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Suboptimal diet quality is associated with the incidence of type 2 diabetes mellitus in middle-aged and older populations in China: evidence from population-based cross-sectional study

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List of Abbreviations

BMI, Body mass index; DBI-16, Dietary balance index; DQD, Dietary quality distance; FBG, Fasting blood glucose; HBS, High bound score; LBS, Lower bound score; RCS, Restricted cubic spline; T2DM, Type 2 diabetes mellitus.

Abstract

The association between dietary quality and type 2 diabetes mellitus (T2DM) based on the Chinese Dietary Balance Index (DBI-16) is seldom reported. We hypothesized that poor dietary quality might increase the risk of T2DM in the middle-aged and older populations. A total of 1816 individuals (≥ 50 years) were included in the study. Demographic characteristics and dietary intake data were collected. Logistic regression and restricted cubic spline (RCS) analyses were conducted to explore the association between DBI-16 indexes and the risk of T2DM. The insufficient intake of vegetables and dairy might decrease the risk of T2DM ($OR_{Vegetable}$ = 0.77, *95%CI* = 0.60 – 0.97; OR_{Dairy} = 0.58, *95%CI* = 0.35 – 0.96), but the individuals with insufficient intake of fruit were more likely to have a higher risk of T2DM (*OR* = 2.26, *95%CI* = 1.69 - 3.06). Compared with the subjects with the lowest quartile of Low Bound Score (LBS) or Diet Quality Distance (DQD), the individuals with Q2 and Q3 level of LBS (OR_{Q2} = 1.40, *95%CI* = 1.03 – 1.90, $P = 0.033$; OR_{Q3} = 1.52, *95%CI* = 1.11 – 2.08, $P < 0.01$) or DQD (OR_{Q2} = 1.45, *95%CI* = 1.06 – 1.99, $P = 0.021$; OR_{Q3} = 1.64, *95%CI* = 1.20 – 2.24, $P < 0.01$) showed increased risk of T2DM with a nonlinear association observed by RCS analysis. We concluded that imbalanced dietary intake, especially insufficient daily fruit intake, might predict an increased risk of T2DM in the middle-aged and elderly Chinese.

Keywords: Dietary quality; Dietary Balance Index; type 2 diabetes mellitus; the middle-aged and older populations; cross-sectional study

1. Introduction

Globally, diabetes mellitus remains a significant public health concern, with type 2 diabetes mellitus (T2DM) accounting for 90% of all diabetes patients [1]. As a risk factor, aging might accelerate the development and progression of T2DM [2]. The prevalence of T2DM in Chinese adults has been reported to be about 11%, and even the prevalence in older adults over 60 is 22.8% [3, 4]. According to the most recent census data, China has reached a staggering 264 million individuals aged 60 and above, with this number expected to surge in tandem with the increase in life expectancy. People with T2DM suffer from a variety of serious complications, including metabolic syndrome, cardiovascular disease, and diabetic nephropathy, all of which severely affect the quality of life and place a burden on families and society [5]. Therefore, preventing T2DM in Chinese middle-aged and older adults is an urgent issue.

Dietary intake is one of the modifiable factors closely associated with the onset of T2DM [6]. Recent studies have shown that 70% of new cases of diabetes worldwide can be attributed to suboptimal intake of various dietary factors [7]. Lower refined sugar or carbohydrate consumption and higher selenium intake are recommended to reduce the risk of developing diabetes [8, 9]. Although numerous studies have demonstrated the beneficial effects of a single nutrient on the risk of T2DM, the latest studies have concentrated more on dietary patterns due to complex synergistic effects among nutrients and biologically active components [10, 11]. A meta-analysis of prospective studies indicated that diet containing more whole grains, vegetables, fruits, and dairy, but low amounts of red and processed meats and eggs could prevent individuals from developing T2DM [12]. It is also reported that a healthy diet pattern was more likely to reduce the risk of T2DM in adults [13].

The Chinese Diet Balance Index 2016 (DBI-16), developed by the current Chinese dietary guidelines and Food Guide Pagoda (2016), was devised to evaluate the dietary quality of Chinese residents [14]. A relatively balanced diet as assessed by the DBI-16, i.e. better adherence to dietary guidelines, has been reported to be associated with a lower risk of T2DM in adults [6]. Data from the China health and nutrition survey of adults showed that the long-duration dietary quality calculated by DBI-16 was positively associated with the risk of diabetes, including insufficient dietary intake and overall dietary imbalance, which is defined as poor adherence to dietary guidelines [15]. Similarly, a study conducted on pregnant women observed higher postprandial glucose attributed to excessive total food intake as calculated by DBI, indicating that lower adherence to the dietary guideline for animal-derived foods increased both postprandial glucose and the risk of diabetes during pregnancy [16]. Results from another study applying DBI-16 for dietary quality assessment indicated that unfavorable dietary quality was related to a higher risk of prediabetes, especially among the subjects who had abdominal obesity, and those who had smoking and alcohol drinking habits [10]. With aging, the food choices, daily dietary intake, and dietary patterns of middle-aged and older people might change and adjust accordingly, thus affecting the dietary quality. The relationship between the dietary pattern and dietary quality and the chronic diseases related to aging is worthy of in-depth exploration. However, to date, few studies have explored the relationship between dietary quality and diabetes based on DBI-16 in middle-aged and older Chinese populations. We therefore hypothesized that imbalanced dietary intake may be associated with the increased risk of T2DM in the middle-aged and elderly population. In the present study, DBI-16 was applied to evaluate the relationship between diet quality and the risk of T2DM in Beijing City and to explore the potential association between specific food intake and the risk of this chronic disease. This issue can establish a scientific foundation for guiding the dietary regimen of Chinese middle-aged and older individuals with T2DM in future clinical practice.

2. Material and methods

2.1 Participants

Two-thousand one-hundred and ninety participants aged 50 years and above were recruited from the Nanyuan, Wulituo, and Guanganmen communities in Beijing City. Type 2 diabetes mellitus was diagnosed according to the guidelines for the prevention and control of T2DM in China (2022 Edition) [17]. The study was endorsed by the Ethics Committee of Capital Medical University (No. 2012SY23) *and* complied with the ethical guidelines of the Helsinki Declaration. All participants in this study provided signed informed consent.

We excluded those who did not complete the questionnaire investigation and anthropometric parameters examination, those with missing information on fasting plasma glucose and lipids concentrations, and those who had no history of diabetes but a fasting blood glucose concentration ≥ 6.1 mmol/L. Finally, a total of 1,816 participants were included in the analysis.

Those who reported having a history of diabetes were defined as T2DM and participants who reported no history of diabetes and had a fasting blood glucose concentration < 6.1 mmol/L were defined as non-T2DM.

2.2 Demography and dietary survey

A face-to-face interview was conducted to collect participants' demographic, lifestyle, and disease history information. Anthropometric parameters (height and weight) were only measured once using an automatic height and weight instrument (LEKA, HW-900A, China). Body mass index (BMI) was calculated as weight (kilogram) divided by the square of height (meter). Physical activity data were collected through the questionnaire to ask the participants "How often do you have sports per week", and physical activity was categorized into "never, 1-3 days/week, 4-6 days/week, every day" according to the self-reported frequency of physical activity.

The daily dietary intake of the participants was assessed using a validated semi-quantitative food frequency questionnaire (FFQ). This questionnaire was developed based on the version adopted by the Chinese Nutrition Society as previously described [18]. The investigation of the consumption frequencies (on a daily and weekly basis) as well as the quantities consumed for 11 food items was conducted by nutritionists and registered nurses who underwent specialized training. The food items listed included cereal, fruits, vegetables, legumes, whole grains, red meat, poultry, fish, eggs, tea, milk, and cooking oil. Cooking oil consumption was calculated based on the number of family members and the amount of cooking oil consumed monthly.

The dietary quality was evaluated using the DBI-16, a tool specifically designed to assess the nutritional adequacy of the Chinese population [14]. A score of 0 is assigned when the subgroup's food intake meets the recommended intake level. If the subgroup's food intake exceeded or was insufficient to meet the recommended levels, a positive or negative score was given, respectively. We calculated and adjusted three indicators of the DBI-16 component score after calculating each component score because we lacked intake data for alcoholic beverages, added sugar, drinking water, and salt. The High Bound Score (HBS) is the sum of all positive scores indicating an excessive amount of dietary intake. The absolute value of the sum of all negative scores indicating an insufficient extent of dietary intake is defined as the Low Bound Score (LBS). Diet Quality Distance (DQD) is the sum of HBS and LBS, indicating the overall extent of dietary imbalance. The score range of HBS, LBS, and DQD is 0-26, 0-56, and 0-62, respectively.

2.3 Plasma parameter measurement

Participants fasted for 12 hours before blood sampling. Fasting blood samples were obtained from all participants, and plasma was separated for biochemical parameter measurement. Fasting blood glucose (FBG), total cholesterol (TC), and triglyceride (TG) concentrations were determined using an ILAB8600 clinical chemistry analyzer (Instrumentation Laboratory, Lexington, WI, USA). Blood high-density lipoprotein cholesterol (HDL-C) concentration was measured by a commercially available assay from the Instrumentation Laboratory (Lexington, WI, USA). Blood low-density lipoprotein cholesterol (LDL-C) was calculated based on the Friedewald formula [19]. All samples were analyzed together in one batch with intraassay coefficients of variation (CV) below 5%.

2.4 Potential covariates

We evaluated the modifying effect of demographic characteristics as potential confounding factors, including age, gender, BMI, education (illiterate, primary school, junior high school, high school, junior college, undergraduate, and above), smoking (never, former, and current), drinking alcohol, physical activity (never, 1-3 days/week, 4-6 days/week, every day), usage of dietary supplements, drinking tea, and history of the disease, including hyperlipidemia, stroke, and chronic kidney disease (CKD). The history of hyperlipidemia, stroke, or CKD was identified according to self-reports. The individuals with "yes" to the question "Ever did you have hyperlipidemia, stroke or CKD" were defined to have a history of hyperlipidemia, stroke, or CKD.

2.5 Statistical analysis

All analyses were performed using SPSS 23.0 and R 4.3 software, and all analyses were two-sided. Two-sided *P* values less than 0.05 were considered statistically significant. Continuous and categorical data were expressed as mean ± SD or number (n) and percentage (%). Student's *t* test or chi-square test was applied to compare the differences in demographic characteristics between T2DM and control groups. The Mann-Whitney *U* test was used to compare the differences in daily dietary intake and dietary balance index between groups.

The association between the DBI-16 index of specific food intake and the concentration of FBG without controlling the effects of other food intakes was analyzed by univariate linear regression. To further evaluate the impact of all food intakes on the FBG concentration, we also implemented multiple linear regression by incorporating all food intakes into models. Similar analyses for associations between the DBI-16 index of each food intake and the risk of T2DM were also analyzed by univariate and multiple logistic regression. The β coefficient, odds ratio (OR), and corresponding 95% confidence intervals (CIs) were determined by comparing insufficient or excessive intake and sufficiency of intake in each food.

For LBS, HBS, and DQD as three primary assessing indicators of DBI-16, univariate linear regression was employed to estimate the association between the primary indicators of DBI-16 and FBG concentration respectively, and we implemented multiple linear regression to evaluate the independent effect of HBS and LBS on FBG concentration by incorporating LBS and HBS together in models. Univariate logistic regression was conducted to evaluate the association between the three primary indicators of DBI-16 and the risk of T2DM respectively. The full-adjusted logistic regression was then used to make the independent effect of HBS and LBS on T2DM by incorporating HBS and LBS into the model. The β coefficient, odds ratio (OR), and corresponding 95% CIs were determined by comparing three quartiles (Q2, Q3, and Q4) to the reference quartile (Q1). We performed the trend test using HBS, LBS, or DQD with four quartiles transformed into an ordinal categorical variable. The dose-response relation between HBS, LBS, or DQD scores and the risk of T2DM was determined using logistic regression fitted by restricted cubic spline (RCS) with three knots (25th, 50th, and 75th).

The covariates were adjusted as follows: model 1 was adjusted for age and gender; model 2 was further adjusted for BMI, education, physical activity, smoking status, alcohol consumption, usage of dietary supplements, and tea consumption based on model 1; model 3 was further adjusted for CKD, stroke, and hyperlipidemia based on model 2.

We also conducted the stratified analysis to investigate potential effect modifications of BMI, gender, tea consumption, smoking, and alcohol drinking. Considering the possible interactive effects between the stratifying factors and three primary indicators of DBI-16, a likelihood ratio test was performed to compare models with or without an interactive variable.

3. Results

3.1 Demographic characteristics of participants and dietary intake

In this cross-sectional study, 502 participants were T2DM patients (Table 1). Compared with the non-T2DM group, the percentage of male subjects and the percentage of subjects with hyperlipidemia, stroke, or CKD were higher in the T2DM group (*P* < 0.05). The subjects in the T2DM group also had higher BMI, and the percentage of subjects with overweight and obesity were higher than the non-T2DM group (*P* < 0.05). Plasma TC, HDL-c, and LDL-c concentrations were lower in the T2DM group, whereas the TG concentration was higher in the T2DM group than in the non-T2DM group (all *P* < 0.01). As shown in Supplementary Table 1, the percentage of subjects with insufficient consumption of fruit and soybean was higher in the T2DM group than in the non-T2DM group (*P* < 0.01). In addition, the T2DM group had a lower percentage of subjects with insufficient intake of dairy compared to the non-T2DM group (*P* < 0.05).

3.2 Association between DBI-16 components, FBG concentration, and the risk of T2DM

Statistical significances were observed in the association between daily intakes of cereal, fruit, and dairy with the FBG concentration (Supplementary Table 2) (all *P* < 0.05). When incorporating all food components into the models, we consistently found a significant association between daily cereal, fruit, and dairy intakes and the FBG concentration. Specifically, in comparison with the sufficient diets consumption group, excessive intake of cereal and insufficient intake of dairy were negatively associated with FBG concentrations in the participants (β_{cereal} = -0.20, *95% CI* = -0.39 – -0.02, *P* = 0.031; β_{dairy} = -0.71, *95% CI* = -1.11 – -0.32, *P* < 0.001), but the positive association for the insufficient fruit intake (*β* = 0.41, *95% CI* = 0.22 – 0.61, *P* < 0.001).

The results of univariable logistic regression showed a significant relation of dietary fruit, dairy, soybean, and meat intakes with the risk of T2DM (all *P* < 0.05). The association between these diets with the risk of T2DM remained unchanged in models 2 and 3 after adjusting for age, gender, and other confounding factors (Table 2). In addition, the results from multivariable full-adjusted logistic regression consistently demonstrated that insufficient fruit consumption might increase the risk of T2DM among middle-aged and older people (OR = 2.26, *95% CI* = 1.69 – 3.06, P < 0.001). Conversely, daily insufficient intake of vegetables and dairy showed a negative correlation with the risk of T2DM in middle-aged and older individuals ($OR_{vegetable}$ = 0.77, *95% CI* = 0.60 – 0.97, P = 0.030; OR_{dairy} = 0.58, *95% CI* = 0.35 – 0.96, P = 0.031) (Table 3).

3.3 The association between primary DBI-16 indexes, the FBG concentration, and the risk of T2DM

The results in univariable regression from Table 4 indicated that individuals with the highest quartile of HBS have the lowest risk of T2DM ($OR_{Q4\ vs.\ Q1}$ = 0.67; *95% CI*: 0.49 – 0.92; P_{trend} = 0.025). Conversely, an increase in LBS appears to be associated with a raised risk of T2DM among the middle-aged and older population ($OR_{Q2\ vs.\ Q1}$ = 1.45; *95% CI*: 1.07 – 1.97; $OR_{Q3\ vs\ Q1}$ = 1.61; *95% CI*: 1.18 – 2.19; P_{trend} = 0.033). Furthermore, individuals with the Q2 and Q3 quartiles of DQD exhibited a 45% and 64% increased risk of T2DM in comparison to those in the lowest quartile, respectively ($OR_{Q2\ vs.\ Q1}$ = 1.45; *95% CI*: 1.06 – 1.99; $OR_{Q3\ vs\ Q1}$ = 1.64; *95% CI*: 1.20 – 2.24; P_{trend} > 0.05). However, this association was not consistently observed for individuals with the highest DQD quartile. The association between LBS and the risk of T2DM remained unchanged ($OR_{Q2\ vs\ Q1}$ = 1.40; *95% CI*: 1.03 – 1.90; $OR_{Q3\ vs\ Q1}$ = 1.52; *95% CI*: 1.11 – 2.08) after incorporating HBS and LBS within a comprehensive model that considered all confounding factors. No significant association was found for HBS. In RCS analysis, we found that subjects with Q2 and Q3 levels of LBS or DQD showed an increased risk of T2DM when compared to the subjects with Q1 levels of LBS or DQD. Meanwhile, a nonlinear relationship was also identified between LBS or DQD and the risk of T2DM (all $P_{nonlinear}$ < 0.05; Figure 1).

Compared with the subjects with the lowest quartile of HBS, individuals with the highest quartile of HBS had lower FBG concentrations (β = -0.31, *95% CI* = -0.55 – -0.08, P < 0.01; P_{trend} = 0.01). This association between HBS and FBG remained unchanged after incorporating both HBS and LBS into a full model with adjustment for all confounders (Supplemental Table 4).

3.4 Associations between primary DBI-16 indexes and risk of T2DM according to demographic factors

Upon stratifying the participants according to the demographic factors potentially linked to food intake and the risk of T2DM, we observed the impacts of LBS and DQD on the risk of T2DM appeared to be potentially modified by gender, BMI, tea consumption, smoking status, and alcohol drinking, although the interaction test did not reach a significant difference (all $P_{interaction}$ > 0.05; Supplemental Table 5 - 9). Positive associations between LBS, DQD and the risk of T2DM were found exclusively among middle-aged and older females, and those who were overweight, never smokers, or non-drinkers. Furthermore, the strength of the impacts of LBS and DQD on the risk of T2DM appeared to increase, albeit to varying degrees (Supplemental Table 5, 6, 8, and 9). Regarding tea consumption, the previously observed positive association between DQD and the risk of T2DM vanished in the subgroup of non-tea drinkers. Conversely, in the subgroup of drinking tea, a significant association between LBS and an increased risk of T2DM was found in subjects with Q2 level in comparison to the reference group (Supplemental Table 7).

4. Discussion

In the current study, we investigated the impact of dietary quality on the risk of T2DM in middle-aged and older individuals based on the DBI-16 index. We confirmed our hypothesis that a more severe overall imbalance of dietary intake might elevate the risk of T2DM in the middle-aged and older population, probably attributed to insufficient dietary intake. Notably, after adjusting for confounding factors, a lower risk of T2DM was found in subjects with insufficient consumption of daily vegetables and dairy. Conversely, the middle-aged and older population with insufficient fruit intake are prone to have an increased risk of T2DM. Additionally, we identified nonlinear dose-response relationships between LBS, DQD, and the risk of T2DM. Besides, the impacts of LBS and DQD on the risk of T2DM were affected by BMI, gender, tea consumption, smoking status, and alcohol consumption.

We observed that middle-aged and older individuals with T2DM displayed more pronounced inadequacies in fruit and soybean intake, while a lower prevalence of dairy intake insufficiency. Data from the China Health and Nutrition Survey (CHNS) revealed that participants with prediabetes had higher negative scores in the DBI-16 than control ones [10]. Additionally, a case-control study conducted in southern China reported a reduced overall fruit intake in T2DM patients in comparison to control subjects, although no significant disparities were observed in soybean and related product consumption between the two groups [20]. Similarly, a population-based cross-sectional study also found that subjects with gestational diabetes mellitus have higher dairy product consumption and lower legume intake compared to normal subjects [21]. These findings align, in part, with our study results. However, it is crucial to acknowledge potential biases stemming from variations in study design, demographic characteristics, and dietary assessment methods across studies.

Consistent with the findings of previous prospective studies [22, 23], we identified significant associations between daily fruit, vegetable, and dairy intakes and the risk of T2DM in models with comprehensive food adjustments. Moreover, our findings revealed that the intake of dairy and fruit significantly influenced FBG concentrations. This suggests that these three food categories might primarily contribute to the burden of T2DM among middle-aged and older Chinese individuals. The positive impact of insufficient fruit intake on the risk of T2DM might be attributable to the fruit intake-associated changes in gut microbiota and metabolism, which were associated with a decrease in the risk of T2DM [24]. However, some studies did not observe a significant association between fruit or vegetable intake and the risk of T2DM [25, 26]. These discrepancies may be attributed to factors such as gender, the specific types of vegetables and fruits consumed, smoking, alcohol consumption, and the temporal course of T2DM, which are more likely to influence the relationship between dietary intake and T2DM [22, 23, 26-28].

The impact of dietary patterns on the risk of T2DM has been reported by previous studies, suggesting that the Mediterranean or Dietary Approaches to Stop Hypertension (DASH) diet was beneficial in glycemic control, and improving health outcomes [29, 30]. In the current study, the DBI-16 was utilized to investigate the correlation between dietary patterns and T2DM as well. Surprisingly, our study yielded contrasting results to previous research, as it revealed that “meat/dairy product” dietary pattern negatively exhibited correlation with the risk of developing T2DM [6]. However, data derived from the Danish Diet, Cancer, and Health cohort study found that skimmed milk intake, but not semi-skimmed milk, was positively associated with an increased risk of T2DM among individuals aged 56-59 years [31], demonstrating that the type of dairy foods might be an important factor in affecting the relation between dairy intake and the risk of T2DM. As a result, the relationship between different types of dairy products (e.g., milk, yogurt, cheese, condensed milk) and disease should be evaluated in analyzing the relationship between dietary patterns and the risk of T2DM in future studies.

Few studies have applied the DBI index to investigate the relationship between dietary quality and the risk of T2DM in middle-aged and older populations. Unfavorable dietary quality, as assessed by DBI indexes, may be linked to an increased risk of prediabetes or T2DM. Previous studies have reported positive associations between LBS, DQD and the risk of T2DM [10, 15]. Our findings are partly consistent with these results, as we also observed that individuals with a higher level of LBS or DQD showed an increased risk of T2DM. We also identified a nonlinear relationship between LBS or DQD and the risk of T2DM. Moreover, our study revealed that, compared with the subjects with the lowest quartile of HBS, the subjects with the highest quartile of HBS displayed reduced FBG concentrations. This outcome may partly be explained by the fact that the excessive consumption of multiple nutrients, including energy and subsequently leading to abnormal glucose and lipid metabolism as well as hyperglycemia, was observed with a higher prevalence of excessive cereal, meat, and egg intakes in the non-T2DM even though no significant difference [10].

Studies utilizing alternative dietary assessment approaches have also demonstrated that adopting a healthy dietary pattern could reduce the risk of T2DM. For instance, a study conducted among urban Chinese adults found that a healthy diet score (HDS) was inversely associated with the risk of T2DM after adjusting for potential confounders. Subjects who maintained a high HDS during the follow-up study showed a 26% lower risk of T2DM compared to the subjects with a consistently low HDS (HR= 0.74, 95% CI: 0.63-0.85]) [32]. Data from a 13.3-year cohort study found that participants who consumed diets characterized as the most hyperinsulinemia or proinflammatory, as calculated by the Empirical Dietary Index for

Hyperinsulinemia (EDIH) or Empirical Dietary Inflammatory Pattern (EDIP), displayed an elevated risk of T2DM compared to the subjects with the lowest dietary levels [33].

After stratifying the subjects according to gender, BMI, tea consumption, smoking status, and alcohol consumption, distinctive associations in specific subgroups were observed. Notably, the significant relationships between LBS or DQD and the risk of T2DM were predominantly observed among the females and the subjects with overweight, tea drinkers, non-smokers, or non-alcohol drinkers. Comparable studies have also reported modified effects of BMI, and lifestyle including smoking and alcohol drinking on the risk of T2DM in relation to dietary indices [33-36]. However, the heterogeneity in the association between dietary indices and the risk of T2DM across genders did not reach significance in these studies [32, 36]. Given the variations in food weighting and composition between DBI-16 and other dietary indices utilized in different studies, further research on the interaction between gender, BMI, tea consumption, smoking, and alcohol consumption with DBI-16 indexes on the risk of T2DM is warranted.

Our study exhibits several strengths. Firstly, few studies have explored the impacts of dietary patterns based on the DBI-16 dietary assessment method on the risk of T2DM in the Chinese population, particularly among the middle-aged and older population. The DBI-16 method is considered to offer a more comprehensive reflection of total dietary quality and patterns in Chinese individuals compared to other dietary indices. Secondly, while many studies mainly focus on the effects of diet on the risk of T2DM among adults (aged ≥ 18 years), our research underscores the importance of this relationship, specifically focusing on the middle-aged and older population in China.

Some limitations in this study should be mentioned here. Firstly, the reliance on a single dietary survey in this cross-sectional study may not fully capture long-term dietary trends, warranting consideration for repeated measures to assess better the prolonged effects of diets on the risk of T2DM. Secondly, the data derived from the FFQ is subject to potential reporting bias due to its reliance on self-reported information, introducing a degree of measurement error in dietary assessments. Thirdly, despite our efforts to adjust for numerous potential confounding factors associated with the risk of T2DM, the possibility of residual confounding by unmeasured variables remains a consideration. Fourthly, due to the cross-sectional study design, this study could not draw a causal conclusion, and it is necessary to conduct a large-scale cohort study in the future to uncover the association between dietary quality and the risk of T2DM in the middle-aged and older populations.

5. Conclusion

In conclusion, our study furnishes compelling evidence that a higher degree of overall dietary imbalance or insufficiency is associated with an elevated risk of T2DM in the middle-aged and older population. Dietary components, including fruits, vegetables, and dairy products, are significant factors in the overall dietary pattern linked to the risk of T2DM. Insufficient fruit intake may significantly contribute to the overall dietary insufficiency that increases the risk of T2DM. Furthermore, the linkage between DQD or LBS and the risk of T2DM appears to be influenced by gender, BMI, smoking, alcohol drinking, and tea consumption. The findings provide evidence to support the potential efficacy of balanced diets, particularly dietary sufficiency, may be beneficial for mitigating the risk of T2DM among middle-aged and older adults in China.

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Author Contributions

Conceptualization: Linhong Yuan, Pengfei Li, Xiaojun Ma; Formal analysis and investigation: Yu Liu, Lu Liu, Jingjing Xu, Xixiang Wang, Xiuwen Ren; Ying Wang; Data analysis: Pengfei Li, Xiaojun Ma; Writing - original draft preparation: Xiaojun Ma, Pengfei Li, Writing - review and editing: Xiaojun Ma, Shaobo Zhou, Linhong Yuan; Funding acquisition: Linhong Yuan. All authors reviewed the manuscript.

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Legends to Figures

Figure 1. Dose-response relationships between HBS, LBS and DQD scores with risk of T2DM in the middle-aged and elderly. Individuals with high LBS or DQD showed increased risk of T2DM. The dose-response relationship between HBS, LBS or DQD and T2DM was fitted by restricted cubic spline function with three knots (25th, 50th, 75th), adjusting for age, gender, BMI, education, physical activity, smoking, alcohol consumption, usage of dietary supplement, tea consumption, hyperlipidemia, stroke, and chronic kidney disease. Note that the association for HBS scores with three knots and T2DM was adjusted simultaneously by LBS as a categorical variable in quartile, vice versa. CI, confidence interval; DQD, diet quality distance; HBS, high bound score; LBS, low bound score; T2DM, type 2 diabetes mellitus; OR, odds ratio.

Table 1 | Demographic characters and plasma lipids in T2DM and control subjects

Characteristic	T2DM (n = 502)	Non-T2DM (n = 1314)	Total (n = 1816)	*P* value
Age (year)	66.7 ± 6.5	66.2 ± 6.2	66.3 ± 6.3	0.114
Gender (male)	190 (37.8)	421 (32.0)	611 (33.6)	**0.019**
Education				
Illiterate	31 (6.2)	67 (5.1)	98 (5.4)	0.383
Primary school	92 (18.3)	223 (17.0)	315 (17.3)	
Junior high school	215 (42.8)	531 (40.4)	746 (41.1)	
High school	111 (22.1)	352 (26.8)	463 (25.5)	
Junior college	37 (7.4)	91 (6.9)	128 (7.0)	
Undergraduate and above	16 (3.2)	50 (3.8)	66 (3.6)	
Smoking				
Never	361 (71.9)	992 (75.5)	1353 (74.5)	0.171
Former	68 (13.5)	139 (10.6)	207 (11.4)	
Current	73 (14.5)	183 (13.9)	256 (14.1)	
Hyperlipidemia (yes)	280 (55.8)	503 (38.3)	783 (43.1)	**< 0.001**
Stroke (yes)	53 (10.6)	83 (6.3)	136 (7.5)	**< 0.01**
Chronic kidney disease (yes)	45 (9.0)	63 (4.8)	108 (5.9)	**< 0.01**
Physical activity				
Never	35 (7.0)	95 (7.2)	130 (7.2)	0.132
1-3 days/week	47 (9.4)	138 (10.5)	185 (10.2)	
4-6 days/week	38 (7.6)	143 (10.9)	181 (10.0)	
Everyday	382 (76.1)	938 (71.4)	1320 (72.7)	
Alcohol drinking (yes)	142 (28.3)	336 (25.6)	478 (26.3)	0.240
Dietary supplement (yes)	132 (26.3)	300 (22.8)	432 (23.8)	0.116
Drinking tea (yes)	289 (57.6)	729 (55.5)	1018 (56.1)	0.422
BMI (kg/m^2)	25.4 ± 3.3	24.9 ± 3.4	25.0 ± 3.4	**< 0.01**
BMI category				
Underweight	6 (1.2)	25 (1.9)	31 (1.7)	**0.028**
Normal weight	169 (33.7)	513 (39.2)	682 (37.7)	
Overweight	213 (42.5)	542 (41.4)	755 (41.7)	
Obesity	113 (22.6)	228 (17.4)	341 (18.9)	
Plasma parameters, (mmol/L)				
TC	4.8 ± 1.1	5.1 ± 1.0	5.0 ± 1.0	**< 0.001**
TG	1.9 ± 1.6	1.7 ± 1.1	1.7 ± 1.3	**< 0.01**
HDL-c	1.4 ± 0.3	1.5 ± 0.3	1.4 ± 0.3	**< 0.001**
LDL-c	2.8 ± 1.0	3.0 ± 0.8	2.9 ± 0.9	**< 0.001**

The data are presented as mean ± SD and n (%) according to whether the continuous or category variable, respectively. T2DM, type 2 diabetes mellitus. BMI, body mass index. The comparison of continuous data was performed by Student's *t* test, and Chi-square test or Fisher's test was used to compare differences in categorical data. The statistical significance was two-side $P < 0.05$. BMI, body mass index; TC, total cholesterol; TG, triglyceride; HDL-c, high density lipoprotein cholesterol; LDL-c, low density lipoprotein cholesterol.

Table 2 | Univariate logistic regression for the specific food and risk of T2DM among total participants (n = 1816)

DBI-16 item	N	Model 1		Model 2		Model 3	
		OR (95% CI)	*P*	*OR (95% CI)*	*P*	*OR (95% CI)*	*P*
Cereal							
Sufficiency	618	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	384	1.26 (0.95 - 1.67)	0.114	1.27 (0.95 - 1.69)	0.104	1.28 (0.96 - 1.71)	0.097
Excessive	814	0.88 (0.70 - 1.12)	0.298	0.86 (0.67 - 1.09)	0.204	0.84 (0.66 - 1.08)	0.169
Vegetable							
Sufficiency	604	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1212	0.92 (0.74 - 1.15)	0.463	0.92 (0.74 - 1.16)	0.493	0.92 (0.74 - 1.16)	0.493
Fruit							
Sufficiency	461	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1355	**2.18 (1.65 - 2.89)**	**< 0.001**	**2.25 (1.70 - 3.00)**	**< 0.001**	**2.34 (1.76 - 3.14)**	**< 0.001**
Dairy							
Sufficiency	78	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1738	**0.60 (0.37 - 0.96)**	**0.031**	**0.58 (0.36 - 0.94)**	**0.024**	**0.60 (0.37 - 0.98)**	**0.038**
Soybean							
Sufficiency	1531	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	285	**1.55 (1.18 - 2.03)**	**< 0.01**	**1.54 (1.17 - 2.03)**	**< 0.01**	**1.46 (1.10 - 1.94)**	**< 0.01**
Meat							
Sufficiency	270	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	975	0.88 (0.66 - 1.19)	0.417	0.91 (0.67 - 1.23)	0.520	0.92 (0.68 - 1.26)	0.618
Excessive	571	**0.68 (0.49 - 0.95)**	**0.023**	**0.69 (0.50 - 0.96)**	**0.027**	**0.68 (0.49 - 0.95)**	**0.025**
Fish							
Sufficiency	132	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1684	1.34 (0.89 - 2.08)	0.171	1.38 (0.91 - 2.15)	0.141	1.52 (1.00 - 2.40)	0.059
Egg							
Sufficiency	593	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	902	1.22 (0.97 - 1.55)	0.095	1.26 (0.99 - 1.60)	0.063	1.24 (0.97 - 1.58)	0.087
Excessive	321	1.06 (0.77 - 1.45)	0.730	1.04 (0.75 - 1.43)	0.819	0.99 (0.71 - 1.37)	0.954
Cooking oil							
Sufficiency	836	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Excessive	980	1.18 (0.96 - 1.46)	0.114	1.16 (0.94 - 1.44)	0.157	1.22 (0.98 - 1.51)	0.073
Diet variety							
Sufficiency	134	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1682	1.36 (0.90 - 2.09)	0.151	1.36 (0.90 - 2.10)	0.158	1.37 (0.90 - 2.14)	0.154

The association between the DBI-16 index of a single food intake and the risk of T2DM without controlling the effects of other food intakes was analyzed by univariate logistic regression. Model 1 was adjusted by age and gender; Model 2 was further adjusted by BMI, education, physical activity, smoking, drinking alcohol, usage of dietary supplement, and drinking tea on model 1; Model 3 was further adjusted by CKD, CVA and hyperlipidemia on model 2. CKD, chronic kidney disease; CVA, cerebrovascular accident; CI, confidence interval; DBI-16, dietary balance index; T2DM, type 2 diabetes mellitus; OR, odds ratio.

Table 3 | Multivariate logistic regression for the specific food and risk of T2DM among total participants (n = 1816)

DBI-16 item	N	Model 1		Model 2		Model 3	
		OR (95% CI)	*P*	*OR (95% CI)*	*P*	*OR (95% CI)*	*P*
Cereal							
Sufficiency	618	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	384	1.23 (0.92 - 1.65)	0.154	1.23 (0.92 - 1.65)	0.163	1.25 (0.92 - 1.69)	0.147
Excessive	814	0.90 (0.70 - 1.14)	0.374	0.88 (0.69 - 1.12)	0.303	0.87 (0.68 - 1.12)	0.271
Vegetable							
Sufficiency	604	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1212	**0.76 (0.60 - 0.96)**	**0.023**	**0.77 (0.61 - 0.97)**	**0.029**	**0.77 (0.60 - 0.97)**	**0.030**
Fruit							
Sufficiency	461	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1355	**2.10 (1.59 - 2.82)**	**< 0.001**	**2.16 (1.62 - 2.91)**	**< 0.001**	**2.26 (1.69 - 3.06)**	**< 0.001**
Dairy							
Sufficiency	78	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1738	**0.57 (0.35 - 0.94)**	**0.024**	**0.56 (0.34 - 0.92)**	**0.021**	**0.58 (0.35 - 0.96)**	**0.031**
Soybean							
Sufficiency	1531	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	285	**1.44 (1.08 - 1.90)**	**0.012**	**1.42 (1.06 - 1.89)**	**0.016**	1.33 (0.99 - 1.79)	0.055
Meat							
Sufficiency	270	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	975	0.84 (0.62 - 1.14)	0.265	0.86 (0.64 - 1.18)	0.358	0.88 (0.65 - 1.22)	0.447
Excessive	571	0.72 (0.51 - 1.01)	0.059	0.73 (0.52 - 1.03)	0.069	0.72 (0.51 - 1.03)	0.071
Fish							
Sufficiency	132	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1684	1.15 (0.75 - 1.82)	0.529	1.19 (0.77 - 1.89)	0.452	1.30 (0.83 - 2.08)	0.263
Egg							
Sufficiency	593	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	902	1.22 (0.96 - 1.55)	0.113	1.25 (0.98 - 1.60)	0.077	1.23 (0.96 - 1.59)	0.105
Excessive	321	1.17 (0.84 - 1.62)	0.348	1.16 (0.83 - 1.62)	0.369	1.13 (0.80 - 1.59)	0.475
Cooking oil							
Sufficiency	836	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Excessive	980	1.21 (0.98 - 1.49)	0.083	1.19 (0.96 - 1.48)	0.115	1.24 (1.00 - 1.55)	0.054
Diet variety							
Sufficiency	134	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Insufficiency	1682	1.04 (0.66 - 1.66)	0.870	1.03 (0.65 - 1.65)	0.915	1.01 (0.63 - 1.64)	0.969

The independent association between the DBI-16 index of a single food intake and the risk of T2DM after controlling the effects of other food intakes was analyzed by multiple logistic regression incorporating all foods intakes into models. Model 1 was adjusted by age and gender; Model 2 was further adjusted by BMI, education, physical activity, smoking, drinking alcohol, usage of dietary supplement, and drinking tea on model 1; Model 3 was further adjusted by CKD, CVA and hyperlipidemia on model 2. CKD, chronic kidney disease; CVA, cerebrovascular accident; CI, confidence interval; DBI-16, dietary balance index; T2DM, type 2 diabetes mellitus; OR, odds ratio.

Table 4 | The association between DBI-16 indexes with the risk of T2DM among the total participants (n = 1816)

DBI-16 item	n	Model 1		Model 2		Model 3	
		OR (*95% CI*)	*P*	*OR* (*95% CI*)	*P*	*OR* (*95% CI*)	*P*
Univariable							
HBS							
Quartile 1	414	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Quartile 2	440	0.86 (0.64 - 1.16)	0.325	0.87 (0.64 - 1.17)	0.351	0.84 (0.62 - 1.14)	0.272
Quartile 3	509	0.91 (0.69 - 1.22)	0.532	0.90 (0.67 - 1.20)	0.478	0.88 (0.65 - 1.18)	0.392
Quartile 4	453	**0.72 (0.53 - 0.98)**	**0.036**	**0.69 (0.51 - 0.94)**	**0.019**	**0.67 (0.49 - 0.92)**	**0.013**
P_{trend}			0.064		**0.034**		**0.025**
LBS							
Quartile 1	459	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Quartile 2	483	**1.38 (1.03 - 1.85)**	**0.033**	**1.38 (1.02 - 1.87)**	**0.034**	**1.45 (1.07 - 1.97)**	**0.018**
Quartile 3	469	**1.52 (1.13 - 2.04)**	**< 0.01**	**1.58 (1.17 - 2.14)**	**< 0.01**	**1.61 (1.18 - 2.19)**	**< 0.01**
Quartile 4	405	1.32 (0.96 - 1.80)	0.084	1.37 (0.99 - 1.89)	0.055	1.39 (1.00 - 1.93)	0.050
P_{trend}			0.058		**0.032**		**0.033**
DQD							
Quartile 1	422	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Quartile 2	466	**1.41 (1.04 - 1.92)**	**0.028**	**1.42 (1.04 - 1.94)**	**0.027**	**1.45 (1.06 - 1.99)**	**0.021**
Quartile 3	496	**1.60 (1.19 - 2.17)**	**< 0.01**	**1.59 (1.17 - 2.16)**	**< 0.01**	**1.64 (1.20 - 2.24)**	**< 0.01**
Quartile 4	432	1.30 (0.95 - 1.79)	0.100	1.31 (0.95 - 1.82)	0.105	1.31 (0.94 - 1.83)	0.112
P_{trend}			0.073		0.086		0.089
Multivariable							
HBS							
Quartile 1	414	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Quartile 2	440	0.88 (0.65 - 1.19)	0.405	0.89 (0.66 - 1.21)	0.452	0.87 (0.64 - 1.18)	0.364
Quartile 3	509	0.94 (0.70 - 1.25)	0.658	0.93 (0.69 - 1.25)	0.624	0.91 (0.67 - 1.22)	0.523
Quartile 4	453	0.77 (0.56 - 1.05)	0.104	0.75 (0.54 - 1.03)	0.073	0.73 (0.53 - 1.00)	0.053
P_{trend}			0.166		0.114		0.086
LBS							
Quartile 1	459	1.00 (Ref)	-	1.00 (Ref)	-	1.00 (Ref)	-
Quartile 2	483	1.34 (1.00 - 1.81)	0.053	1.33 (0.99 - 1.81)	0.061	**1.40 (1.03 - 1.90)**	**0.033**
Quartile 3	469	**1.45 (1.08 - 1.96)**	**0.014**	**1.49 (1.10 - 2.03)**	**0.010**	**1.52 (1.11 - 2.08)**	**< 0.01**
Quartile 4	405	1.24 (0.90 - 1.71)	0.181	1.28 (0.92 - 1.78)	0.149	1.29 (0.92 - 1.80)	0.142
P_{trend}			0.145		0.107		0.115

Univariate logistic regression was employed to estimate the association between the primary indicators of DBI-16 and risk of T2DM respectively, and we implemented multiple logistic regression to evaluate the independent effect of HBS and LBS on risk of T2DM by incorporating LBS and HBS together in models. Model 1 was adjusted by age and gender; Model 2 was further adjusted by BMI, education, physical activity, smoking, drinking alcohol, usage of dietary supplement, and drinking tea on model 1; Model 3 was further adjusted by CKD, CVA and hyperlipidemia on model 2. CKD, chronic kidney disease; CVA, cerebrovascular accident; CI, confidence interval; DBI-16, dietary balance index; DQD, diet quality distance; HBS, high bound score; LBS, low bound score; T2DM, type 2 diabetes mellitus; OR, odds ratio.