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Association between tea consumption and glucose metabolism and insulin secretion in the Shanghai High-risk Diabetic Screen (SHiDS) study

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ABSTRACT

Introduction The relationship between tea consumption and glucose metabolism remains controversial. This study investigated the associations of tea consumption with impaired glucose regulation, insulin secretion and sensitivity in Shanghai High-risk Diabetic Screen project.

Research design and methods A total of 2337 Chinese subjects were enrolled in the study from 2014 to 2019. Each participant conducted a 75 g oral glucose tolerance test (OGTT) with five-point glucose and insulin level examined. They also completed a nurse-administered standard questionnaire including tea, coffee, and alcohol consumption, smoking habit, physical activity, education, sleep quality, etc.

Results The result showed that tea consumption was positively associated with plasma glucose levels during OGTT after adjusting for confounder (Ps <0.05) and was associated with worsening glucose tolerance (OR 1.21, 95% CI 1.01–1.44; p=0.034). Strong tea consumption or long-term tea intake (>10 years) had an increased risk of glucose intolerance (all p<0.05). These associations did not vary in participants drinking green tea. In addition, insulin secretion indexes were decreased 7.0%–13.0% in tea consumption group. Logistic regression analysis showed that tea consumption was independently associated with lower insulin secretion (homeostasis model assessment of β-cell function (HOMA-β) (OR 0.81, 95% CI 0.68–0.97; p=0.021); Stumvoll first-phase index (OR 0.81, 95% CI 0.68–0.97; p=0.020)) in a fully adjusted model. Green tea consumption showed a negative association with insulin secretion (HOMA-β (OR 0.77, 95% CI 0.62–0.96; p=0.019)).

Conclusions Tea intake is associated with an increased risk of glucose intolerance in a large high-risk diabetic Chinese population. Habitual tea consumption subjects might have lower pancreatic β-cell function.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Epidemiological studies on the relationship between type 2 diabetes and intake of tea have yielded inconsistent results. The relationship between glucose metabolism and tea consumption has not been thoroughly investigated in China, especially in a high-risk population for diabetes.

WHAT THIS STUDY ADDS

⇒ Tea and green tea consumption is associated with worsening glucose tolerance and insulin secretion in a large high-risk diabetic Chinese population.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our observation study cannot prove a cause–effect relationship; further studies are required to be done on the effects of tea consumption on glucose homeostasis and insulin secretion and resistance.

INTRODUCTION

Diabetes is one of the major public health issues across the world. According to the International Diabetes Federation, the global prevalence of diabetes among adults in 2021 was estimated to be 10.5% (536.6 million) and the prevalence is expected to rise to 12.2% (783.2 million) in 2045.[1] The prevalence of diabetes is also increasing dramatically in China partly due to rapid nutrition transitions among Chinese people.[2]

Tea is one of the most consumed beverages worldwide. The effects of tea consumption on metabolic syndrome, obesity, cardiovascular diseases and type 2 diabetes mellitus (T2DM) have been investigated through observational and interventional research.[3–6] Although accumulating evidence suggested that tea may be beneficial to health,[7] epidemiological studies on the relationship between type 2 diabetes and intake of tea have yielded inconsistent results. In a large Dutch prospective study, participants who frequently drank tea had a lower risk of developing diabetes over a 10-year follow-up.[8] However, another prospective study involving 119 373 Chinese adults showed that consumption of green tea was associated with an increased risk of diabetes.[9] Moreover, various kinds of tea may have different impacts on T2DM. In a

Table 1 General characteristics of study participants.

Characteristics	Non-drinkers (N=1389)	Tea drinkers (N=948)		Green tea drinkers (N=499)	
		Description	P value	Description	P value
Age (years)	49.3 (15.47)	50.9 (12.96)	0.012	53.2 (13.15)	<0.001
Age, years, n (%)			<0.001		<0.001
18–39	462 (33.26)	216 (22.78)		89 (17.84)	
40–59	478 (34.41)	446 (47.05)		221 (44.29)	
>60	449 (32.33)	286 (30.17)		189 (37.88)	
Gender, n (%)			<0.001		<0.001
Male	401 (28.87)	516 (54.43)		283 (56.71)	
Female	988 (71.13)	432 (45.57)		216 (43.29)	
BMI (kg/m^2)	24.13 (4.00)	24.93 (3.66)	<0.001	25.01 (3.58)	<0.001
BMI, kg/m^2, n (%)			<0.001		<0.001
<24	720 (51.95)	397 (41.92)		204 (40.88)	
24–27.99	459 (33.12)	386 (40.76)		208 (41.68)	
>28	207 (14.94)	164 (17.32)		87 (17.43)	
Blood pressure (mm Hg)					
SBP	130.43 (17.42)	131.07 (17.04)	0.494	131.73 (16.68)	0.148
DBP	79.34 (11.22)	80.01 (11.02)	0.530	80.02 (10.44)	0.553
Hypertension, n (%)					
Yes	626 (45.07)	447 (47.15)	0.321	235 (47.09)	0.436
No	763 (54.93)	501 (52.85)		264 (52.91)	
Family history of diabetes, n (%)					
Yes	321 (23.11)	255 (26.90)	0.037	131 (26.25)	0.159
No	1068 (76.89)	693 (73.10)		368 (73.75)	
History of dyslipidemia (%)					
Yes	331 (23.83)	317 (33.44)	<0.001	171 (34.27)	<0.001
No	1058 (76.17)	631 (66.56)		328 (65.73)	
Alcohol consumption, n (%)			<0.001		<0.001
Yes	105 (7.60)	211 (22.30)		117 (23.49)	
No	1277 (92.40)	735 (77.70)		381 (76.51)	
Coffee drinking, n (%)			<0.001		<0.001
Yes	332 (23.94)	475 (50.16)		233 (46.69)	
No	1055 (76.06)	472 (49.84)		266 (53.31)	
Smoking status, n (%)			<0.001		<0.001
Daily	65 (4.69)	160 (16.95)		81 (16.30)	
Occasional	26 (1.88)	40 (4.24)		18 (3.62)	
Never	1294 (93.43)	744 (78.81)		398 (80.08)	
Physical activity at work, n (%)			0.001		0.297
High	12 (0.87)	5 (0.53)		3 (0.60)	
Moderate	64 (4.62)	25 (2.64)		15 (3.01)	
Low	636 (45.89)	505 (53.27)		246 (49.30)	
None/unemployed	674 (48.63)	413 (43.57)		235 (47.09)	
Leisure-time physical activity, n (%)			0.198		0.214
High	12 (0.88)	18 (1.91)		10 (2.02)	
Moderate	130 (9.52)	88 (9.36)		43 (8.70)	
Low	939 (68.79)	642 (68.30)		334 (67.61)	

Continued

Table 1 Continued

Characteristics	Non-drinkers (N=1389)	Tea drinkers (N=948)		Green tea drinkers (N=499)	
		Description	P value	Description	P value
None	284 (20.81)	192 (20.43)		107 (21.66)	
Education, n (%)			<0.001		0.031
Bachelor's degree or higher	716 (52.07)	565 (60.36)		275 (55.67)	
High school	576 (41.89)	343 (36.65)		203 (41.09)	
Primary school	68 (4.95)	24 (2.56)		14 (2.83)	
Illiterate	15 (1.09)	4 (0.43)		2 (0.40)	
PSQI score	4.83 (3.30)	4.54 (2.90)	0.347	4.73 (2.95)	0.647

Data are presented as mean (SD) or median (IQR) for continuous variables and n (%) for categorical variables.
BMI, body mass index; DBP, diastolic blood pressure; PSQI, Pittsburgh Sleep Quality Index; SBP, systolic blood pressure.

Japanese cohort study, Iso *et al* only found a decreased risk of diabetes among people who consumed green tea but not black tea or oolong tea.[10]

It is well known that insulin resistance and pancreatic β-cell dysfunction are the two main pathophysiological changes underlying the development of type 2 diabetes. However, the role of tea consumption in relation to pathogenesis of diabetes is still debatable. Clinical trials showed a beneficial effect of different types of teas on increasing insulin sensitivity[11–13] while some other trials did not confirm this observation.[14 15] For insulin secretion, although in vitro study showed green tea or green tea extract can protect against the damage of pancreatic islets and maintain insulin secretion,[16] a cross-sectional study observed no association between green tea consumption and insulin secretion.[17]

Although diet plays an important part in the development of diabetes, the relationship between glucose metabolism and tea consumption has not been thoroughly investigated in China, especially in a high-risk population for diabetes. Thus, we analyzed the associations of tea consumption with impaired glucose regulation in Shanghai High-risk Diabetic Screen (SHiDS) project. In addition, the relationship between tea consumption and insulin secretion as well as insulin resistance was also analyzed.

RESEARCH DESIGN AND METHODS

Study design and subjects

The study population was selected from SHiDS project. Details of this study have been described previously.[18–22] Briefly, the SHiDS study was initiated in 2002 aiming to identify diabetes in subjects with known risk factors, that is, family history of diabetes, overweight or obesity, previously identified impaired fasting glucose or impaired glucose tolerance, history of gestational diabetes, polycystic ovary syndrome, hypertension, and dyslipidemia. Patients with previously diagnosed diabetes were not invited. At the first stage, demographic characteristics, anthropometric parameters and family histories of diabetes were collected. More comprehensive information on lifestyle characteristics, depressive symptoms as well as sleep quality assessment has been available since 2014. For the present study, a total of 2337 people who completed the questionnaires and have the information of tea intake were enrolled from March 2014 to February 2019.

Data collection and calculation

Each participant conducted a nurse-administered standard questionnaire[22 23] (online supplemental figure 1). Detailed information included demographics, tea, coffee and alcohol consumption, smoking habit, physical activity, family history of diabetes, history of dyslipidemia, depressive symptoms, sleep quality, etc. Tea drinkers were defined as subjects who drink tea daily. Those who drink green tea only were classified as green tea drinkers. The amount of tea consumption was classified into three groups: <1 cup/day, 1–2 cups/day, and >2 cups/day; and 1 cup is defined as 250 mL. Tea concentrations were defined as light (<1 g of tea/cup), medium (1–3 g of tea/cup), and strong (>3 g of tea/cup). The duration of tea drinking was classified into four groups: <1 year, 1–5 years, 6–10 years and >10 years. Coffee drinkers were defined as subjects who occasionally or often drink coffee. Participants who drank alcohol at least 12 times in the last 12 months were defined as alcohol consumers. Smoking habit was classified into three groups: daily, occasionally and never. Physical activities at work and at leisure time were classified into four groups: high, moderate, low and none. A history of family positive for diabetes was defined as a diabetic diagnosis in a first-degree relative of the participant.[18] The Patient Health Questionaire-9 depression scale was used to measure depressive symptoms.[24] The Pittsburgh Sleep Quality Index (PSQI) score was used to measure sleep quality among participants.[25]

Standard 75 g oral glucose tolerance test (OGTT), physical examination, anthropometric parameters, and blood sampling at 0, 30, 60, 120 and 180 min during OGTT were performed in each participant. Plasma glucose levels were assessed using a glucose oxidase method and serum insulin levels were examined using a chemical

Table 2 Glucose, insulin and derived indexes during OGTT in study participants

Characteristics	Non-drinkers (N=1389)	Tea drinkers (N=948)		Green tea drinkers (N=499)	
		Description	P value	Description	P value
Plasma glucose level during OGTT (mmol/L)					
FPG	6.0 (1.38)	6.5 (1.69)	<0.001	6.5 (1.78)	<0.001
PG30min	10.2 (2.30)	10.9 (2.52)	<0.001	11.0 (2.58)	<0.001
PG1h	11.7 (3.62)	12.7 (3.88)	<0.001	12.8 (3.90)	<0.001
PG2h	10.1 (4.33)	11.1 (4.79)	<0.001	11.2 (4.84)	<0.001
PG3h	7.2 (3.64)	7.4 (4.04)	0.970	7.4 (4.09)	0.953
Plasma insulin level during OGTT (μIU/mL)					
FIN	10.8 (7.72)	11.5 (7.89)	0.009	11.3 (7.55)	0.167
IN30min	65.8 (56.81)	64.3 (64.37)	0.035	61.9 (54.79)	0.014
IN1h	86.9 (64.25)	88.5 (72.53)	0.561	86.6 (72.25)	0.095
IN2h	96.0 (75.09)	96.6 (75.11)	0.847	95.2 (72.95)	0.556
IN3h	49.1 (47.17)	44.1 (43.62)	0.002	42.6 (44.66)	<0.001
HbA1c					
mmol/mol	42.3 (10.51)	45.0 (12.04)	<0.001	45.5 (12.90)	<0.001
%	6.0 (0.96)	6.3 (1.10)	<0.001	6.3 (1.18)	<0.001
Glucose tolerance categories, n (%)			<0.001		<0.001
Normal glucose tolerance	460 (33.12)	233 (24.58)		110 (22.04)	
Pre-diabetes	420 (30.24)	286 (30.17)		154 (30.86)	
Newly diagnosed diabetes	509 (36.65)	429 (45.25)		235 (47.09)	
OGTT-derived indexes					
Modified Matsuda index	67.9 (45.5, 105.0)	63.2 (42.1, 91.5)	<0.001	63.4 (43.2, 92.4)	0.008
HOMA-IR	2.4 (1.5, 3.8)	2.7 (1.8, 4.1)	<0.001	2.6 (1.8, 4.0)	<0.001
HOMA-β	78.6 (49.5, 126.3)	72.8 (47.1, 116.2)	0.017	68.5 (44.5, 110.4)	0.002
Stumvoll first-phase index	828.2 (287.3, 1265.4)	720.6 (13.0, 1190.5)	<0.001	658.8 (–5.1, 1158.1)	<0.001
Stumvoll second-phase index	247.8 (122.1, 349.2)	225.7 (69.9, 346.7)	0.005	213.5 (59.6, 334.6)	0.001

Data are presented as mean (SD) or median (IQR) for continuous variables and n (%) for categorical variables.
FIN, fasting serum insulin; FPG, fasting plasma glucose; HbA1c, glycosylated hemoglobin A1c; HOMA-IR, homeostasis model assessment of insulin resistance; HOMA-β, homeostasis model assessment of β-cell function; IN1h, 1-hour postprandial serum insulin; IN2h, 2-hour postprandial serum insulin; IN3h, 3-hour postprandial serum insulin; IN30min, 30 min postprandial serum insulin; OGTT, oral glucose tolerance test; PG1h, 1-hour postprandial plasma glucose; PG2h, 2-hour postprandial plasma glucose; PG3h, 3-hour postprandial plasma glucose; PG30min, 30 min postprandial plasma glucose.

luminescence method. Glycated hemoglobin (HbA1c) was assayed by high-performance liquid chromatography (HLC-723 G7, Tosoh, Japan).

Subjects were classified as normal glucose tolerance (fasting plasma glucose (FPG) <6.1 mmol/L and 2-hour plasma glucose (PG2h) <7.8 mmol/L), pre-diabetes (FPG ≥6.1 and <7.0 mmol/L, and/or PG2h ≥7.8 and <11.1 mmol/L), and diabetes (FPG ≥7.0 mmol/L and/or PG2h ≥11.1 mmol/L) according to 1999 WHO criteria.[26] The definitions of overweight (body mass index (BMI) ≥24 kg/m^2) and obesity (BMI ≥28 kg/m^2) were based on the 2002 Working Group on Obesity in China criteria.[27] Hypertension was defined as systolic blood pressure of at least 140 mm Hg, or diastolic blood pressure of at least 90 mm Hg, or self-reported antihypertensive medication use in the previous 2 weeks.[28]

For OGTT-derived indices of insulin secretion, we calculated the homeostasis model assessment of β-cell function (HOMA-β) index[29] and Stumvoll first-phase and second-phase indexes.[30] We also calculated the homeostasis model assessment of insulin resistance (HOMA-IR)[29] and the modified Matsuda index for whole body insulin sensitivity.[31]

Statistical analysis

Data were presented as mean (SD), median (Q1–Q3) or frequency (%). Student's t-test and Pearson's χ^2 test were used to compare differences of continuous and categorical variables, respectively. Wilcoxon rank-sum test was used for variables that were not normally distributed and Cochran-Mantel-Haenszel (CMH) χ^2 test was used for the ordered categorical variables. Logistic regression

Table 3 Associations of tea drinking with glucose levels using multivariate liner regression model

	Tea drinking		Green tea drinking	
	β	P value	β	P value
FPG	0.292	<0.001	0.318	<0.001
PG30min	0.370	<0.001	0.407	0.002
PG1h	0.484	0.003	0.491	0.013
PG2h	0.484	0.016	0.534	0.016
PG3h	0.197	0.259	0.208	0.259
FIN	−0.013	0.968	−0.113	0.780
IN30min	−3.050	0.254	−3.422	0.267
IN1h	−2.684	0.369	−3.017	0.408
IN2h	−3.787	0.258	−4.489	0.273
IN3h	−2.894	0.162	−4.053	0.117

Model adjusted for categorical age, gender, categorical body mass index (BMI), alcohol consumption, coffee drinking, smoking status, education, family history of diabetes, history of dyslipidemia and physical activity at work.
FIN, fasting serum insulin; FPG, fasting plasma glucose; IN1h, 1-hour postprandial serum insulin; IN2h, 2-hour postprandial serum insulin; IN3h, 3-hour postprandial serum insulin; IN30min, 30 min postprandial serum insulin; PG1h, 1-hour postprandial plasma glucose; PG2h, 2-hour postprandial plasma glucose; PG3h, 3-hour postprandial plasma glucose; PG30min, 30 min postprandial plasma glucose.

was used to assess the association between tea drinking or green tea drinking and diabetes, considering possible confounders. Tests for trend were performed by entering ordered categorical variables as continuous variables into the model. Besides, linear multivariate models were used to test the simultaneous dependence of OGTT glucose levels or insulin levels on tea/green tea drinking and other parameters; and we also considered the associations between the tertiles of β-cell function or insulin resistance and tea/green tea drinking. Statistical analyses were performed using SAS V.9.4 (SAS Institute) and all reported p values were two tailed and p≤0.05 was considered statistically significant.

RESULTS

General clinical characteristics of the participants stratified by tea consumption

Table 1 presents the general characteristics of study population according to the consumption of tea. Tea drinkers tended to be older, male, smokers, alcohol consumers, coffee drinkers (all p<0.001) and had a lower level of physical activity at work (p=0.001), higher BMI, higher education level, positive history of dyslipidemia and family history of diabetes compared with people who did not drink tea (all p<0.05). The levels of leisure-time physical activity, blood pressure and PSQI score were comparable between tea drinkers and non-drinkers (all p>0.05). Among 948 tea consumers, there were 499 who drank green tea. Similar results were observed in green tea drinker group except for the level of physical activity at work (p=0.297) and family history of diabetes (p=0.159).

In terms of glucose metabolism (table 2), both tea and green tea consumers had higher FPG, 30 min postprandial plasma glucose (PG30min), 1-hour postprandial plasma glucose (PG1h), and PG2h during OGTT (all p<0.001), so as the HbA1c level (p<0.001). For serum insulin levels, tea consumers had higher FIN. However, tea and green tea consumers had lower IN30min and IN3h during OGTT (table 2). Both tea and green tea intake groups had higher prevalence of newly diagnosed diabetes (p<0.001).

Pancreatic β-cell function and insulin resistance were estimated by HOMA and Stumvoll indexes (table 2). The results showed the HOMA-IR level was higher in the tea and green tea intake groups (p<0.001), while modified Matsuda index (p<0.001), HOMA-β (p=0.017), and Stumvoll first-phase (p<0.001) and second-phase indexes (p=0.005) were lower in the tea and green tea consumption groups. These implied that both tea and green tea drinkers had lower insulin secretion level (HOMA-β, Stumvoll first-phase and second-phase indexes) and higher insulin resistance (HOMA-IR, modified Matsuda index).

Linear regression analysis of tea consumption with plasma glucose levels

The associations between tea consumption and plasma glucose and serum insulin levels during OGTT were further analyzed by linear regression with adjusted model (table 3). The result showed that tea consumption was positively associated with plasma glucose levels (FPG, PG30min, PG1h and PG2h) during OGTT after adjusting for age, gender, BMI, alcohol consumption, coffee drinking, smoking status, education level, family history of diabetes, history of dyslipidemia and physical activity at work (all p<0.05). However, no correlation was observed between 3-hour OGTT plasma glucose level, serum insulin levels and tea consumption. These associations did not vary in participants drinking green tea.

Logistic regression analysis of tea consumption with risk of worsening glucose tolerance

The association between tea consumption and glucose intolerance (normal, pre-diabetes, diabetes) was also analyzed by ordinal logistic regression (table 4). Tea consumption was associated with worsening glucose tolerance after adjusting for age, gender, BMI, alcohol consumption, coffee consumption, smoking status, education level, family history of diabetes, history of dyslipidemia and physical activity at work (OR 1.21, 95% CI 1.01–1.44; p=0.034). Compared with non-tea consumers, participants who consumed 1–2 cups of tea per day had a higher risk of worsening glucose intolerance. In addition, positive associations between glucose intolerance and tea concentration and duration of tea consumption were also found (p value for trend <0.05). People who

Table 4 Associations of tea drinking or green tea drinking with risk of glucose metabolism impaired

	Tea drinking		Green tea drinking	
	OR (95% CI)	P value	OR (95% CI)	P value
Tea/green tea drinking				
Non-drinkers	1.00 (reference)		1.00 (reference)	
Drinkers	1.21 (1.01, 1.44)	0.034	1.25 (1.01, 1.54)	0.045
Amount of tea consumption (cups/day)				
<1	1.00 (reference)		1.00 (reference)	
1–2	1.61 (1.23, 2.12)	0.001	1.56 (1.10, 2.20)	0.012
>2	1.11 (0.92, 1.35)	0.277	1.18 (0.92, 1.51)	0.190
P value for trend		0.166		0.088
Tea concentrations				
Light	1.00 (reference)		1.00 (reference)	
Medium	1.03 (0.78, 1.36)	0.841	1.13 (0.78, 1.65)	0.512
Strong	1.76 (1.15, 2.70)	0.010	2.70 (1.40, 5.21)	0.003
P value for trend		0.034		0.012
Duration of tea drinking (years)				
Non-drinkers	1.00 (reference)		1.00 (reference)	
<1	0.96 (0.61, 1.51)	0.853	1.05 (0.61, 1.82)	0.855
1–5	1.20 (0.90, 1.59)	0.209	1.25 (0.84, 1.84)	0.272
6–10	1.29 (0.91, 1.84)	0.155	1.21 (0.74, 1.98)	0.437
>10	1.27 (1.02, 1.58)	0.033	1.31 (0.99, 1.72)	0.056
P value for trend		0.016		0.035

Model adjusted for categorical age, gender, categorical body mass index (BMI), alcohol consumption, coffee drinking, smoking status, education, family history of diabetes, history of dyslipidemia and physical activity at work.

consumed strong tea were associated with higher risk of glucose intolerance as compared with people drinking light tea (OR 1.76, 95% CI 1.15–2.70; p=0.010). Participants who had drunk tea for more than 10 years had an increased risk of glucose intolerance (OR 1.27, 95% CI 1.02–1.58; p=0.033). Similar associations were also found in the green tea consumers.

Logistic regression analysis about the relationship of tea consumption and β-cell function and insulin resistance

Logistic regression was conducted to analyze the relationship of tea consumption and insulin secretion and resistance (table 5). Insulin secretion and resistance indexes were expressed in tertiles and were taken as dependent variables. Tea drinking, categorical age, gender, categorical BMI, alcohol consumption, smoking status, education level, family history of diabetes, history of dyslipidemia and physical activity at work were taken as independent variables. After adjusting for confounders, the result showed tea consumption was positively associated with insulin resistance index of HOMA-IR (OR 1.20, 95% CI 1.02–1.42; p=0.032). However, tea consumption was not significantly associated with insulin resistance index of modified Matsuda index (p>0.05) and insulin secretion (HOMA-β, Stumvoll first-phase and second-phase indexes, all p>0.05). Moreover, green tea consumption was not significantly associated with insulin secretion and resistance (all p>0.05). Coffee consumption was further added as an independent variable. Tea consumption was negatively associated with insulin secretion (HOMA-β (OR 0.81, 95% CI 0.68–0.97; p=0.021); Stumvoll first-phase index (OR 0.81, 95% CI 0.68–0.97; p=0.020)), but no longer significantly associated with insulin resistance. In addition, green tea consumption showed a negative association with insulin secretion (HOMA-β (OR 0.77, 95% CI 0.62–0.96; p=0.019)).

DISCUSSION

As far as we know, this is the first observational study on the relationship of tea consumption and glycemic control as well as its pathophysiology in high diabetic risk individuals with detailed glucose and insulin levels during OGTT. According to the study, about 40.6% of subjects had the habit of drinking tea and green tea which accounted for 21.4%. The result showed tea consumption was positively associated with fasting and 30 min, 1-hour and 2-hour glucose levels during OGTT. Logistic analysis revealed a positive and time-dependent association between tea drinking and glucose intolerance. These findings were consistent with some previous studies,[9 10 32 33] but inconsistent with some other studies.[6 34 35] In addition, we

Table 5 Associations of tea drinking or green tea drinking with β-cell function and insulin resistance

	Tea drinking		Green tea drinking	
	OR (95% CI)	P value	OR (95% CI)	P value
Modified Matsuda index				
Model 1	0.85 (0.72, 1.01)	0.062	0.90 (0.73, 1.11)	0.344
Model 2	0.92 (0.77, 1.09)	0.34	0.99 (0.80, 1.22)	0.896
HOMA-IR				
Model 1	1.20 (1.02, 1.42)	0.032	1.21 (0.98, 1.49)	0.074
Model 2	1.11 (0.93, 1.32)	0.252	1.13 (0.91, 1.40)	0.281
HOMA-β				
Model 1	0.91 (0.77, 1.07)	0.248	0.87 (0.70, 1.07)	0.185
Model 2	0.81 (0.68, 0.97)	0.021	0.77 (0.62, 0.96)	0.019
Stumvoll first-phase index				
Model 1	0.89 (0.75, 1.05)	0.151	0.89 (0.73, 1.10)	0.284
Model 2	0.81 (0.68, 0.97)	0.02	0.82 (0.66, 1.01)	0.06
Stumvoll second-phase index				
Model 1	0.97 (0.82, 1.15)	0.736	0.94 (0.76, 1.15)	0.551
Model 2	0.89 (0.75, 1.06)	0.199	0.85 (0.69, 1.06)	0.144

Model 1: adjusted for categorical age, gender, categorical body mass index (BMI), alcohol consumption, smoking status, education, family history of diabetes, history of dyslipidemia and physical activity at work.
Model 2: model 1+coffee drinking.
HOMA-IR, homeostasis model assessment of insulin resistance; HOMA-β, homeostasis model assessment of β-cell function.

found tea consumption was negatively associated with insulin secretion.

Tea contains polyphenolic antioxidants, such as catechins, theaflavins and thearubigins, that may benefit health.[36] Catechins are mostly presented in green teas, including epigallocatechin-3-gallate (EGCG), epigallocatechin, epicatechin-3-gallate and epicatechin, while theaflavins and thearubigins are mostly presented in black tea and oolong tea.[37] These polyphenols were found to have cytoprotective and antiapoptotic effects.[38] In vitro study showed that EGCG can increase glucose uptake and decrease glucose content, thus alleviates insulin resistance in the HepG2 cell line.[39] Black tea exhibited significant dose-dependent and marked hypoglycemic and antihyperglycemic activities in streptozotocin-induced diabetic rats.[40] Consistent with these beneficial effects, tea intake was found to be associated with reduced risk of diabetes.[6 34 35] However, similar to our study, tea drinking has been associated with an increased risk of diabetes in some other studies.[9 32 33]

In a large population-based cohort study, Liu *et al* studied on the urban population of Shanghai with 119 373 participants and showed more than 5 years of green tea drinking raised the risk of T2DM at 16%–22%.[9] In our study, high-risk individuals for diabetes who had drunk tea for more than 10 years were associated with higher risk of glucose intolerance. As we all know, environmental and lifestyle changes are believed to account for the rapid increase of T2DM prevalence in recent years.[41] In our study, we also found that the tea drinkers were more likely to have coffee and alcohol consumption, smoking habit and less physical activity at work. In addition, age, sex, BMI, education level, family history of diabetes and history of dyslipidemia were also different. However, after controlling for these confounders, this positive association was still observed. It should be noted that in this study diabetes was all newly diagnosed by OGTT. Therefore, the influence of hypoglycemic drugs was ruled out. In a prospective cohort study, Hayashino *et al* found drinking two or more cups of oolong tea per day increased the risk of T2DM at 64% in 4975 male workers over a median of 3.4 years of follow-up.[33] They suggested the mechanism of positive association of oolong tea drinking and risk of diabetes is pesticide residue. Indeed, exposure to pesticides could increase the risk of diabetes.[42] Previous study showed the serum level of organochlorine pesticides in urban Shanghai women was much higher than other populations, and this concentration was positively associated with tea consumption.[43] Interestingly, our study showed only strong tea consuming, not light or medium, was associated with higher risk of glucose intolerance and may explain this in some degree. However, further verification is still needed to confirm this speculation.

In our study, we used several OGTT-derived indexes to calculate insulin secretion and resistance level. Basic insulin secretion function was evaluated by HOMA-β.[44] The Stumvoll first-phase index reflected insulin stored, while the Stumvoll second-phase index reflected insulin synthesis. Both HOMA-IR and modified Matsuda index reflected the insulin sensitivity, with the latter showing

the highest correlation with the hyperinsulinemic-euglycemic clamp-derived M value in our population.[18] In this study, the tea drinkers had lower insulin secretion level and higher insulin resistance compared with non-drinkers. However, logistic analysis revealed that tea consumption was not significantly associated with insulin secretion after adjusting for age, sex, BMI, alcohol consumption, smoking status, education, family history of diabetes, history of dyslipidemia and physical activity at work. Nevertheless, if coffee consumption was further added in as a covariant, an opposite result was observed. Tea intake and green tea intake were both negatively associated with insulin secretion but tea intake was no longer associated with insulin resistance. Furthermore, early insulin response was negatively associated with tea drinking. Previous studies have shown coffee may have beneficial effects on pancreatic β-cell function.[23 45] Thus, after adjusting for coffee consumption, the negative association of tea consumption and insulin secretion was exposed. The effects of tea catechins on insulin secretion are controversial. Green tea EGCG can ameliorate oxidative damage of iron-loaded β cells by removing redox iron and free radicals and attenuating insulin production.[16] In MIN6 cell line, catechin can significantly increase glucose-stimulated insulin secretion (GSIS).[46] In contrast, Li *et al* reported that EGCG showed no effect on insulin secretion under high glucose condition.[47] In addition, some green tea catechins showed inhibitory effects on GSIS in INS-1D β cells under high glucose exposure.[48] The mechanism that tea may have a negative effect on insulin secretion is still unclear. It may still be due to pesticide residue, since exposure to organochlorine pesticides can induce pancreatic β-cell dysfunction.[49–51]

In this study, we found tea consumption was not associated with insulin resistance. Our finding was consistent with other previous studies. Ryu *et al* showed insulin resistance was unchanged after green tea consumption in patients with T2DM.[52] In a randomized controlled trial study, Fukino *et al* observed no insulin resistance change after daily supplementary intake of 500 mg green tea polyphenols in diabetic subjects.[15] In addition, Brown *et al* found that regular intake of EGCG had no effect on insulin resistance in overweight or obese male subjects.[53] However, some studies showed tea consumption can reduce insulin resistance.[12 54] The differences in population selection criteria might be the reason causing this discrepancy.

The limitations of the current study warrant further study. First, tea consumption-related assessment was from questionnaire rather than direct measurement, some bias in tea drinking may be possible. In addition, the level of organochlorine pesticides in tea and participants was not measured, this required further study.

In conclusion, we showed that tea intake is associated with an increased risk of glucose intolerance in a large high-risk diabetic Chinese population, and habitual tea consumption might have a negative effect on insulin secretion.

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