabetes (CRPCD) program—an ongoing large-scale epidemiological project launched in Jiangsu, China, in 2013 to explore the determinants of type 2 diabetes (T2D) and its complications [14–17]. In this program, a total of 10,166 adults aged 30 years and above with diagnosed T2D were recruited from 30 community centers between December 2013 and January 2014. Individuals with chronic renal failure, liver cirrhosis, psychiatric disorders, or severe autoimmune conditions (e.g., rheumatoid arthritis) were excluded.

At baseline, trained healthcare professionals conducted structured, face-to-face interviews using electronic questionnaires and standardized physical assessments after obtaining informed consent. Data collected included family history of CVD and T2D, comorbid conditions, and medication use for hypertension, diabetes, and dyslipidemia. Participants were re-examined between December 2019 and January 2020. The CRPCD study protocol complied with the Declaration of Helsinki and received ethical approval from the Jiangsu Provincial Center for Disease Control and Prevention Ethics Committee (Approval No. 2013026).

For the current analysis, which focused on the relationship between green tea consumption and CVD risk among overweight or obese T2D patients, 5,744 participants aged 30–80 years with a BMI ≥ 24 kg/m² at baseline were selected. Exclusion criteria included:

1. Prior diagnosis of cancer (n = 29), coronary heart disease (n = 350), or stroke (n = 352);
2. Missing data on tea consumption (n = 13);

3. Consumption of non-green teas (e.g., black, oolong, dark, yellow, or other types) (n = 244).

After exclusions, 4,756 participants were included in the final dataset (Supplementary Fig. 1)

Assessment of Green Tea Consumption

Green tea intake was evaluated through a structured questionnaire adapted from previous research [10, 11, 13, 14]. Participants were initially asked whether they drank tea: usually ≥3 times per week, occasionally <3 times per week, or not at all. Those who reported tea drinking were asked additional questions regarding:

1. Age at first tea consumption;
2. Type of tea consumed most frequently (green, black, oolong, dark, yellow, or other);
3. Frequency and number of cups consumed daily, as well as the frequency of leaf replacement;
4. Amount of tea leaves used per serving, illustrated through reference images showing quantities in grams.

Daily tea leaf consumption was estimated by multiplying the amount per serving by frequency of intake. Based on responses, participants were categorized as non-consumers (no tea in the past year) or green tea consumers (≥3 times/week). Green tea drinkers were further stratified by daily intake (<2.5 g/day, 2.5–5 g/day, >5 g/day) and duration of tea drinking (<25 years, 25–40 years, >40 years).

Assessment of Covariates

Baseline data included sociodemographic factors (age, sex), lifestyle variables (smoking, alcohol use, physical activity), personal and family medical history, and medication use. Anthropometric measurements—weight, height, waist circumference, and blood pressure—were collected following standardized protocols. Body mass index (BMI) was computed as weight (kg)/height² (m^2).

Type 2 diabetes was diagnosed according to ADA criteria [18]: fasting plasma glucose (FPG) ≥7.0 mmol/L (126 mg/dL), random glucose ≥11.1 mmol/L (200 mg/dL), HbA1c ≥6.5%, or current use of antidiabetic medication verified by self-report and medication inventory. Physical activity below 150 minutes per week (3–5 days) was classified as non-regular exercise [19].

Education was grouped as low (no formal, primary, secondary, or technical/vocational) and high (college or university). Annual household income was dichotomized as <100,000 CNY or ≥100,000 CNY. Employment status was categorized as employed, unemployed, or retired, and marital status as currently married or not married. Dietary habits (meat, fruit, and vegetable intake) were evaluated via questionnaire [14–17].

Family history of CVD was defined as a self-reported diagnosis of coronary artery disease, heart failure, stroke, or peripheral vascular disease among first- or second-degree relatives. Family history of T2D was defined as having at least one affected close relative. Central obesity was defined as waist circumference ≥90 cm in men and ≥85 cm in women, based on the Chinese adult health standards (WS/T 428–2013) [20]. The presence of diabetic complications—such as retinopathy, neuropathy, nephropathy, or diabetic foot ulcers—was recorded [21, 22].

Laboratory Measurement

Fasting venous blood samples were collected and centrifuged at 2,000×g for 10 minutes at 4°C to obtain serum and plasma. Biochemical analyses included total cholesterol (TC), triglycerides (TG), and high-density lipoprotein cholesterol (HDL-C), measured with automated analyzers (Hitachi, Tokyo, Japan) using commercial kits [23]. The coefficient of variation (CV) for intra- and inter-assay precision was <10%. Low-density lipoprotein cholesterol (LDL-C) was estimated using the Friedewald formula: LDL-C = TC – HDL-C – TG/5 [24].

Fasting plasma glucose (FPG) was determined by the hexokinase method (Roche 702 Analyzer), and HbA1c was measured using the BIO-RAD VARIANT II system, with intra- and inter-assay CVs below 7.9% and 9.9%, respectively [25, 26].

Assessment of Study Outcomes

Participants were monitored from the baseline survey until December 31, 2020. Data on cardiovascular disease (CVD) outcomes were obtained using a structured physician-administered questionnaire, along with ICD-9 and ICD-10 diagnostic codes. These outcomes included both fatal and non-fatal coronary heart disease (CHD) — such as myocardial infarction (I21, I22) — and stroke events

including subarachnoid hemorrhage (I60), hemorrhagic stroke (I61), ischemic stroke (I63), and unspecified stroke (I64) [27].

Information on fatal cases, including the exact date and cause of death, was retrieved from the Cause of Death Registry of the Changshu Industrial Park Centers for Disease Control and Prevention.

Statistical Analysis

Data were summarized as means ± standard deviation (SD) for continuous variables or as percentages for categorical variables. The Student's t-test, Mann–Whitney U, or Kruskal–Wallis H tests were applied for continuous data, while Chi-square tests were used for categorical comparisons. P-values were corrected using the Benjamini–Hochberg (BH) method [28].

Missing baseline values for serum lipid profiles (n=24), vegetable intake (n=73), fruit intake (n=70), and meat intake (n=64) were estimated using multiple imputation [29]. Follow-up time for each participant was calculated from the date of the baseline questionnaire until the first CVD event, death, loss to follow-up, or December 31, 2020, whichever came first. Participants lost to follow-up without mortality data were assumed to be alive beyond that point.

To determine the relationship between green tea consumption and CVD risk, multivariable Cox proportional hazards models were used to estimate hazard ratios (HRs) and 95% confidence intervals (Cis). The proportional hazard assumption was verified using Schoenfeld residuals.

HRs were further computed for total CVD, CHD, and stroke based on daily tea intake categories (<2.5, 2.5–5, >5 g/day) and duration of tea consumption (<25, 25–40, >40 years).

Potential confounders were identified via a directed acyclic graph (DAG) (Supplementary Fig. 2) [30, 31].

Model 1: unadjusted.

Model 2: adjusted for age, sex, BMI, smoking, alcohol use, education, income, marital and employment status, physical activity, blood pressure, dyslipidemia, hypertension, medication use, and family history of CVD or T2D.

Model 3: further adjusted for HbA1c, fasting plasma glucose (FPG), T2D complications, and diabetes duration. Linear trends were examined using Wald tests, assigning median values to each exposure group. Sensitivity analyses included replacing BMI with waist circumference, adding TC and TG, and considering insulin use. Additional analyses assessed associations in patients with central obesity. The E-value approach [32, 33]

was also employed to quantify the possible influence of unmeasured confounding, representing the minimum association strength a confounder would require with both exposure and outcome to negate the observed association.

Subgroup analyses were conducted according to sex, age, household income, smoking status, and diabetes duration, with interaction terms added individually to test for effect modification regarding CVD, CHD, and stroke incidence.

All analyses were conducted using R software (version 4.1.0), and two-sided P-values <0.05 were considered statistically significant.

Results

Over a total follow-up period of 29,818.62 person-years, 915 new cardiovascular disease (CVD) events were recorded, including 625 stroke and 398 coronary heart disease (CHD) cases. The overall crude incidence rate of CVD was 30.69 cases per 1,000 person-years.

When compared to individuals who did not consume green tea, those who reported habitual green tea consumption were generally younger, predominantly male, and more likely to smoke or consume alcohol. They also tended to have lower waist circumference, higher blood pressure, longer duration of type 2 diabetes (T2D), and higher levels of fasting plasma glucose (FPG), HbA1c, and total cholesterol (TC), alongside lower HDL-C concentrations.

In addition, green tea consumers were typically more physically active, with higher intakes of red meat and fresh fruit, but lower vegetable consumption. No statistically significant differences were found between the two groups regarding family history of CVD or T2D (Table 1).

As presented in Table 2 and Supplementary Table 1, after adjusting for potential confounding factors, green tea consumption remained associated with variations in cardiovascular outcomes.

Table 1 (continued)

	Non- consumption (n = 2933)	Green tea consumption (n = 1823)	P_1-values/ Adjusted P_1-values	Daily green tea leaves consumption (g/day)			P_2-values/ Adjusted P_2-values	Duration of green tea consumption (years)			P_3-values/ Adjusted P_3-values
				<2.5	2.5–5	>5		< 25	25–40	>40	
Family history of T2D, n (%)	776 (26.5)	503 (27.6)	0.410/0.454	165 (26.2)	188 (28.8)	150 (27.8)	0.604/0.671	165 (35.1)	219 (26.8)	119 (22.2)	<0.001/0.002
T2D duration, years	6.26 ± 5.23	6.59 ± 5.52	0.041/0.064	6.50 ± 5.52	6.63 ± 5.58	6.79 ± 5.39	0.074/0.101	5.91 ± 5.13	6.49 ± 5.29	7.51 ± 6.01	<0.001/0.002
T2D complications, n (%)	445 (15.2)	275 (15.1)	0.968/0.968	76 (12.1)	103 (15.8)	96 (17.8)	0.051/0.077	57 (12.1)	116 (14.2)	102 (19.0)	0.017/0.021
HbA1c, %	7.49 ± 1.46	7.73 ± 1.53	< 0.001/0.002	7.71 ± 1.58	7.71 ± 1.48	7.90 ± 1.63	<0.001/0.002	7.71 ± 1.60	7.87 ± 1.57	7.65 ± 1.51	<0.001/0.002
FPG, mmol/L	8.59 ± 2.45	9.01 ± 2.66	< 0.001/0.002	9.01 ± 2.73	9.00 ± 2.70	9.03 ± 2.51	<0.001/0.002	9.22 ± 2.71	9.16 ± 2.76	8.61 ± 2.40	<0.001/0.002
TG, mmol/L	2.13 ± 1.69	2.22 ± 1.96	0.095/0.140	2.27 ± 2.05	2.15 ± 1.98	2.29 ± 1.99	0.114/0.143	2.39 ± 2.09	2.30 ± 2.04	1.98 ± 1.86	<0.001/0.002
TC, mmol/L	5.32 ± 1.15	5.24 ± 1.06	0.009/0.017	5.30 ± 1.07	5.18 ± 0.98	5.24 ± 1.14	0.011/0.021	5.33 ± 1.06	5.22 ± 1.03	5.18 ± 1.11	0.005/0.007
LDL - C, mmol/L	3.18 ± 0.89	3.16 ± 0.88	0.289/0.320	3.18 ± 0.92	3.14 ± 0.85	3.16 ± 0.88	0.674/0.722	3.19 ± 0.83	3.16 ± 0.90	3.14 ± 0.90	0.625/0.647
HDL - C, mmol/L	1.46 ± 0.35	1.36 ± 0.34	< 0.001/0.002	1.37 ± 0.34	1.37 ± 0.34	1.34 ± 0.33	<0.001/0.002	1.35 ± 0.33	1.34 ± 0.33	1.41 ± 0.35	<0.001/0.002

P_1: Continuous data were compared using the Student t-test, and Mann–Whitney U test, as appropriate. Categorical variables were compared using the χ^2 Chi-square test

P_2&P_3: Continuous data were compared using the Kruskal-Wallis H test. Categorical variables were compared using the χ^2 Chi-square test

CVD: Cardiovascular disease; T2D: Type 2 diabetes; FPG: Fasting plasma glucose; TC: Total cholesterol; TG: Triglycerides; LDL-C: low-density lipoprotein-cholesterol; HDL-C: high-density lipoprotein-cholesterol.

Currently married, n (%)	2910 (99.2)	1800 (98.7)	0.138/0.178	626 (99.4)	640 (98.0)	534 (98.9)	0.029/0.046	464 (98.7)	809 (99.0)	527 (98.3)	0.228/0.263
Regular physical activities, n (%)	1749 (59.6)	1131 (62.0)	0.105/0.148	372 (59.0)	425 (65.1)	334 (61.9)	0.054/0.077	260 (55.3)	508 (62.2)	363 (67.7)	<0.001/0.002
Red meat consumption ≥400 g/week, n (%)	816 (27.8)	677 (37.1)	<0.001/0.002	227 (36.0)	242 (37.1)	208 (38.5)	<0.001/0.002	177 (37.7)	296 (36.2)	204 (38.1)	<0.001/0.002
Fresh fruits consumption ≥400 g/week, n (%)	507 (17.3)	368 (20.2)	0.013/0.024	117 (18.6)	130 (19.9)	121 (22.4)	0.027/0.045	104 (22.1)	164 (20.1)	100 (18.7)	0.040/0.048
Fresh vegetables consumption ≥ 400 g/week, n (%)	2769 (94.4)	1683 (92.3)	0.005/0.010	589 (93.5)	602 (92.2)	492 (91.1)	0.012/0.021	429 (91.3)	753 (92.2)	501 (93.5)	0.016/0.021
Hypertension, n (%)	2524 (86.1)	1567 (86.0)	0.959/0.968	607 (87.0)	642 (85.7)	526 (84.8)	0.732/0.757	419 (78.9)	809 (86.0)	547 (91.9)	<0.001/0.002
Antihypertensive drugs, n (%)	1934 (65.9)	1169 (64.1)	0.213/0.264	447 (64.0)	463 (61.8)	413 (66.6)	0.143/0.172	304 (57.3)	590 (62.7)	429 (72.1)	<0.001/0.002
Dyslipidemia, n (%)	1430 (48.8)	956 (52.4)	0.015/0.026	382 (54.7)	371 (49.5)	333 (53.7)	0.010/0.020	304 (57.3)	512 (54.4)	270 (45.4)	<0.001/0.002
Lipid-lowering drugs, n (%)	53 (1.8)	57 (3.1)	0.004/0.009	18 (2.9)	13 (2.0)	26 (4.8)	<0.001/0.002	11 (2.3)	29 (3.5)	17 (3.2)	0.014/0.019
Oral hypoglycaemic agents, n (%)	2345 (80.0)	1491 (81.8)	0.128/0.173	512 (81.3)	532 (81.5)	447 (82.8)	0.404/0.466	378 (80.4)	676 (82.7)	437 (81.5)	0.322/0.358
Family history of CVD, n (%)	178 (6.1)	127 (7.0)	0.243/0.290	60 (8.6)	44 (5.9)	44 (7.1)	0.080/0.104	37 (7.0)	67 (7.1)	44 (7.4)	0.483/0.518

Green tea consumption demonstrated a significant inverse association with the risk of cardiovascular disease (CVD) among overweight and obese individuals with type 2 diabetes (T2D), showing a hazard ratio (HR) of 0.76 (95% CI: 0.63–0.91). Similarly, habitual green tea intake was linked to a notable reduction in stroke risk (adjusted HR: 0.77, 95% CI: 0.62–0.96) and coronary heart disease (CHD) (adjusted HR: 0.68, 95% CI: 0.52–0.90).

When daily green tea leaf intake was analyzed by category (<2.5 g, 2.5–5 g, and >5 g/day), participants who consumed more than 5 g of green tea leaves per day showed a markedly lower likelihood of developing CVD, stroke, or CHD compared with non-consumers. The adjusted HRs (95% Cis) were 0.71 (0.55–0.92) for total CVD, 0.70 (0.51–0.95) for stroke, and 0.60 (0.40–0.89) for CHD (Table 2, Supplementary Table 1).

Sensitivity analyses further confirmed these associations. The inverse relationship between daily tea intake and the risks of total CVD, stroke, and CHD remained consistent even after additional adjustments for insulin use, total cholesterol (TC), triglycerides (TG), or replacing BMI with waist circumference, as well as among individuals with central obesity (Supplementary Tables 2–4) Moreover, E-value analysis indicated that the observed associations were unlikely to be substantially influenced by unmeasured confounding. Most E-values for total CVD risk and tea consumption exceeded the HRs typically associated with major CVD risk factors such as hypertension, smoking, and alcohol intake (Supplementary Tables 5–6).

In terms of duration, participants who had consumed green tea for over 40 years exhibited a significantly lower risk of total CVD (HR: 0.69, 95% CI: 0.54–0.88), stroke (HR: 0.67, 95% CI: 0.50–0.90), and CHD (HR: 0.61, 95% CI: 0.42–0.88) (Table 2, Supplementary Table 1). These findings remained robust under additional adjustments for insulin, lipid levels, or waist circumference (Supplementary Tables 7–9). Similarly, the E-values for the duration of green tea intake exceeded the HRs of traditional CVD predictors, reinforcing the stability of this association (Supplementary Tables 5–6).Subgroup analyses revealed that the protective effect of green tea was particularly evident among older adults (≥65 years) (HR: 0.67, 95% CI: 0.48–0.93), non-smokers (HR: 0.64, 95% CI: 0.46–0.91), and participants with a T2D duration of less than 5 years (HR: 0.55, 95% CI: 0.35–0.86) (Fig. 1a). Corresponding associations between daily tea leaf intake and CVD incidence are illustrated in Figure 1b.

Table 2 Association between green tea consumption and the risk of CVD, stroke, and CHD

	Total CVD		Stroke		CHD	
	HR (95% CI)	Adjusted P_{values}	HR (95% CI)	Adjusted P_{values}	HR (95% CI)	Adjusted P_{values}
Green tea consumption						
Non- consumption	1		1		1	
Green tea consumers	0.76 (0.63–0.91)	0.003	0.77 (0.62–0.96)	0.020	0.68 (0.52–0.90)	0.006
Daily tea leaves consumption						
Non- consumption	1		1		1	
<2.5 g/day	0.79 (0.63–0.98)	0.034	0.81 (0.62–1.06)	0.127	0.72 (0.51–1.01)	0.06
2.5–5 g/day	0.76 (0.60–0.96)	0.024	0.78 (0.58–1.04)	0.094	0.70 (0.49–1.01)	0.054
>5 g/day	0.71 (0.55–0.92)	0.008	0.70 (0.51–0.95)	0.022	0.60 (0.40–0.89)	0.011
P trend		0.019		0.036		0.020
Duration of consumption						
Non- consumption	1		1		1	
<25 years	0.77 (0.58–1.01)	0.056	0.77 (0.55–1.07)	0.118	0.74 (0.49–1.12)	0.152
25–40 years	0.82 (0.65–1.03)	0.089	0.88 (0.67–1.16)	0.359	0.71 (0.49–1.01)	0.054
>40 years	0.69 (0.54–0.88)	0.002	0.67 (0.50–0.90)	0.008	0.61 (0.42–0.88)	0.009
P trend		0.003		0.015		0.005

Models were adjusted for covariates in age, sex, smoking status, alcohol consumption status, BMI, annual income, education, employment, marital status, physical exercise, SBP, DBP, dyslipidemia, hypertension,lipid-lowering drugs, antihypertensive drugs, oral hypoglycaemic agents, family history of CVD, family history of T2DM, times of weekly meat/fruit/vegetable consumption, HbA1c, FPG, diabetes duration, and diabetes complications.

A stronger inverse relationship between daily green tea leaf intake and the risk of CVD was particularly evident among participants with lower household income (HR: 0.47–0.996), older adults (≥65 years) (HR: 0.66, 95% CI: 0.45–0.99), and those with a T2D duration of less than 5 years (HR: 0.41, 95% CI: 0.23–0.72).

Regarding coronary heart disease (CHD), the protective association of green tea intake was especially pronounced in elderly participants (≥65 years) (HR: 0.52, 95% CI: 0.31–0.88), individuals with lower income levels (HR: 0.62, 95% CI: 0.39–0.99), non-smokers (HR: 0.35, 95% CI: 0.19–0.66), and participants with a T2D history of ≥5 years (HR: 0.50, 95% CI: 0.30–0.82) (Fig. 1c). In the multivariate model, significant interactions were detected between sex and daily tea consumption (P-interaction = 0.015), as well as between smoking status and tea intake (P-interaction = 0.021), in predicting future CHD risk.

As illustrated in Figure 2a, the duration of green tea consumption showed a clear negative association with CVD incidence, particularly among older adults (≥65 years) (HR: 0.65, 95% CI: 0.49–0.86), lower-income participants (HR: 0.71, 95% CI: 0.54–0.93), non-smokers (HR: 0.69, 95% CI: 0.51–0.94), and those with <5 years of T2D (HR: 0.52, 95% CI: 0.34–0.80).

Furthermore, a significant relationship between the duration of green tea intake and stroke risk was observed among males (HR: 0.65, 95% CI: 0.45–0.94), older individuals (≥65 years) (HR: 0.64, 95% CI: 0.46–0.90), participants with lower household income (HR: 0.69, 95% CI: 0.49–0.98), smokers (HR: 0.56, 95% CI: 0.32–0.996), and those with a shorter duration of diabetes (<5 years) (HR: 0.43, 95% CI: 0.26–0.74) (Fig. 2b).

As presented in Figure 2c, the association between long-term green tea consumption and incident CHD was more strongly inverse among females (HR: 0.27, 95% CI: 0.09–0.86), elderly individuals (≥65 years) (HR: 0.54, 95% CI: 0.35–0.82), lower-income participants (HR: 0.65, 95% CI: 0.43–0.99), non-smokers (HR: 0.52, 95% CI: 0.31–0.85), and patients with ≥5-year T2D duration (HR: 0.54, 95% CI: 0.35–0.85). Notably, a significant interaction between sex and tea-drinking duration on CHD risk was found (P-interaction = 0.031).

Moreover, as shown in Table 3, there was no combined effect between the amount and duration of green tea consumption on the risk of total CVD, stroke, or CHD in overweight or obese T2D participants during the follow-up, when compared to those consuming less than 2.5 g/day for under 30 years.

Discussion

This large-scale community-based cohort study provides compelling new evidence supporting the cardio protective effects of green tea among overweight and obese patients with type 2 diabetes. The main findings can be summarized as follows:

1. Green tea consumption was significantly associated with a lower risk of total CVD, CHD, and stroke in this population, and both higher intake and longer duration of tea drinking amplified the benefit.
2. Among participants with a diabetes duration of less than 5 years, green tea intake was strongly linked to a reduction in stroke risk.
3. Among those with ≥5 years of diabetes, green tea consumption was related to a marked decline in CHD risk.
4. However, there was no evidence of a joint or synergistic effect between the quantity and duration of tea intake on cardiovascular outcomes.

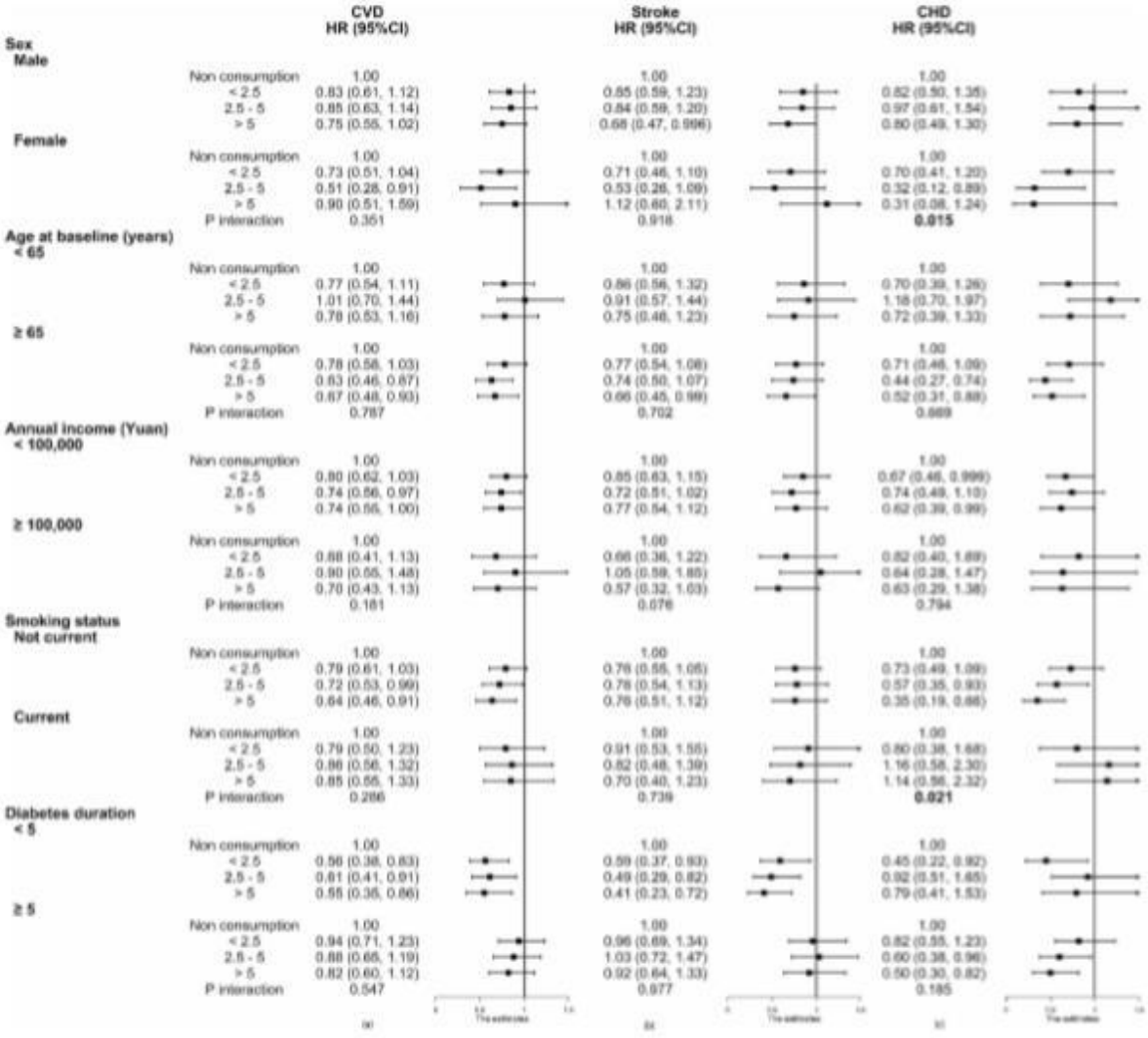

Fig. 1 Subgroup analysis of associations between daily consumption of green tea leaves and the risk of total CVD (**a**), stroke (**b**), and CHD (**c**) according to potential baseline risk factors. Values were obtained from Cox proportional hazards analysis. Except for the baseline stratifying variable, the model was adjusted for the same covariates as in the model of Table 2

The amount and duration of green tea consumption showed no significant combined effect on the risk of total cardiovascular disease (CVD), coronary heart disease (CHD), or stroke among overweight or obese patients with type 2 diabetes (T2D). As one of the most widely consumed beverages in China

Green tea is rich in polyphenols, theaflavins, and other antioxidants with potential health benefits. For instance, Li et al. reported that Thea Flavin can alleviate cerebral ischemia/reperfusion injury by inhibiting miRNA-128-3p–mediated suppression of Nrf2 and reducing oxidative stress.

Therefore, our findings support the hypothesis that habitual green tea consumption may offer protective effects against the development of CVD, CHD, and stroke. Over the past decades, several epidemiological studies have investigated the relationship between habitual tea consumption and the risks of CVD, stroke, and CHD. While some studies have suggested that green tea intake is associated with a reduced risk of myocardial infarction and stroke among diabetic individuals, findings from the China Kadoorie Bio bank study indicated no association between green tea consumption and microvascular complications in diabetic patients.

In the present study, however, our results demonstrated that green tea consumption was linked to a lower risk of CVD, CHD, and stroke. Considering that the risks of these diseases are significantly higher in overweight or obese T2D patients compared to non-obese diabetic patients and the general population, we speculate that variations in previous study outcomes may be attributed to differences in participant characteristics.

Table 3 The combined effect of the amount and duration of green tea consumption on the risk of CVD, stroke, and CHD

Daily consumption of tea leaves	Duration of tea consumption	Cases	Cases/PYs (/1000)	HR (95% CI)	Adjusted $P_{-values}$
Total CVD					
< 2.5 g/day	< 30 years	40	21.98	1	
	≥ 30 years	76	35.53	1.08 (0.73–1.60)	0.699
≥ 2.5 g/day	< 30 years	52	21.16	0.96 (0.63–1.46)	0.847
	≥ 30 years	168	33.25	0.99 (0.691.43)	0.977
Stroke					
< 2.5 g/day	< 30 years	28	15.39	1	
	≥ 30 years	53	24.78	1.08 (0.67–1.72)	0.761
≥ 2.5 g/day	< 30 years	36	14.65	0.98 (0.59–1.62)	0.937
	≥ 30 years	112	22.16	0.95 (0.61–1.46)	0.805
CHD					
< 2.5 g/day	< 30 years	18	9.89	1	
	≥ 30 years	30	14.02	0.95 (0.52–1.73)	0.862
≥ 2.5 g/day	< 30 years	20	8.14	0.80 (0.42–1.53)	0.507
	≥ 30 years	69	13.65	0.90 (0.52–1.54)	0.700

Models were adjusted for covariates in age, sex, smoking status, alcohol Consumption status, BMI, annual income, education, employment, marital Status, physical exercise, SBP, DBP, dyslipidemia, hypertension,lipid-lowering Drugs, antihypertensive drugs, oral hypoglycaemic agents, family historyOf CVD, family history of T2DM, times of weekly meat/fruit/vegetable Consumption, HbA1c, FPG, diabetes duration, and diabetes complication

The stratified analysis revealed that the inverse relationship between green tea consumption and cardiovascular disease (CVD) was more pronounced among non-smokers, older adults (≥65 years), and participants with a diabetes duration of less than five years. Moreover, this study is the first to identify potential modifying effects of sex and smoking status on the association between green tea intake and coronary heart disease (CHD).

A possible explanation for these findings is that individuals with CVD who habitually consume green tea often exhibit less favorable lifestyle behaviors, such as cigarette smoking and alcohol consumption. Supporting this, a large Chinese cohort study involving 164,681 men by Liu et al. found that regular green tea consumption was inversely associated with CVD risk among non-smokers and those who did not drink alcohol regularly—consistent with our current results.

To our knowledge, this is the first prospective cohort study to examine the effects of green tea consumption on total CVD, CHD, and stroke risk in overweight or obese patients with type 2 diabetes (T2D). The study's strengths include its prospective design, large sample size, extended follow-up period, and comprehensive adjustment for multiple confounders. Additionally, both the average daily intake (g/day) and duration of green tea consumption were quantified, providing a more accurate reflection of bioactive compound exposure.

However, several limitations should be acknowledged. First, green tea intake was self-reported, which may have led to recall bias and inaccurate estimations of actual consumption. Moreover, both green tea intake and other covariates were measured only at baseline, and changes over time prior to CVD events were not captured. Second, the study population—middle-aged and older Chinese individuals who were overweight or obese and had T2D—may limit the generalizability of the findings to other populations with different demographic or health characteristics. Third, although our findings suggest a protective effect of green tea on CVD, CHD, and stroke, the influence of other tea types (such as black tea) could not be fully assessed due to small sample sizes.

Fourth, despite adjusting for many potential confounders, residual confounding cannot be completely ruled out. Factors such as geographic location (urban vs. rural), dietary habits (e.g., sodium and sugar intake), environmental exposures (e.g., air pollution or heavy metals), timing of tea consumption, and specific tea varieties were not fully accounted for. Nevertheless, the E-value analysis suggested that unmeasured confounders were unlikely to completely explain the observed associations, indicating that the relationship between green tea consumption and reduced CVD risk among overweight or obese T2D patients was robust.

Finally, the underlying biological mechanisms remain unclear. For instance, while the duration of green tea consumption was inversely associated with CVD among non-drinkers, higher daily intake of tea leaves was significantly linked to lower CVD risk among current alcohol consumers. Similarly, green tea intake showed a protective effect against CVD in participants with hypertension but not in those with normal blood pressure, suggesting complex interactions between traditional cardiovascular risk factors and green tea consumption.

Conclusions

In summary, this community-based cohort study Revealed that green tea consumption has protective

Effects on the development of total CVD, CHD, and Stroke in overweight/obese T2D patients. If our present Findings are validated in other populations, it will sup-Port the recommendation of green tea consumption as A healthy habit to protect against CVD in T2D patients With overweight/obesity.

Abbreviations

CVD Cardiovascular disease

CHD Coronary heart disease

T2D Type 2 diabetes

HR Hazard ratios

95% Cis 95% confidence intervals

BMI Body mass index

SBP Systolic blood pressure

DBP Diastolic blood pressure

FPG Fasting plasma glucose

WC Waist circumference

TC Total cholesterol

TG Triglycerides

LDL-C Low-density lipoprotein-cholesterol

HDL-C High-density lipoprotein-cholesterol

BH Benjamin–Hochberg

DAG Directed acyclic graph

Supplementary Information

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Supplementary Material 1

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Author contributions

CD and JZ contributed to the conception and design of the study; BL, SG, JZ, and CD contributed to manuscript drafting; BL, SG, HZ, JZ, SW, JJ, QS,And ZZ contributed to the statistical analysis; QS, JZ, and JS contributed to The acquisition of data; BL, JZ, and CD contributed to critical revisions of the Manuscript. All authors read and approved the final manuscript.

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Data availability

All data and materials presented in this research paper are available by Contacting the corresponding author upon request.

Declarations

Ethics approval and consent to participate

The study protocol of CRPCD adhered to the Declaration of Helsinki and Was approved by the institutional review board and ethics committee of the Jiangsu Provincial Centers for Disease Control and Prevention (No. 2013026).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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