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Dark tea consumption is associated with a reduced risk of dysglycaemia and increased urinary glucose and sodium excretion in Chinese adults

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Abstract

Aim: To examine the associations of tea consumption (both frequency and type) with (1) prediabetes and diabetes and (2) urinary glucose and sodium excretion in Chinese community-dwelling adults.

Materials and Methods: In 1923 participants (457 with diabetes, 720 with prediabetes, and 746 with normoglycaemia), the frequency (occasional, frequent, daily, or nil) and type (green, black, dark, or other) of tea consumption were assessed using a standardized questionnaire. Morning spot urinary glucose and urine glucose-to-creatinine ratios (UGCRs) were assessed as markers of urinary glucose excretion. Tanaka's equation was used to estimate 24-h urinary sodium excretion. Logistic and multivariate linear regression analyses were performed.

Results: Compared with non-tea drinkers, the corresponding multivariable-adjusted odds ratios (ORs) for prediabetes and diabetes were 0.63 (95% confidence interval [CI] 0.48, 0.83) and 0.58 (95% CI 0.41, 0.82) in participants drinking tea daily. However, only drinking dark tea was associated with reduced ORs for prediabetes (0.49, 95% CI 0.36, 0.66) and diabetes (0.41, 95% CI 0.28, 0.62). Dark tea consumption was associated with increased morning spot urinary glucose (0.22 mmol/L, 95% CI 0.11, 0.34 mmol/L), UGCR (0.15 mmol/mmol, 95% CI 0.05, 0.25 mmol/L) and estimated 24-h urinary sodium (7.78 mEq/day, 95% CI 2.27, 13.28 mEq/day).

[#] Contributed equally to this work.

Conclusions: Regular tea consumption, especially dark tea, is associated with a reduced risk of dysglycaemia and increased urinary glucose and sodium excretion in Chinese community-dwelling adults.

KEYWORDS
observational study, glycaemic control, dietary intervention, database research

1 | INTRODUCTION

Tea consumption represents an important component of dietary intake. Globally, more than 2 billion cups of tea are consumed each day.[1] Habitual tea consumption, which may be green, white, yellow, black or dark, is associated with favourable cardiometabolic profiles, including a substantial reduction in the risk of dysglycaemia.[2,3] However, the effects of different types of tea on cardiometabolic outcomes and the underlying mechanisms remain uncertain. Addressing these knowledge gaps is potentially of major relevance to dietary recommendations for both the prevention and management of cardiometabolic disorders.

Based on the manufacturing process, tea can be classified into non-fermented green tea, partly fermented white and yellow tea, semi-fermented oolong tea, fully fermented black tea, and post-fermented dark tea.[4] Variations in the process of tea production, such as the involvement of microbial fermentation in the production of dark tea compared to other varieties, may lead to substantial differences in the abundance of bioactive compounds (e.g., alkaloids, free amino acids, polyphenols, polysaccharides, and their derivatives)[5] and accordingly, potential cardiometabolic effects. In a cross-sectional study of Chinese community-dwelling adults, regular consumption of dark tea, but not green or black tea, was associated with a reduced risk of newly diagnosed type 2 diabetes.[2] Although consumption of green tea in excess of 6 cups per day, was associated with a reduced risk of self-reported diabetes in a Japanese cohort,[6] a prospective study in Singapore Chinese adults indicated that consumption of more than one cup of black tea per day was more effective than green tea in reducing the risk of type 2 diabetes.[7] Outcomes for habitual consumption of oolong tea are inconsistent, with studies reporting both a reduced risk of dyslipidaemia[8] and an increased risk of diabetes.[9] There is little information about the association of tea consumption with the risk of prediabetes, even though the latter affects up to ~40% of the adult population in some communities.[10] Accordingly, there is a need to define the association between consumption of tea, including both the type and frequency, with glycaemic outcomes.

The mechanisms underpinning the apparent cardiometabolic effects of tea consumption are also rarely understood. Preclinical studies have reported pleiotropic actions of tea and tea extracts, including attenuation of systemic oxidation and inflammation, improvement of insulin sensitivity, and change in the composition of the gut microbiome.[11,12] It has recently been appreciated that dietary intake has the potential to influence renal glucose excretion and, hence, the risk of dysglycaemia. For example, a range of diets, generally regarded as 'unhealthy', such as high-fat,[13] high-salt high-fat,[14] high fructose[15] and Western diets,[16] upregulate renal sodium-glucose cotransporter-2 (SGLT2) expression, leading to enhanced renal glucose reabsorption, reduced urinary glucose excretion and an increased risk of glucose intolerance. However, it is not known whether tea consumption leads to an increase in urinary glucose excretion. This may well be important, particularly given that it is now established that SGLT2 inhibitors, which augment urinary glucose and sodium excretion, are effective in both the prevention and management of type 2 diabetes, with additional benefits of cardio-renal protection.[17]

Our study examined the associations of both the frequency and type of habitual tea consumption with glycaemic status and markers of urinary glucose and sodium excretion, in a Chinese community-dwelling adult population.

2 | MATERIALS AND METHODS

2.1 | Study population

This study represents a cross-sectional analysis of the third-wave survey data on tea consumption from the Study on Evaluation of iNnovated Screening tools and determInation of optimal diagnostic cut-off points for type 2 diaBetes in Chinese muLti-Ethnic (SENSIBLE) cohort study,[18] which was designed to determine the optimal cut-off values of advanced glycation end-products and glycated haemoglobin (HbA1c) for the diagnosis of type 2 diabetes in China. The present survey was conducted between April 2020 and January 2021 across eight provinces in China and enrolled a total of 2398 community dwellers aged over 18 years. The protocol of the SENSIBLE cohort study was approved by the Human Research Ethics Committee of Zhongda Hospital, Southeast University, Nanjing, China (approval number: 2016ZDSYLL092-P01). Written informed consent was obtained from all participants.

Of the 2398 participants surveyed, 88 were excluded because of missing data on anthropometrics (including systolic blood pressure [SBP], diastolic blood pressure [DBP], height, weight, and waist circumference [WC]) or laboratory parameters (including fasting blood glucose [FPG] and urinary glucose), 244 because of insufficient information about the types of tea consumed, and 143 because of habitual consumption of ≥2 types of tea. Accordingly, a total of 1923 participants were included in the final analysis (Figure S1).

2.2 | Data collection

Information on tea consumption (including the frequency and type of tea consumption), family history of diabetes, and usual pattern of exercise, alcohol consumption, and smoking, were collected using a standardized questionnaire by trained interviewers. Body weight, height, WC, SBP and DBP were measured according to standardized protocols, as reported.[19]

Venous blood was collected after an overnight fast (>8 h) and used to measure FPG, glycated haemoglobin (HbA1c, %), total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and serum creatinine. Participants without a history of diabetes underwent a 75-g oral glucose tolerance test, with additional venous blood sampled at 2 h to determine the 2-h post-load glucose (2hPG). The estimated glomerular filtration rate (eGFR) was calculated using the Chronic Kidney Disease Epidemiology Collaboration formula for the Chinese population.[20] A morning fasting spot urine sample was collected for measurements of urinary glucose and urinary creatinine (UCr). Urinary glucose excretion was assessed using both the morning spot urinary glucose level and glucose-to-creatinine ratio (M-UGCR), which were log-transformed prior to analysis.[21] The estimated 24-h urinary sodium excretion (e24UNa) was derived from the urine sodium and creatinine values using Tanaka's equation:[22]

$$\text{e24UNa(mEq/day)} = 21.98 \times U_{Na}/U_{Cr} \times [-2.04 \times \text{age} + 14.89 \times \text{weight(kg)} + 16.14 \times \text{height(cm)} - 2244.45]^{0.392}$$

2.3 | Definitions

Based on the American Diabetes Association criteria,[23] prediabetes was defined as FPG 5.6–6.9 mmol/L, 2hPG 7.8–11.0 mmol/L during the 75-g oral glucose tolerance test or HbA1c 39–47 mmol/mol (5.7%–6.4%), diabetes was defined as FPG ≥ 7.0 mmol/L, 2hPG ≥ 11.1 mmol/L, HbA1c ≥ 48 mmol/mol (6.5%), self-reported history or the use of glucose-lowering medication for established diabetes, and normoglycaemia was defined as FPG <5.6 mmol/L, 2hPG <7.8 mmol/L and HbA1c < 39 mmol/mol (5.7%).

The frequency of tea consumption was defined as (1) nil, (2) occasional (at least once a month), (3) frequent (at least once a week), or (4) daily. The type of tea was classified as green, black, dark, or other tea.

2.4 | Statistical analysis

Continuous variables are presented as means ± standard deviation or medians (25th percentile, 75th percentile), and categorical variables as numbers (percentages). Participants were stratified into three subgroups: (1) those with normoglycaemia, (2) those with prediabetes, and (3) those with diabetes. Differences across the three groups were compared using one-way analysis of variance or non-parametric Kruskal–Wallis tests for continuous variables. Categorical variables were compared using the χ^2 test. Post hoc comparisons among subgroups were adjusted using Bonferroni's correction. Multinomial logistic regression analysis was performed to evaluate the association between the presence of prediabetes and diabetes with tea consumption in both the crude model (Model 1) and fully adjusted model (Model 2, adjusted for age, gender, ethnicity [Han or other], body mass index [BMI], mean arterial pressure, TG, HDL-C, LDL-C, eGFR, alcohol intake, smoking status, family history of diabetes and regular exercise). Multiple linear regression analysis was used to assess the associations of markers of urinary glucose and sodium excretion with tea consumption, with the use of antidiabetic medication additionally included in the adjusted model. Subgroup analyses based on glycaemic status (normoglycaemia or dysglycaemia [i.e., prediabetes and diabetes]) were performed to assess the association between markers of urinary glucose and sodium excretion with tea consumption. A variance inflation factor > 10 was considered for collinearity between variables,[24] but no significant collinearity between variables was detected in any of our analyses. All statistical analyses were conducted using SPSS (version 25.0, IBM, New York, USA). p values < 0.05 were taken to indicate statistical significance.

3 | RESULTS

3.1 | Characteristics of the participants

A total of 1923 participants (Table 1) were included in the final analysis. Of these, glycaemic status was normoglycaemia in 746, prediabetes in 720, and diabetes in 457 participants. Participants with prediabetes and diabetes were slightly older and had higher BMI, WC, blood pressure, glycaemia, TG, TC, LDL-C and lower eGFR, compared to those with normoglycaemia. Participants with diabetes also had higher urinary glucose and M-UGCR and lower HDL-C compared to those with normoglycaemia. e24UNa and the proportion of individuals who smoked and exercised regularly did not differ among the three groups, However, the proportions of female participants, those with habitual alcohol consumption, and those with a family history of diabetes were higher in the group with diabetes.

3.2 | Tea consumption and glycaemic status

Compared with participants who did not consume tea, the odds ratios (ORs) of prediabetes and diabetes in tea drinkers were 0.61 (95% confidence interval [CI] 0.50 to 0.76; p < 0.001) and 0.64 (95% CI 0.51 to 0.81; p < 0.001), and those who consumed tea daily were 0.61 (95% CI 0.49 to 0.76; p < 0.001) and 0.57 (95% CI 0.44 to 0.74; p < 0.001) in the crude model (Model 1). After multivariable adjustment (Model 2), these associations remained significant. Of the different types of tea, consumption of dark tea, but not the other varieties, was associated with lower odds of both prediabetes and diabetes in the crude model (OR 0.52 [95% CI 0.41 to 0.67; p < 0.001] and 0.44 [95% CI

TABLE 1 Clinical characteristics of participants included in the final analysis.

Clinical characteristics	Normoglycemia ($n = 746$)	Prediabetes ($n = 720$)	Diabetes ($n = 457$)	p
Female, *n* (%)	568 (76.1%)	522 (72.5%)	271 (59.3%)*	<0.001
Age, years	50.7 ± 11.4	56.6 ± 10.6***	61.7 ± 9.0***	<0.001
BMI, kg/m^2	25.3 ± 4.2	26.2 ± 4.1***	26.4 ± 4.1***	<0.001
Ethnicity, *n* (%)				<0.001
Han	268 (35.9)	275 (38.3)	239 (52.4)*	
Other	478 (64.1)	443 (61.7)	217 (47.6)*	
WC, cm	84.6 ± 0.4	88.7 ± 0.4***	91.4 ± 0.5***	<0.001
SBP, mmHg	131.7 ± 21.4	139.1 ± 20.7***	144.9 ± 21.4***	<0.001
DBP, mmHg	80.6 ± 13.4	84.2 ± 12.9***	85.9 ± 13.0***	<0.001
FPG, mmol/L	4.9 ± 0.3	5.3 ± 0.5***	7.3 ± 2.6***	<0.001
2hPG, mmol/L[a]	5.8 ± 1.1	7.3 ± 1.7***	11.2 ± 3.6***	<0.001
HbA1c, %[a]	5.3 ± 0.3	5.7 ± 0.3***	7.1 ± 1.7***	<0.001
Urinary glucose, mmol/L	0.32 (0.21,0.48)	0.31 (0.20,0.45)	0.50 (0.28,1.34)***	<0.001
M-UGCR	0.032 (0.03,0.04)	0.03 (0.03,0.04)	0.05 (0.03,0.13)***	<0.001
e24UNa	161.8 ± 45.7	164.5 ± 48.6	157.7 ± 49.1	0.06
TC, mmol/L	4.7 ± 0.9	5.0 ± 1.0***	5.0 ± 1.0***	<0.001
TG, mmol/L	1.2 ± 0.8	1.5 ± 0.9***	1.9 ± 1.4***	<0.001
HDL-C, mmol/L	1.4 ± 0.3	1.4 ± 0.3	1.3 ± 0.3*	0.05
LDL-C, mmol/L	2.6 ± 0.7	2.9 ± 0.7***	2.8 ± 0.8***	<0.001
eGFR, mL/min/1.73 m^2	105.3 ± 14.3	101.2 ± 12.5***	97.0 ± 14.4***	<0.001
Current smoker, *n* (%)	83 (11.1)	86 (11.9)	66 (14.1)	0.23
Habitual alcohol drinker, *n* (%)	92 (12.3)	114 (15.8)	84 (18.4)*	0.01
Family history of diabetes[a], *n* (%)	178 (24.1)	160 (22.5)	158 (35.0)*	<0.001
Regular exercise[a], *n* (%)	184 (24.7)	151 (21)	107 (23.5)	0.25

Note: Data are presented as means ± standard deviations or medians (25th percentile, 75th percentile) or numbers (%), where appropriate. One-way analysis of variance and the non-parametric Kruskal–Wallis test were used for comparisons of continuous variables, while the χ2 test was used for comparison of categorical variables. Post hoc comparisons were adjusted by Bonferroni's correction. *$p < 0.05$ and **$p < 0.01$, ***$p < 0.001$, compared to participants with normoglycemia.

Abbreviations: 2hPG, 2-h postprandial glucose; BMI, body mass index; DBP, diastolic blood pressure; e24UNa, estimated 24-h urinary sodium excretion; eGFR, estimated glomerular filtration rate; FPG, fasting plasma glucose; HbA1c, glycated haemoglobin; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; M-UGCR, morning spot urine glucose-to-creatinine ratio; SBP, systolic blood pressure; TC, total cholesterol; TG, triglycerides; WC, waist circumference.

[a]Indicates missing values, including $n = 237$ for 2hPG, $n = 6$ for HbA1c, $n = 20$ for family history of diabetes, and $n = 3$ for information on exercise.

0.33 to 0.60; $p < 0.001$], respectively). After multivariable adjustment, the ORs of prediabetes and diabetes were 0.49 (95% CI 0.36 to 0.66; $p < 0.001$) and 0.41 (95% CI 0.28 to 0.62; $p < 0.001$), respectively (Table 2). Moreover, consumption of dark tea was also associated with a decrease in FPG of 0.19 mmol/L (95% CI −0.35 to −0.02 mmol/L; $p < 0.05$) after multivariate adjustment, although a negative association between HbA1c and dark tea consumption was not evident (Table S1).

3.3 | Tea consumption and markers of urinary glucose excretion

Compared with participants who did not consume tea, those who consumed tea daily exhibited an increase in fasting urinary glucose of 0.15 mmol/L (95% CI 0.03 to 0.28 mmol/L; $p = 0.02$), without a significant difference in M-UGCR in the crude model. However, after multivariable adjustment, daily tea consumption was associated with increases in both fasting urinary glucose of 0.17 mmol/L (95% CI 0.07 to 0.27 mmol/L; $p = 0.001$) and M-UGCR of 0.10 mmol/mmol (95% CI 0.01 to 0.19 mmol/mmol; $p = 0.02$ [Table 3]).

Of the different types of tea, only the consumption of dark tea was associated with increases in fasting urinary glucose of 0.22 mmol/L (95% CI 0.11 to 0.34 mmol/L; $p < 0.001$) and M-UGCR of 0.15 mmol/mmol (95% CI 0.05 to 0.25 mmol/mmol; $p = 0.003$ [Model 2, Table 3]). Subgroup analysis revealed that tea consumption, daily tea consumption, and dark tea consumption were associated with an increase in urine glucose of 0.14 mmol/L (95% CI 0.02 to 0.27 mmol/L; $p = 0.03$), 0.17 mmol/L (95% CI 0.03 to 0.32 mmol/L; $p = 0.02$), and 0.26 mmol/L (95% CI 0.09 to 0.43 mmol/L; $p = 0.002$),

TABLE 2 Association of glycaemic status with tea consumption.

	Prediabetes			Diabetes		
		Model 1	Model 2		Model 1	Model 2
Clinical characteristics	*N*, cases/total	OR (95% CI)	OR (95% CI)	*N*, cases/total	OR (95% CI)	OR (95% CI)
Tea consumption						
No	381/923	1.00	1.00	237/923	1.00	1.00
Yes	339/1000	0.61 (0.50, 0.76)	0.67 (0.52, 0.85)	220/1000	0.64 (0.51, 0.81)	0.69 (0.51, 0.92)
Frequency of tea consumption						
Never	381/923	1.00	1.00	237/923	1.00	1.00
Occasionally	29/98	0.58 (0.35, 0.96)	0.71 (0.41, 1.21)	29/98	0.93 (0.56, 1.55)	1.16 (0.64, 2.11)
Often	68/201	0.66 (0.40, 0.94)	0.75 (0.51, 1.10)	50/201	0.78 (0.53, 1.15)	0.78 (0.49, 1.24)
Daily	242/701	0.61 (0.49, 0.76)	0.63 (0.48, 0.83)	141/701	0.57 (0.44, 0.74)	0.58 (0.41, 0.82)
Type of tea						
No tea	381/923	1.00	1.00	237/923	1.00	1.00
Green tea	109/300	0.78 (0.58, 1.06)	0.83 (0.60, 1.15)	79/300	0.91 (0.65, 1.27)	0.87 (0.59, 1.30)
Black tea	43/125	0.68 (0.44, 1.04)	0.87 (0.54, 1.40)	31/125	0.78 (0.49, 1.26)	1.09 (0.61, 1.93)
Dark tea	170/521	0.52 (0.41, 0.67)	0.49 (0.36, 0.66)	90/521	0.44 (0.33, 0.60)	0.41 (0.28, 0.62)
Other	17/54	0.80 (0.40, 1.59)	0.86 (0.41, 1.79)	20/54	1.51 (0.78, 2.95)	1.12 (0.51, 2.42)

Note: Model 1: Unadjusted. Model 2: Adjusted for age, gender, ethnicity (Han and other), body mass index, mean arterial blood pressure, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, estimated glomerular filtration rate, current smoking status, current alcohol consumption, family history of diabetes and regular excise.
Abbreviations: CI, confidence interval; OR, odds ratio.

TABLE 3 Association of urinary glucose excretion with tea consumption.

	Urine glucose (mmol/L)				M-UGCR (mmol/mmol)			
	Model 1		Model 2		Model 1		Model 2	
Clinical characteristics	Mean (95% CI)	*p*	Mean (95% CI)	*p*	Mean (95% CI)	*p*	Mean (95% CI)	*p*
Tea consumption								
No	Reference		Reference		Reference		Reference	
Yes	0.15 (0.04, 0.26)	0.01	0.12 (0.03, 0.21)	0.01	0.01 (−0.09, 0.11)	0.87	0.07 (−0.003, 0.15)	0.06
Frequency of tea consumption								
Never	Reference		Reference		Reference		Reference	
Occasionally	0.15 (−0.11, 0.42)	0.26	0.15 (−0.04, 0.34)	0.12	0.01 (−0.23, 0.26)	0.92	0.07 (−0.09, 0.23)	0.41
Often	0.14 (−0.06, 0.33)	0.17	0.001 (−0.14, 0.14)	1.00	0.05 (−0.13, 0.23)	0.57	0.01 (−0.11, 0.13)	0.91
Daily	0.15 (0.03, 0.28)	0.02	0.17 (0.07, 0.27)	0.001	−0.01 (−0.12, 0.11)	0.94	0.10 (0.01, 0.19)	0.02
Type of tea								
No tea	Reference		Reference		Reference		Reference	
Green tea	0.09 (−0.08, 0.25)	0.29	0.06 (−0.06, 0.18)	0.33	−0.03 (−0.19, 0.12)	0.68	0.02 (−0.08, 0.13)	0.66
Black tea	0.11 (−0.13, 0.34)	0.38	0.06 (−0.12, 0.23)	0.50	−0.05 (−0.27, 0.17)	0.64	0.03 (−0.12, 0.18)	0.68
Dark tea	0.18 (0.04, 0.32)	0.01	0.22 (0.11, 0.34)	< 0.001	0.03 (−0.09, 0.16)	0.63	0.15 (0.05, 0.25)	0.003
Other	0.28 (−0.07, 0.63)	0.11	0.001 (−0.25, 0.25)	0.99	0.16 (−0.16, 0.48)	0.33	−0.03 (−0.25, 0.18)	0.77

Note: Model 1: Unadjusted. Model 2: Adjusted for age, gender, ethnicity (Han and other), body mass index, mean arterial blood pressure, fasting plasma glucose, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, estimated glomerular filtration rate, current smoking status, current alcohol consumption, family history of diabetes regular excise, and use of antihyperglycaemic medication. *Urinary glucose and urinary glucose to creatinine ratio were normalized by log-transformation.
Abbreviations: CI, confidence interval; M-UGCR, morning spot urine glucose-to-creatinine ratio.

respectively, in participants with dysglycaemia (i.e., both prediabetes and diabetes), while there were no significant associations in participants with normoglycaemia (Table S2).

3.4 | Tea consumption and estimated 24-h urinary sodium excretion

Neither overall nor daily tea consumption was associated with e24UNa, with or without adjustment for covariates (Table 4). However, consumption of dark tea was associated with an increase in e24UNa of 7.79 mEq/day in Model 1 (95% CI 2.69 to 12.89 mEq/day; $p = 0.003$) and 7.78 mEq/day (95% CI 2.27 to 13.28 mEq/day; $p = 0.01$) in Model 2 (Table 4). Subgroup analysis showed that neither overall nor daily tea consumption was associated with 24-h sodium excretion in participants with normoglycaemia or dysglycaemia. However, consumption of dark tea remained associated with an increase in e24UNa of 9.74 mEq/day (95% CI 2.21 to 17.27 mEq/day; $p = 0.01$) in participants with dysglycaemia (Table S3).

4 | DISCUSSION

In this cross-sectional analysis of a large cohort of Chinese community-dwelling adults, consumption of tea daily, particularly dark tea, was associated with a substantially reduced odds of both prediabetes and diabetes. Moreover, consumption of dark tea was also associated with increased urinary excretion of both glucose and sodium. Subgroup analysis in participants with dysglycaemia indicated similar associations between urinary glucose and sodium excretion with dark tea consumption. Together, these observations are indicative of a favourable effect of regular tea consumption on glycaemic control. The effects of dark tea, in particular, support a renal mechanism of action, which warrants further investigation.

As reported,[2,4,25] we observed that in tea drinkers the risk of diabetes was reduced, both before and after multivariable adjustment. Furthermore, we found that tea consumption was associated with a 33% reduction in the odds of prediabetes. Together, these findings provide a strong rationale for interventional studies to examine whether tea consumption could represent a safe and cost-effective measure for the prevention and management of type 2 diabetes. Interestingly, only dark tea, among several varieties investigated, was associated with lower odds of prediabetes and diabetes, and the reduction in the risk for prediabetes and diabetes in dark tea drinkers approximated 51% and 59%, respectively. A previous study in a Chinese adult population also reported that habitual consumption of dark tea, rather than green or black tea, was associated with a reduced risk of screen-detected type 2 diabetes.[2] However, several other studies have reported potential benefits of consumption of green tea and black tea to reduce the risk of type 2 diabetes. For example, a cohort study conducted among urban Chinese ($n = 119\,373$) reported that, in healthy individuals identified as current green tea drinkers, there was a reduction in the risk of future onset of type 2 diabetes of 20%, compared with those who did not consume.[26] Moreover, in a cohort

TABLE 4 Association of estimated 24-h urinary sodium excretion with tea consumption.

	Estimated 24-h urinary sodium excretion (mEq/ day)			
	Model 1		Model 2	
Clinical characteristics	Mean (95% CI)	p	Mean (95% CI)	p
Tea consumption				
No	Reference		Reference	
Yes	1.87 (−2.39, 6.13)	0.39	1.63 (−2.79, 6.05)	0.47
Frequency of tea consumption				
Never	Reference		Reference	
Occasionally	−9.65 (−19.56, 0.26)	0.06	−7.47 (−17.11, 2.17)	0.13
Often	−1.74 (−8.99, 5.52)	0.64	−0.70 (−7.84, 6.44)	0.85
Daily	4.51 (−0.16, 9.18)	0.06	4.00 (−0.92, 8.91)	0.11
Type of tea				
No tea	Reference		Reference	
Green tea	−6.82 (−13.00, −0.64)	0.03	−6.01 (−12.10, 0.08)	0.05
Black tea	3.33 (−5.53, 12.19)	0.46	4.62 (−4.11, 13.35)	0.30
Dark tea	7.79 (2.69, 12.89)	0.003	7.78 (2.27, 13.28)	0.01
Other	−10.41 (−23.42, 2.62)	0.12	−6.27 (−19.05, 6.52)	0.34

Note: Model 1: Unadjusted. Model 2: Adjusted for ethnicity (Han and other), mean arterial blood pressure, fasting plasma glucose, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, estimated glomerular filtration rate, current smoking status, current alcohol consumption, family history of diabetes, regular excise, and use of antihyperglycaemic medication.
Abbreviation: CI, confidence interval.

study enrolling 0.5 million Chinese adults, habitual consumption of green tea was associated with a 50% reduction in the risk of developing diabetic retinopathy.[27] Similarly, consumption of black tea (more than three cups per day) was reported to reduce the progression of type 2 diabetes.[28] In a prospective cohort study of Singapore Chinese adults ($n = 36\,908$), consumption of black tea appeared to be more effective than green tea in reducing the risk of diabetes.[7] Accordingly, we cannot exclude the possibility that the lack of associations between consumption of green or black tea with prediabetes and diabetes in our study reflects the smaller sample size.

Consistent with the association between glycaemic status and tea consumption, we observed that consumption of dark tea was associated with decreased FPG. However, this negative association was not evident for HbA1c, probably because of the relatively low HbA1c of the participants involved in this analysis. It is well appreciated that the magnitude of lowering of HbA1c by any glucose-lowering treatments is dependent on HbA1c levels at baseline.[29] Accordingly, in individuals with HbA1c levels close to the therapeutic target (i.e., 7%), a profound reduction in HbA1c by any glucose-lowering therapy is less likely to be demonstrated.

The mechanisms underpinning the beneficial cardiometabolic effects of tea are poorly defined. Previous studies reported that dark tea, as well as other varieties (e.g., green and black tea), may reduce insulin resistance[30] and improve epithelial function[31] and reduce waist circumference.[32] The current study demonstrates for the first time that consumption of dark tea is associated with significant increases in urinary glucose and sodium, which were not observed with other types of tea. Our subgroup analysis revealed that these associations are best demonstrated in participants with dysglycaemia, probably reflecting that individuals with dysglycaemia are more prone to excreting glucose in the urine.[33] The disparity in the effects of different types of tea on the excretion of urinary glucose and sodium may reflect their production.[5] Distinct from other teas, the manufacture of dark tea involves microbial fermentation, a process that may yield unique bioactive compounds with antioxidant and anti-inflammatory properties[34] and modulate the gut microbiome,[35] to directly, or indirectly influence renal glucose and sodium excretion and the consequent risk of dysglycaemia. It is possible, but remains to be determined, that the consumption of dark tea to some extent mimics the effects of SGLT2 inhibitors, which are used widely for the management of type 2 diabetes and reduce the onset of type 2 diabetes.[36] Increases in urinary glucose and sodium excretion with SGLT2 inhibitors are accompanied by a reduction in systemic inflammation, oxidative stress and blood pressure, and improved kidney and heart function.[17] In view of our observations, further mechanistic studies are warranted to clarify whether dark tea can modulate the expression and/or function of renal SGLT2 in humans, and the mechanisms by which it may do so.

Several limitations should be considered in interpreting our results. First, this was a cross-sectional study, so causality cannot be inferred from the associations observed. Second, the data on lifestyle and tea consumption were obtained by self-report using questionnaires, which inevitably entails a risk of bias. Third, we could not accurately quantify the amount or the time of tea consumed, so that 'dose- and time-dependent' effects could not be evaluated. Fourth, the study population had a higher proportion of female than male participants, indicating that a sampling bias was present. Although adjustments for multiple confounding factors were incorporated into our analysis, some unmeasured residual factors, such as consumption of milk, sugar, and other beverages, could have influenced the study outcomes. Finally, because the present study involved only Chinese community-dwelling adults, it remains to be established whether the findings are applicable to non-Chinese populations.

In conclusion, in Chinese community-dwelling adults, regular tea consumption, particularly of dark tea, is associated with a reduced risk of dysglycaemia, and increased urinary glucose and sodium excretion. These observations provide strong support for further cohort studies to validate the glycaemic benefits of dark tea, and provide a rationale for mechanistic studies to investigate the effects of tea consumption on renal glucose handling.

AUTHOR CONTRIBUTIONS

Tingting Li and Miaomiao Sang, Zilin Sun, Shanhu Qiu and Tongzhi Wu contributed to the conception and design of the study. Tingting Li, Miaomiao Sang, Jinbang Wang, Zilin Sun, Duolao Wang, Shanhu Qiu and Tongzhi Wu contributed to the acquisition, analysis, or interpretation of data. Tingting Li, Cong Xie, Weikun Huang, Michael Horowitz, Christopher K. Rayner, Shanhu Qiu and Tongzhi Wu contributed to the writing and revising of the manuscript. Shanhu Qiu and Tongzhi Wu contributed to the study supervision and are the guarantors of this work. All authors reviewed and approved the final version of the article submitted for publication.

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CONFLICT OF INTEREST STATEMENT

No potential conflict of interest relevant to this article was reported.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on reasonable request from the corresponding authors. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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