

The relationship between ambient temperature and FPG: a series of cross-sectional studies in Guangdong Province, China

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Abstract

Background There existed evidence that the prevalence and glycemic control rate of type 2 diabetes mellitus (T2DM) have seasonal variation. The present study aimed to examine the associations between ambient temperature exposure and FPG among different groups (total, non-T2DM, old T2DM and new T2DM groups) and calculate temperature adjusted prevalence and glycemic control rate of T2DM.

Methods Four cross-sectional health surveys with 26,350 respondents were conducted in Guangdong Province from 2007 to 2015. Multistage cluster sampling was used to recruit study participants. Generalized additive model was employed to evaluate the associations between daily mean temperature and FPG among different groups. The prevalence and glycemic control rate of T2DM were calculated based on the exposure-response association between temperature and FPG.

Results The exposure-response curves of temperature and FPG were downward parabola in total, non-T2DM and old-T2DM groups, while it was “U”-shaped without statistically significant for new T2DM cases. When temperature decreased from 30°C to 4°C, the FPG significantly increased 0.59 (95%CI: 0.49, 0.68) mmol/L, 0.47 (95%CI: 0.43, 0.52) mmol/L and 1.59 (95%CI: 0.59, 2.59) mmol/L in total, non-T2DM and old-T2DM groups, respectively. When the ambient temperature increased from 5°C to 30°C, the prevalence of T2DM slowly decreased from 10.03% to 9.39%, and the glycemic control rate of T2DM greatly increased from 31.9% to 58.5%.

Conclusion The prevalence and glycemic control rate of T2DM are associated with ambient temperature, which suggests temperature should be considered and adjusted when estimating T2DM prevalence and developing clinical management of T2DM.

Background

Type 2 diabetes mellitus (T2DM) is a metabolic disorder characterized by high blood glucose in the context of insulin resistance and relative insulin deficiency. T2DM has been a very serious public health problem worldwide and accounted for about 90% of diabetes cases. It was estimated that diabetes affected more than 425 million people worldwide in 2017, and 114.4 million diabetes cases were in China [1]. Diabetes is a major contributor to cardiovascular diseases and is the eleventh common cause of disability worldwide [1].

Many risk factors such as heredity, individual life style and insufficient activity are associated with T2DM [2-4]. Environmental factors such as ambient temperature, were related to fasting plasma glucose (FPG). There was much evidence on seasonal variation of FPG. For example, there was a mean 0.6 mmol/L difference in FPG between winter and spring in Southern California [5]. *Gikas* et al. found that mean FPG was higher during cold seasons than warm seasons in a study, with the nadir in August (7.60 mmol/L) and the zenith in February (9.12 mmol/L) [6]. In terms of acute effect of ambient temperature, previous studies have observed a negative relationship between temperature and FPG [5, 7]. Nevertheless, *Li* et al. found that the association between temperature and FPG was U-shaped that FPG level was higher in cold or hot temperature [8].

There were also existing evidence that the prevalence of T2DM and glycemic control rate had seasonal variation. A population-based study in *Csongrad*, Hungary revealed the seasonal variation in the prevalence of T2DM with the peak on March and the trough on August [9]. Several studies also revealed seasonal variation of glycemic control rate for T2DM cases that lower control rate emerged in cold winter [6, 10]. These seasonal variations can be attributed to temperature variation to a certain extent.

Despite the confirmed effects of ambient temperature on FPG, previous epidemiological surveys conducted in different regions or seasons did not adjust temperature when computing T2DM prevalence and control rate [11]. In addition, different nutritional prescription and hypoglycemic drug therapy made for diabetic cases by considering temperature-FPG association can help achieve better diabetic clinic care and management.

In order to fill the knowledge gap, in the current study, we examined the associations of ambient temperature with FPG in different subgroups based on a series of cross-sectional surveys, and further calculated temperature adjusted prevalence and control rate of T2DM. Our findings are informative for accurately estimating the prevalence of T2DM in large-scale surveys across different climate zones and seasons, and clinic management of cases with T2DM in different seasons.

Methods

Study design and population

The Guangdong Chronic Disease and Risk Factors Surveys are a series of provincially representative surveys, which were conducted by Guangdong Provincial Center for Disease Control and Prevention in 2007, 2010 and 2013. These surveys aimed to understand the prevalence trend and risk factors of non-communicable diseases such as hypertension, T2DM, and obesity. The Guangdong Nutrition and Health Survey conducted in 2015 was designed to assess the nutrition and health status in Guangdong province. The data from the four surveys were combined to examine the association of ambient temperature with FPG. All participants agreed to participate and signed informed consent form prior to the surveys. The study was approved by the Ethics Committee of Guangdong Provincial Center for Disease Control and Prevention (Ethical review code: 2019009).

Similar sampling protocols were adopted for the surveys of 2007, 2010 and 2013, which has been described previously elsewhere [12]. Briefly, in each of the surveys, 21 districts or counties in Guangdong province were randomly selected by stratified multistage cluster sampling with probability proportional to size. In the second stage, four neighborhoods or townships from each district or county were selected; In the third stage, three communities or villages from each neighborhood or township were chosen; In the fourth stage, 50 to 100 households from each community or village were randomly sampled; Finally, 1 resident aged ≥ 18 years from each sampled household was selected using the Kish grid method. If there is no resident ≥ 18 years in the selected household or if the selected resident did not

agree to participate in the survey, the household was replaced with another randomly selected household nearby. Details of sampling methods and survey protocols for the nutrition and health survey conducted in 2015 have been described in the previous study [13]. The sample size and survey site of four surveys were show in Table S1 (Additional file 1).

FPG measurement and T2DM definition

Participants were asked to fast at least 8 hours before blood collection. Fasting blood samples were collected by registered nurses. Fasting plasma glucose levels were measured on a Hitachi 7600 automatic biochemical analyzer (Hitachi, Ltd., Tokyo, Japan) using reagents obtained from Wako Pure Chemical Industries *Ltd.* at the National CDC of China. Old T2DM subgroup was defined as physician-diagnosed T2DM (confirmed with medical history). According to World Health Organization 2006 criteria, new T2DM subgroup was defined a new detection of diabetes with an FPG level of 7.0 mmol/L or over among undiagnosed diabetes (without a history of diabetes and hypoglycemic use); non-T2DM subgroup was defined as participants with an FPG level less than 7.0 mmol/L [14]. The T2DM prevalence was defined as the proportion of old T2DM patients and undiagnosed diabetes with an FPG level of 7.0 mmol/L or over. The glycemic control rate was defined as the proportion of old T2DM subgroup with FPG less than 7.0 mmol/L [14].

Data collection

Questionnaire survey and anthropometric Measurements

Participants were interviewed and provided with onsite health examinations. All interviews and examinations were conducted following standard protocols by physicians who had received specific training for the survey and health examination. Questionnaires were used to collect a wide range of information including demographic characteristics, lifestyle, household location. Demographic characteristics included age, gender, career, education. Physical activity time was defined as leisure time spend in high intensity sports or moderate intensity exercise, such as running, swimming, doing Tai Chi (in hour/day). Sedentary leisure time was defined as time spent in sedentary activities after work, such as watching TV, reading a newspaper and using a computer (in hour/day). Smoking status was measured by whether smoking in the past or present (yes vs no). Drinking status was defined as whether drinking alcohol in the past 12 months (yes vs no). Height and weight were measured following standard protocols. Body mass index (BMI) was calculated as weight divided by the square of height (in kg/m²). The information of using hypoglycemic medicine in old T2DM subgroup was also collected. In addition, the information of the weekly food consumption of grains, vegetable, fruit, meat and family history of diabetes was also collected in the surveys of 2010 and 2015.

Meteorological data

Daily meteorological data were obtained from the China National Weather Data Sharing System (<http://data.cma.cn/>). Monitoring locations included thirty-six areas and the number of survey areas was shown in Table S1 in additional file 1. Daily meteorological variables from each survey's nearby weather station included daily mean, minimum, maximum temperature (°C), relative humidity (%) and sunlight (hour/day), which will be matched to individual survey information based on the date of survey. Daily meteorological data was passed through quality control checks and the integrity of meteorological data was close to 99.9%.

Statistical analysis

We described distributions of all variables, continuous variables as the means±SD for normally distributed data and median (25th-75th percentile) for skew distributed data. Categorical variables were expressed as numbers and percentages. T-test (for normally distributed continuous data), Kruskal-Wallis test (for skew distributed continuous data) or χ^2 test (for categorical variables) were used to compared the difference between non-T2DM, old T2DM and new T2DM subgroups. A generalized additive Gaussian models was used to investigate the effect of ambient temperature exposure on FPG in different subgroups after adjusting for covariates. Daily mean temperature was selected as exposure according to the minimum value of Akaike's Information criterion (*AIC*) in the model (see Figure S1 in the Additional file 1). And daily mean temperature, humidity, age and BMI were fitted using a penalized cubic spline function with a degree of freedom (*df*) of 3. The selection of optimal *df* of daily mean temperature was based on graphic smoothness and minimum value of *AIC* (see Figure S2 in Additional file 1). The regression model was described as the following .

$$Y_{im} = \beta_{0m} + \beta_{1m} s(X_{temp}, k=3) + \beta_{2m} s(X_{humidity}, k=3) + \beta_{3m} s(X_{age}, k=3) + \beta_{4m} s(X_{BMI}, k=3) + \beta_{5m} X_{1i} + \dots + \beta_{nm} X_{ni} + \epsilon_{im} \quad (1)$$

Where *m* represents groups (total/non-T2DM/new-T2DM/old-T2DM participants), Y_{im} represents participant's FPG; β_{0m} is the overall intercept, $\beta_{1m} \dots \beta_{nm}$ corresponds to coefficients for variables. X_{temp} , $X_{humidity}$, X_{age} , X_{BMI} and $X_{1i} \dots X_{ni}$ denotes variables. *S*() is a penalized cubic spline function and ϵ_{im} is the residual error.

After constructing the model, we obtained the exposure-response curve between daily mean temperature and the change of FPG compared to the minimum FPG temperature. In order to quantitatively estimate the temperature effect on FPG, we calculated the change of FPG comparing the minimum/maximum temperature with the minimum FPG temperature. Based

on exposure-response curve, we could compute the change of FPG (ΔFPG_{ijm}) at different ambient temperature. Temperature-adjusted FPG (FPG_{2ijm}) (2), prevalence ($Rate_{1j}$) (3) and glycemic control rate ($Rate_{2j}$) (4) of T2DM can be calculated as the follows:

$$FPG_{2ijm} = FPG_{1im} - \Delta FPG_{ijm} \quad (2)$$

$$Rate_{1j} = N_{1j}/N_3 \quad (3)$$

$$Rate_{2j} = N_{2j}/N_4 \quad (4)$$

Where m corresponds to groups (total/non-T2DM/new-T2DM/old-T2DM participants); j represents reference temperature points (5°C, 10°C, 15°C, 20°C, 22.5°C, 25°C and 30°C). ΔFPG_{ijm} corresponds to the change of FPG at temperature on the survey date compared to reference temperature points. FPG_{1im} is each participant FPG; N_{1j} represents the sum of the number of old and new T2DM patients and the number of non-T2DM subgroup with FPG_{2ijm} level of 7 mmol/L or greater; N_3 is the number of total population; N_{2j} represents the number of old-T2DM with a FPG_{2ijm} less than 7 mmol/L; N_4 is the number of old-T2DM patients.

In sensitivity analysis, we analysis the association between ambient temperature and FPG at different lags (lag1 to lag6). We further added sunshine and precipitation to the model to test the robustness of that association. we also performed sensitivity analysis using the participants whose has weekly food consumption and family history of diabetes information. We reanalyzed the temperature-FPG relationships among subgroup of non-T2DM and new T2DM when we defined T2DM using both FPG and 2-hour plasma glucose rather single FPG. We used R software (version 3.5.1, R foundation for Statistical Computing, Vienna, Austria). All statistical tests were two-sided and P values of all statistical analyses less than 0.05 was considered statistically significant. The GAM analysis was performed by using package “*mgcv*”.

Results

Characteristics of study participants

Total sample size was 26350, and 90.6% of participants were non-T2DM; 5.8% of subjects were new T2DM cases and 3.5% were old T2DM cases. Overall, the median age of respondents was 50.1 (40.0-60.1) years old and 44.9% of them were males. Compared with non-T2DM participants, old and new T2DM cases were older and had higher levels in BMI, but lower education attainment. Moreover, there were more nonworkers/houseworkers/retirees, non-smokers and non-drinkers in old and new T2DM

cases than non-T2DM participants (Table 1). Other statistical description of FPG and daily mean temperature were shown in Table S2 and Figure S3 in Additional file 1.

Monthly variation of FPG and ambient temperature

Figure 1 and Table S3 (in Additional file 1) show monthly variation of FPG and ambient temperature. The weather factor is characterized by two main seasons: cold season (lasting from December to March) and warm season (April, May, October, November). The mean FPG levels were significantly higher during cold season than warm season. The zenith of FPG was 6.57 mmol/L for total population, 5.55 mmol/L for non-T2DM participants, 9.41 mmol/L for old T2DM cases, and 10.04 mmol/L for new T2DM cases in cold season, while the nadir of FPG was 5.29 mmol/L for total population, 5.05 mmol/L for non-T2DM participants, 7.39mmol/L for old T2DM cases and 8.99 mmol/L for new T2DM cases in warm season.

Table 1. The characteristic of study participants in the study sample.

Variable	Total	Non-T2DM [†]	Old-T2DM [‡]	New-T2DM [§]	P value
Overall, n (%)	26350(100.0)	23877 (90.6)	916 (3.5)	1557 (5.9)	
Gender, n (%)					0.2
male	11834 (44.9)	10709 (44.9)	398 (43.4)	727 (46.7)	
female	14516 (55.1)	13168 (55.1)	518 (56.6)	830 (53.3)	
Education, n (%)					<0.001
≤Junior high school	12573 (47.7)	11212 (47.0)	506 (55.2)	855 (54.9)	
High school/college	13777 (52.3)	12665 (53.0)	410 (44.8)	702 (45.1)	
Career, n (%)					<0.001
production staff	9170 (34.8)	8428 (35.3)	242 (26.4)	500 (32.1)	
Technical staff	9504 (36.1)	8783 (36.8)	224 (24.5)	497 (31.9)	
Nonworkers/ houseworkers/retirees	7676 (29.1)	6666 (27.9)	450 (49.1)	560 (36.0)	
Smoking status, n (%)					<0.001
Yes (Former/Current)	10747 (40.8)	9835 (41.2)	357 (39.0)	555 (35.6)	
Never	15603 (59.2)	14042 (58.8)	559 (61.0)	1002 (64.4)	
Drinking status, n (%)					<0.001
Yes (past 12 months)	11380 (43.2)	10412 (43.6)	355 (38.8)	613 (39.4)	
Never (past 12 months)	14970 (56.8)	13465 (56.4)	561 (61.2)	944 (60.6)	
BMI (kg/m²), n (%)					<0.001
<18.5	1945 (7.4)	1835 (7.7)	30 (3.3)	80 (5.1)	
18.5-23.9	15061 (57.2)	13945 (58.4)	396 (43.2)	720 (46.2)	
24.0-27.9	7280 (27.6)	6384 (26.7)	359 (39.2)	537 (34.5)	
≥28	2064 (7.8)	1713 (7.2)	131 (14.3)	220 (14.1)	
Use of hypoglycemic medicine, n (%)					—
Yes	676 (2.6)	0	676 (73.8)	0	
Not	25674 (97.4)	23877 (100)	240 (26.2)	1557 (100)	
Age (year), median (25th-75th percentile)	50.1 (40.0-60.1)	49.8 (39.0-59.9)	59.0 (52.0-67.0)	54.0 (44.8-63.0)	<0.001
Body mass index (kg/m²), median (25th-75th percentile)	22.7 (20.6-25.1)	22.6 (20.5-24.9)	24.3 (22.4-26.5)	23.9 (21.5-26.4)	<0.001
Physical activity time (hour/day)*, mean±SD	0.2±0.7	0.2±0.7	0.3±0.6	0.2±0.5	<0.001
Sedentary leisure time (hour/day), median (25th-75th percentile)	4.0 (2.0-6.0)	4.0	4.5	4.0	<0.001

Daily mean humidity [#] , median (25th-75th percentile)	75.0	(2.0-6.0)	(3.0-6.8)	(2.0-6.0)	<0.001
	(66.0-84.0)	(66.0-84.0)	(69.0-90.0)	(64.0-85.0)	

Data were expressed as median (25th-75th percentile) for non-normal continuous variables and as number (percentage) for categorical variables. Statistics analysis: Kruskal-Wallis test for non-normal continuous variables and chi square test for categorical variables.

†: Non-T2DM, no medical history of type 2 diabetes mellitus with fasting plasma glucose less than 7.0 mmol/L.

‡: Old T2DM, physician-diagnosed type 2 diabetes mellitus.

- : New T2DM, newly detected type 2 diabetes mellitus with fasting plasma glucose of 7.0 mmol/L or greater.

*: Physical activity time variable of median (25th-75th percentile) was zero, so it was expressed as mean±SD.

#: Daily mean humidity was matched by the same date of health survey.

The effects of ambient temperature on FPG

In total, non-T2DM and old-T2DM groups, the exposure-response curves were general downward parabola. As temperature increased, FPG concentration significantly decreased. However, the exposure-response curve was “U” shaped with statistically insignificance in new T2DM cases (Figure 2).

When temperature decreased from 30°C to 4°C on the survey day (lag 0), the FPG significantly increased 0.59 (95%CI: 0.49, 0.68) mmol/L, 0.47 (95%CI: 0.43, 0.52) mmol/L and 1.59 (95%CI: 0.59, 2.59) mmol/L in total, non-T2DM and old-T2DM groups, respectively. For new T2DM cases, we found no significant effect of temperature on FPG (Table 2).

Temperature-adjusted FPG, prevalence and glycemic control rate of T2DM

Temperature adjusted FPG decreased when temperature increased for total, non-T2DM and old T2DM groups. For instance, the mean of temperature-adjusted FPG was 5.78 mmol/L at 5°C while 5.20 mmol/L at 30°C in total population; 5.40 mmol/L at 5°C while 4.93 mmol/L at 30°C in non-T2DM participants, 9.07 mmol/L at 5°C while 7.51 mmol/L at 30°C in old T2DM cases. However, the association between temperature and FPG was a down and up

trend in new T2DM cases. For instance, the mean of temperature-adjusted FPG was 9.56 mmol/L at 5°C, 9.08 mmol/L at 20°C and 9.36 mmol/L at 30°C, respectively (Figure 3A).

Based on temperature-FPG association, we adjusted prevalence and glycemic control rate of T2DM (Figure 3B). Low ambient temperature led to gently increase in prevalence of T2DM and greatly decrease in glycemic control rate of T2DM. For example, when ambient temperature increased from 5°C to 30°C, the prevalence of T2DM decreased from 10.03% to 9.39%, while the glycemic control rate of T2DM increased from 31.9% to 58.5%.

Sensitivity analyses

Similar exposure-response relationships between temperature and FPG were observed when different lag times were used or additional covariates like sunshine, precipitation, weekly food consumption and family history of diabetes were controlled (Figure S4, Figure S5 and Figure S6 in Additional file 1). Moreover, there were no significant change of temperature effects on FPG compared to the result of the main model analysis, suggesting that our results were relatively robust (Table 2). In addition, similar relationships between temperature and FPG were observed when using FPG and 2-hour plasma glucose as diagnosed criteria (Figure S7 in Additional file 1).

Table 2 Change of FPG (mmol/L) at different typical interval of temperature.

	Total	Non-T2DM [†]	Old T2DM [‡]	New T2DM [§]	
Temperature	4°C vs 30°C	4°C vs 30°C	4°C vs 30°C	4°C vs 19°C	30°C vs 19°C
a					
Main model					
Lag 0	0.59 (0.49, 0.68)	0.47 (0.43, 0.52)	1.59 (0.59, 2.59)	0.57 (-0.11, 1.25)	0.29 (-0.24, 0.82)
Lag 1	0.58 (0.50, 0.66)	0.45 (0.41, 0.49)	1.18 (0.50, 1.86)	0.58 (-0.03, 1.20)	0.34 (-0.20, 0.87)
Lag 2	0.61 (0.53, 0.69)	0.46 (0.42, 0.50)	1.46 (0.77, 2.16)	0.44 (-0.10, 0.97)	0.07 (-0.40, 0.55)
Lag 3	0.64 (0.55, 0.72)	0.49 (0.45, 0.53)	1.38 (0.36, 2.40)	0.29 (-0.25, 0.84)	0.11 (-0.37, 0.59)
Lag 4	0.55 (0.46, 0.65)	0.37 (0.31, 0.41)	1.66 (0.60, 2.72)	0.27 (-0.14, 0.67)	-0.19 (-0.51, 0.13)
Lag 5	0.56 (0.46, 0.65)	0.35 (0.31, 0.40)	1.76 (0.80, 2.71)	0.27 (-0.10, 0.64)	-0.22 (-0.55, 0.10)
Lag 6	0.52 (0.42, 0.61)	0.36 (0.31, 0.40)	1.67 (0.78, 2.55)	0.04 (-0.36, 0.45)	0.00 (-0.33, 0.33)
Model 2	0.53 (0.44, 0.63)	0.43 (0.39, 0.47)	1.46 (0.51, 2.40)	0.51 (-0.17, 1.19)	0.32 (-0.18, 0.86)

†: Non-T2DM, no medical history of type 2 diabetes mellitus with fasting plasma glucose < 7.0 mmol/L.

‡: Old T2DM, physician-diagnosed type 2 diabetes mellitus.

- : New T2DM, newly detected type 2 diabetes mellitus with fasting plasma glucose ≥ 7.0 mmol/L.

^a Represents the change of FPG when minimum of daily mean temperature (4°C) compared with threshold temperature (30°C) in total population, non-T2DM and old T2DM subgroups, the change of FPG when minimum/maximum of daily mean temperature (4°C/30°C) compared with threshold temperature (19°C) in new T2DM subgroup.

Main model was adjusted for age, sex, BMI, education, career, physical activity, sedentary leisure times, smoking status, drinking status, humidity and use of hypoglycemic medicine variables. Model 2 was adjusted model 1 and additionally sunshine and precipitation variables.

Discussion

In our study, we found that FPG levels were significantly higher in cold season than warm season in total and different T2DM groups. The exposure-response curves between ambient temperature and FPG were downward parabola-shaped in total, non-T2DM and old-T2DM groups, while it was U-shaped in new T2DM cases. The prevalence and glycemic control rate of T2DM varied across temperature. Adjusted T2DM prevalence based on temperature-FPG association decreased as temperature increased, while glycemic control rate of T2DM increased with the rising of temperature. This is the first large-scale study estimating temperature adjusted prevalence and control rate of T2DM.

We found that FPG had apparent seasonal variation with high concentrations in cold season and low concentrations in warm season, which was consistent with previous studies [5, 6, 15]. For instance, a similar association was observed that the level of FPG was 0.6 mmol/L higher in winter (13°C) than in summer (23°C) in San Diego County, California [5]. A large study included 15 middle and high countries also found that higher FPG among adults was observed in winter than summer in both Northern Hemisphere and Southern Hemisphere [15].

Previous studies have reported that a negative association between ambient temperature and FPG [5, 7]. However, the researches just estimated their correlation coefficient rather than the non-linear relationship between ambient temperature and FPG, and they also did not consider the variation in sensitivity to temperature among various people. Our study therefore established the non-linear relationship and found that FPG concentration significantly decreased as temperature increased, and the rate of descent increased as temperature increased among total, non-T2DM and old T2DM groups. In addition, our results indicated that the influence of temperature on the FPG seems to be stronger in old T2DM cases than non-T2DM participants. The reason may be T2DM is associated with declining insulin sensitivity and beta-cell function, and the glucose regulation of T2DM was poorer than non-T2DM [16]. For new T2DM cases, we found that exposure-response curve was U-shaped, but the effect of low and high temperature on FPG was not statistically significance. This result may be explained by that new T2DM cases were under large fluctuation in FPG without taking hypoglycemic medicine, which may affect the stability of FPG. Future studies were needed to investigate this mechanism of this phenomenon. Secondly, as the present study was conducted in winter, spring and autumn and without high temperature, which may not estimate the hot temperature effect on FPG. Future studies conducted in summer can further observe the association of extremely high temperature and FPG.

Related mechanism on the effects of ambient temperature on FPG is that temperature variation may affect glucose homeostasis including plasma insulin and glucagon [17, 18]. Sustained exposure to low ambient temperature increase energy expenditure and insulin resistance [19, 20]. Population study demonstrated that per 10°C increase of outdoor temperature was associated with 0.57 units increase of insulin sensitivity index [21]. Extreme cold temperature exposure could lead to increase in the thyrotropin and decrease in total thyroxine and free thyroxine (TF4), which related to decreased insulin sensitivity [22, 23].

Previous studies found that the prevalence and glycemic control rate of T2DM varied with seasons, which may lead to underestimate of T2DM prevalence and overestimate of T2MD glycemic control rate when epidemiological surveys conducted in hot season [6, 9, 10]. To our knowledge, previous T2DM prevalence surveys rarely considered the effects of ambient temperature [11]. Our study estimated prevalence and glycemic control rate of T2DM after adjusting ambient temperature, and found that temperature adjusted T2DM prevalence declined and glycemic control rate increase as temperature rise. These findings suggested the temperature should be adjusted when estimating the prevalence and glycemic control rate of T2DM, as well as making nutritional prescriptions, exercise plans and treatment protocols for T2DM cases. For example, people with borderline high FPG in hot season could be diagnosed as T2DM in cold season.

Our study had several strengths. First, our study sample was relatively large. Secondly, we analyzed the associations between FPG and temperature among different T2DM subgroups. Thirdly, we calculated the temperature adjusted T2DM prevalence and control rate. However, several limitations should be warranted. Firstly, the daily mean temperature at nearest meteorological station served as temperature exposure, which may somewhat differ from real temperature exposure. But it is infeasible to collect personal temperature exposure in a large-scale survey. In addition, using the daily mean temperature at nearest meteorological station as an alternative of personal exposure has been widely applied in previous studies [24, 25]. Secondly, the cross-sectional design of the study may restrict our ability to estimate the causal effect of temperature on FPG. However, we respectively used the temperature 0-6 days prior to the measurement of FPG as exposure and got consistent results, which partially guarantee the time sequential relationship between temperature exposure and FPG. Thirdly, since we did not obtain the dietary and hereditary information of all participants, which limited us to control these covariates in the analysis. Instead, we performed sensitivity analysis using the participants who has weekly food consumption of grains, vegetables, fruit, meat and family history of diabetes information. The estimate on the association of temperature and FPG remained relatively stable after controlling for weekly food consumption and family history of diabetes (see Figure S6 in Additional file 1). Fourth, we only collected data from October to May, which limited us to estimate the associations between temperature and FPG in hot seasons. Further study should be conducted in the future.

Conclusions

In conclusion, FPG, prevalence and glycemic control rate of T2DM are affected by ambient temperature, which suggests that ambient temperature should be adjusted when estimating prevalence and glycemic control rate of T2DM. For clinical implications of T2DM, the temperature-FPG association can help improve the T2DM diagnosis and guide decisions regarding hypoglycemic treatment to achieve better FPG control.

Additional Files

Additional file1: Table S1. Number (%) of participants in each survey location in Guangdong province during 2007 and 2016.

Figure S1. The non-linear relationships between daily mean, daily minimum, daily maximum temperature and FPG in total population and different T2DM subgroups.

Figure S2. The non-linear relationships between daily mean and FPG in total population and different T2DM subgroups at k=3,4,5.

Figure S3. The density distribution of fasting plasma glucose in total population and different T2DM subgroups.

Table S2. Statistical description of fasting plasma glucose (FPG) and daily mean ambient temperature in total population and different T2DM subgroups.

Table S3. Number (%), Mean and SE of fasting plasma glucose and daily mean temperature according to month.

Figure S4. The exposure-response relationships between lag1 to lag6 of ambient temperature and FPG in total population and different T2DM subgroups.

Figure S5. The exposure-response relationships between ambient temperature and FPG in total population and different T2DM subgroups additionally adjusted sunshine and precipitation.

Figure S6. The exposure-response relationships between ambient temperature and FPG in total population and different T2DM subgroups in survey of 2010 and 2015.

Figure S7. The exposure-response relationships between ambient temperature and FPG in non-T2DM and new-T2DM subgroups for the diagnostic standard of T2DM based on FPG and 2-hour plasma glucose in 2013 survey.

Declarations

Competing interests

The authors have declared that no conflict of competing financial interests.

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Authors contributions

JL carried out the statistical analyses, JL and GH drafted the manuscript and contributed equally to this research. YX, ZC, XX, GJ, WM participated in study design and data collection. SC, JH, TL, WZ, XL, JX, LG, JP, WM reviewed and revised manuscript. All authors approved final version of the manuscript to be published.

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Ethics approval

The protocol was approved by the Ethics Committee of Guangdong Provincial Center for Disease Control and Prevention (Ethical review code: 2019009). All the participants agreed to participate and signed informed consents form prior to the surveys.

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Availability of data

Data are not publicly available and information on how to access the data can contact details: Email: mawj@gdiph.org.cn.

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Figures

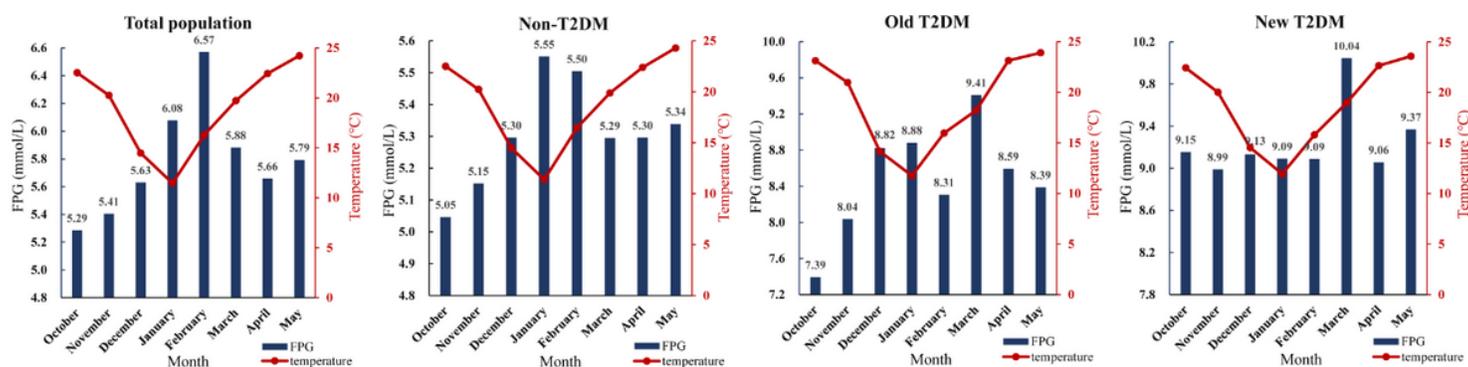


Figure 1

Monthly variation of mean FPG (mmol/L) and ambient temperature (°C) among total population, non-T2DM, old T2DM and new T2DM subgroups.

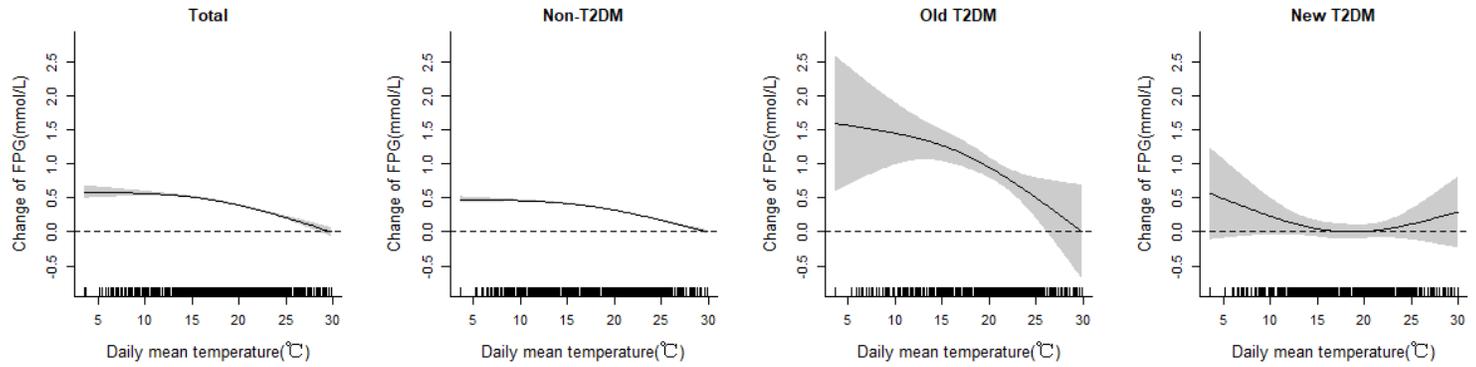


Figure 2

The exposure-response of daily mean temperature and FPG among total population, non-T2DM, old T2DM and new T2DM subgroups. Shade represents 95%CI Confidence interval. Non-T2DM means no medical history of type 2 diabetes mellitus with fasting plasma glucose less than 7.0 mmol/L. Old T2DM stands for physician-diagnosed type 2 diabetes mellitus. New T2DM is newly detected type 2 diabetes mellitus with fasting plasma glucose of 7.0 mmol/L or greater. Gaussian generalized additive models were adjusted for age, sex, BMI, education, career, physical activity, sedentary leisure times, smoking status, drinking status, humidity and use of hypoglycemic medicine variables.

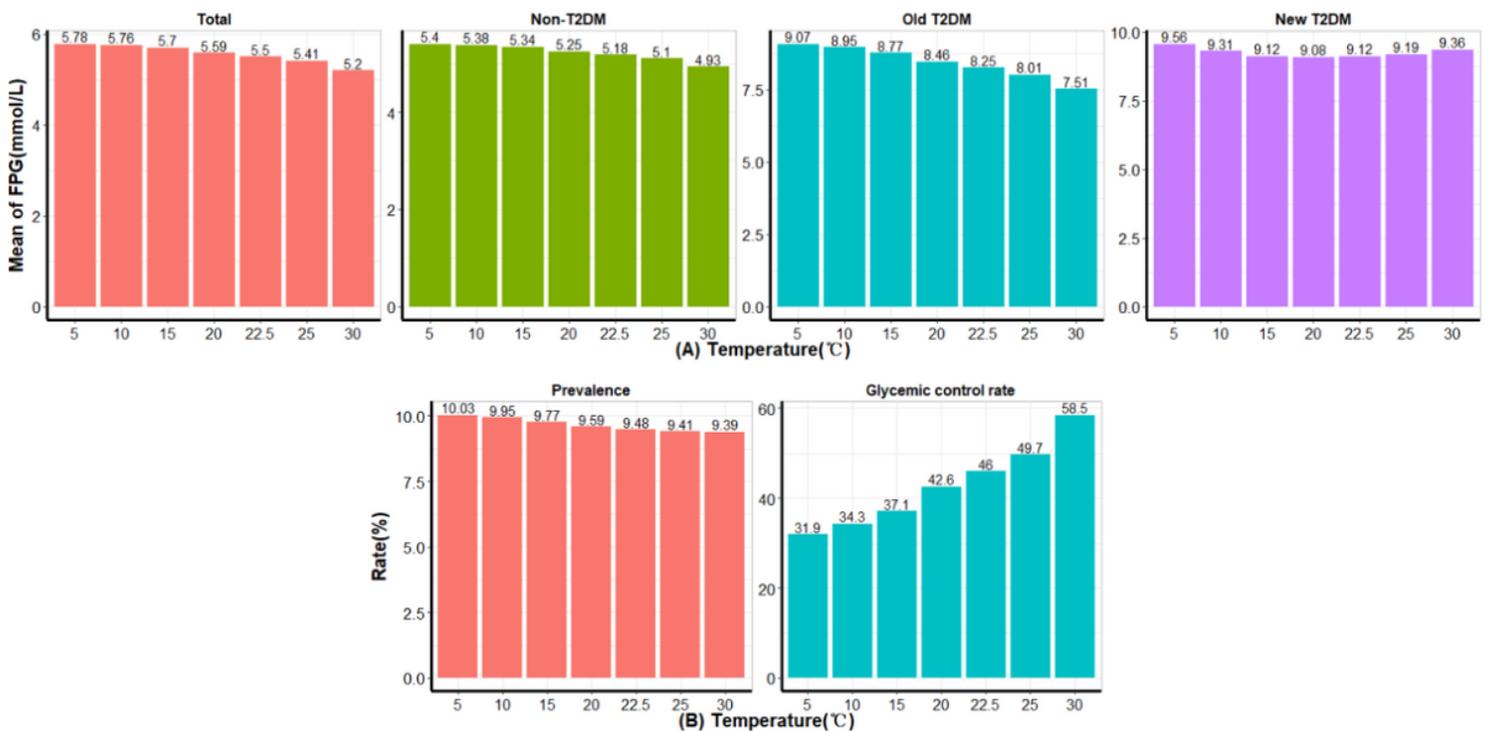


Figure 3

(A) Temperature adjusted FPG concentrations. (B) Adjusted prevalence (%) and glycemic control rate (%) of T2DM based on temperature-FPG association. Adjusted FPG, prevalence and glycemic control rate of

T2DM at 5°C, 10°C, 15°C, 20°C, 22.5°C, 25°C, 30°C. Temperature adjusted FPG calculation was based on exposure-response curve of daily mean temperature and FPG. (*, annual mean temperature in Guangdong Province).

Supplementary Files

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