Relationship between dietary patterns and diabetic microvascular complications in patients with type 2 diabetes mellitus

Y.-J. LIU[1], Y. WANG[2], L.-X. XU[2], J. YANG[2], Y. ZHAO[3], J. QIAO[4], N. LI[5], Y. LI[6], D.-Q. LV[2], W.-Y. SUN[7], CHINA NATIONAL DIABETIC CHRONIC COMPLICATIONS STUDY GROUP

[1]School of the First Clinical Medicine, Shanxi Medical University, Taiyuan, China
[2]Department of Endocrinology, First Hospital of Shanxi Medical University, Taiyuan, China
[3]Department of Chronic Disease, Shanxi Provincial Center for Disease Control and Prevention, Taiyuan, China
[4]Department of Rheumatology, Immuno-Endocrinology, Xi'an Red Cross Hospital, Xi'an, China
[5]Department of Endocrinology, Taiyuan Central Hospital of Shanxi Medical University, Taiyuan, China
[6]Department of Geriatric of Endocrine Ward, Shanxi Provincial Cardiovascular Hospital, Taiyuan, China
[7]Department of Endocrinology, Taiyuan People's Hospital, Taiyuan, China

Abstract. – OBJECTIVE: This study aimed to investigate the relationship between different dietary patterns and diabetic microvascular complications in patients with type 2 diabetes mellitus.

PATIENTS AND METHODS: This study was conducted based on the Chinese Chronic Disease and its Risk Factor Surveillance System. A multi-stage stratified sampling method was used to randomly select two districts (Xinghualing District, Taiyuan City, and Yuzi District, Jinzhong City) and two counties (Huguan County, Changzhi City, and Jiang County, Yuncheng City) from the chronic disease surveillance sites in Shanxi Province to collect general information, dietary records, physical measurements, and laboratory tests. In total, 1,227 patients were enrolled according to the study criteria. Factor analysis was performed to construct six dietary patterns, and the relationship between dietary pattern scores and type 2 diabetic microvascular complications was analysed using binary logistic regression after correcting for confounders.

RESULTS: (1) Regarding the prevalence of type 2 diabetic microvascular complications and dietary characteristics, the prevalence of microvascular complications in patients with type 2 diabetes mellitus was 55.3% and was higher in urban than in rural areas. The prevalence of diabetic kidney disease (DKD), diabetic retinopathy, and diabetic peripheral neuropathy (DPN) were 21.4%, 12.7%, and 38.0%, respectively. (2) Six dietary patterns were constructed, namely, 'animal protein', 'coarse grains and plant protein', 'nuts and fruits', 'refined grains and vegetables', 'dairy', and 'added sugars', with factor contributions of 15.42%, 9.99%, 8.23%, 8.16%, 7.56%, and 7.28% respectively, explaining 56.64% of the total dietary variation. (3) After adjusting for confounding variables, the results of binary logistic regression indicated that patients in the highest quartile of dietary pattern scores for 'nuts and fruits' experienced a 43.3% lower risk of DKD compared to those in the lowest quartile [odds ratio (OR) = 0.567; 95% confidence interval (CI), 0.359-0.894; $p < 0.001$]. Similarly, patients in the highest quartile of dietary pattern scores for 'animal protein' had a 42.8% lower risk of DPN compared with those in the lowest quartile (OR = 0.572; 95% CI, 0.388-0.843; $p < 0.05$).

CONCLUSIONS: The results of this study suggest that in patients with type 2 diabetes mellitus, a 'nuts and fruits' dietary pattern reduces the risk of DKD and an 'animal protein' dietary pattern reduces the risk of DPN.

Key Words:
Type 2 diabetes mellitus, Dietary patterns, Microvascular complications, Factor analysis.

Introduction

According to the International Diabetes Federation[1], the number of individuals with diabetes worldwide has reached 537 million in 2021. By 2030, the number of individuals with type 2 diabetes mellitus (T2DM) is expected to reach 592

Corresponding Author: Yan Wang, MD; e-mail: wysdyy@126.com

million globally[2]. Among the chronic complications of diabetes, microvascular complications of the kidney, retina, and peripheral nerves are significant causes of mortality and disability in patients with diabetes, greatly affecting their quality of life and care burden[3,4]. Diabetic kidney disease (DKD) is characterized by hyperfiltration and microalbuminuria in the early stages, followed by a progressive decrease in the glomerular filtration rate (GFR) in later stages, which is the main cause of progression to end-stage renal disease[5]. Diabetic retinopathy (DR) is a specific diabetic microvascular complication that can lead to blindness, which is difficult to reverse. It is estimated that up to 18.5% of DR cases result in blindness[6]. The incidence of diabetic peripheral neuropathy (DPN) is increasing annually, with approximately 30% of patients with DPN developing painful neuropathy[7], which is the strongest risk factor for diabetic foot ulcers. Lifestyle interventions are crucial for managing patients with diabetes, and a sensible diet can improve glucose metabolism and significantly reduce the risk of microvascular complications[8].

Researchers[9,10] have recently explored the relationship between specific foods or nutrients and diabetic microvascular complications. For example, the proportion of carbohydrate intake is not associated with an increased risk of developing DKD or DR, whereas high sodium intake increases the risk of retinopathy progression in patients with T2DM. However, compared to studies evaluating the effects of a specific nutrient or a single food in isolation, studies on dietary patterns consider the entire diet and the complex interactions between nutrients. This approach captures the potential relationship between dietary components and diabetic microvascular complications[11]. Therefore, it is imperative to comprehensively investigate the relationship between dietary patterns and diabetic microvascular complications. Dietary patterns can be examined using two approaches: *a priori* (i.e., dietary scores or an index of predefined patterns) and *a posteriori* (i.e., data-driven methods). Compared to *a priori* indices, *a posteriori* patterns identify actual dietary patterns that better reflect the true picture of dietary intake and capture the existing food habits of the population. To date, most studies[12] have focused on the relationship between dietary patterns and diabetic microvascular complications. For instance, adherence to a ketogenic dietary pattern may increase epidermal axon density and exacerbate DPN symptoms. Conversely, a Mediterranean dietary pattern is consistently associated with a reduced risk of microvascular complications in patients with diabetes[13]. These findings provide a reasonable basis for dietary recommendations aimed at preventing diabetic microvascular complications. However, most studies in literature conducted on *a priori* dietary patterns have primarily focused on Western countries, and geographical variability should be considered.

Exploratory dietary patterns are novel research tools that facilitate the development of dietary patterns that account for food interactions[14]. These patterns better reflect the effects of specific dietary patterns on various diseases. Factor analysis is the most commonly used method to construct dietary patterns. Several studies[15,16] conducted on Chinese populations have explored the relationship between dietary patterns and the risk of developing T2DM, diabetic macrovascular complications, and metabolic syndrome. For example, a cross-sectional study[15] conducted in South China identified four dietary patterns: 'high light-colored vegetables and low grains', 'high fruits', 'high red meat and low grains', and 'high dark-colored vegetables'. This study showed that the 'high fruits' dietary pattern reduced the risk of T2DM. Another cross-sectional study[16] conducted in Jiangsu Province, China, identified two dietary patterns: 'balanced' and 'high-fat'. This study indicated that a 'balanced' pattern, featuring high-quality protein and fresh vegetables and fruits, reduced the risk of stroke in patients with T2DM. However, few studies have focused on the relationship between dietary patterns and diabetic microvascular complications. As dietary patterns are influenced by cultural customs and economic levels and vary across different regions, this study aimed to use factor analysis on data obtained from the Chinese Chronic Disease and its Risk Factor Surveillance System to develop dietary patterns for patients with T2DM. We analyzed the characteristics of the dietary patterns and investigated the effects of different dietary patterns on microvascular complications. The results of this study may serve as a basis for future dietary guidance in patients with T2DM.

Materials and Methods

Study Design

The Epidemiological Survey on Chronic Complications of Diabetes was a joint effort by the Diabetes Society of the Chinese Medical Association, Chinese Center for the Prevention and Control of Chronic Non-Communicable Diseases, Chinese Center for Disease Control and Prevention, and Bai Qiu'en Foundation in 2018. It is based on the China Chronic Disease and its Risk Factors Surveillance System, which covers 31 provinces, autonomous regions, and municipalities directly under the central government[17].

Survey Participants and Sample Size Estimation

Four sampling sites were selected in Taiyuan, Jinzhong, Changzhi, and Yuncheng cities of Shanxi Province. The required sample size was calculated using the following sample size estimation formula:

$$n = \frac{p(1-p)Z_{1-\alpha/2}}{(\varepsilon p)^2}$$

According to previous studies[18-20], the prevalence of DKD, DR, and DPN were 21.80%, 18.45%, and 17.02%, respectively, with a relative precision (ε) of 10%, α of 0.05, and $Z_{1-\alpha/2}$ of 1.96. Therefore, the minimum sample size was 956. The inclusion criteria were as follows: (1) participants aged > 18 years and who had lived in the surveyed area for at least 6 months during the 12 months before the survey, (2) those diagnosed with T2DM, and (3) those who provided informed consent. The exclusion criteria were as follows: (1) patients with previous renal diseases, such as chronic glomerulonephritis, nephrotic syndrome, or chronic renal failure; (2) those with a history of eye-related disorders or surgery; and (3) those who were unable to cooperate with the survey or missed important data. The final survey was conducted on 1,891 participants, and 1,227 patients were selected after screening according to predefined criteria. This study was approved by the China Chronic Disease Research Ethics Review Committee (approval number: 2018-010) and registered in the China Clinical Trials Registry (ChiCTR180001432). Written informed consent was obtained from all the patients.

Investigation Contents and Methods

Dietary information collection

Food was categorized based on the Chinese food composition table, which included 14 food groups: refined cereals (rice and its products, steamed buns, noodles, baklava), coarse grains (corn, buckwheat, and millet), potatoes (potatoes, yams, taro, sweet potatoes), fresh vegetables (considering seasonality of consumption), fresh fruits (considering seasonality of consumption), beans and their products (lactic tofu, dried bean curd), dairy products (milk, yogurt, cheese), livestock meat (pork, beef, lamb), poultry meat (chicken, duck), aquatic products (freshwater fish, scallops, shrimps, crabs, snails, and clams), eggs (chicken eggs, duck eggs), nuts (melon seeds, peanuts, walnuts, cashew nuts, pistachios, hazelnuts, and pine nuts), sugary drinks (carbonated drinks, commercially available tea drinks, and sports drinks), and fruit juices. A standard dietary questionnaire was developed in accordance with national standards, and a semi-quantitative food frequency questionnaire was used to investigate the intake frequency and mean intake of various food groups by patients as per the nationally standardized dietary questionnaire[17]. Food intake frequency was classified into five categories: (1) almost never, (2) once daily, (3) a few times weekly, (4) once weekly, and (5) once monthly. Additionally, the standard portion sizes for each food type were measured and recorded using visual aids, such as spoons, bowls, and plates. The frequency of food intake was converted into a daily count, and the mean intake of each food item was calculated by multiplying the daily count by the average amount. The recorded average amounts for each food included the raw weight, raw weight of the edible portion, and market weight in grams for solid foods and milliliters for liquid foods.

Body measurements

The body measurements of the participants included height, weight, waist circumference, blood pressure, and heart rate. Height was measured as the tide gauge zero height with a maximum scale of 2.0 m and an accuracy of 0.1 cm. Weight was measured using a TANITA HD-390 body weight scale, with a minimum unit of 0.1 kg. Waist circumference was measured using a torch-shaped telescopic tape measure with a maximum scale of 1.5 m, width of 1.0 cm, and accuracy of 0.1 cm. Measurements were taken horizontally at the lower edge of the rib arch in the mid-axillary line, and a second measurement was recorded after ensuring that the difference between the two measurements was < 1 cm. Blood pressure and heart rate were measured using an Omron HBP-1300 electronic sphygmomanometer. The armband was appropriately wrapped around the left upper arm, and three measurements were taken at 1-minute intervals.

Laboratory testing

Each recruited participant fasted for 10-12 h before a professional nurse drew a fasting venous blood sample (5 mL) and separated it into standard tubes. All biochemical indicators were measured using an automated chemical analyzer according to the standardized practices of the kit manufacturer. Fasting blood glucose levels were measured at a local laboratory following a harmonized quality control program. Blood and urine samples were collected from the survey site, centrifuged, and frozen as required. They were transported to a medical testing facility designated by the National Project Working Group for testing and storage[17].

Examination of microvascular complications

1) Fundoscopy: a specialist fundoscopist trained in fundus photography used a Canon no-dilation fundus camera (CR-2AF) to examine the fundus of both eyes for each patient. Two 45° color fundus images were taken in each eye, one centered on the temporal aspect of the optic papilla and the other centered on the central macular recess. Each fundus photograph was remotely interpreted and graded according to the intern ational clinical diagnosis of DR by two ophthalmologists at Shanghai Sixth People's Hospital. In case of inconsistent results, another senior ophthalmologist provided an interpretation.

2) DPN screening: screening was performed by uniformly trained professional investigators using the national standard neuropathy screening tool. This tool assessed temperature perception using the Tip-Therm cool thermoreceptor, pinprick pain perception using a large-headed needle, vibration perception using a semi-quantitative tuning fork (128 Hz), pressure perception using a 10-g nylon wire test, and ankle reflex using a percussion hammer.

Ending Variables

Normoalbuminuria was defined as a urinary albumin-to-creatinine ratio (UACR) of < 30 mg/g, microalbuminuria as a UACR of 30-300 mg/g, and macroalbuminuria as a UACR of > 300 mg/g. The GFR was estimated using the Chronic Kidney Disease Epidemiology Collaborative Study formula recommended by the Kidney Disease Improving Global Outcomes guidelines[21]. The diagnostic criteria for DKD, DR, and DPN were based on the Chinese Guidelines for the Prevention and Treatment of Type 2 Diabetes Mellitus (2020 edition)[22].

Covariates

The covariates considered in this study included age, duration of diabetes, residential area (urban *vs.* rural), educational level (primary school and below, junior high school, and college and above), occupation (technical, administrative, and service and other positions), medication (unmedicated, oral medication alone, and oral medication combined with insulin), annual per capita household income and expenditure, smoking status, alcohol consumption, total energy of physical activity, exercise intensity, daily sleep duration, body mass index (BMI), waist circumference, systolic blood pressure, diastolic blood pressure, and fasting plasma glucose (FPG), hemoglobin A1 c (HbA1c), total cholesterol (TC), triglyceride (TG), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), and uric acid (UA) levels.

Dietary Model Construction

A dietary model was constructed using factor analysis to downscale food intake and standardize the intake of all foods. To enhance the professional significance of each factor, the initial factor loading matrix was rotated using Varimax[22]. In this study, we set the retention criteria for food groups in the dietary model as factor loadings ≥ 0.400. The number of retained dietary patterns was determined based on a combination of characteristic roots > 1, debris plots, interpretability, and variance contribution of the dietary patterns[23]. The dietary pattern scores were calculated from the intake of food groups under each dietary pattern and weighted according to their factor loadings. These scores represent the extent to which the patients fit their dietary patterns.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences version 25.0 (IBM Corp., Armonk, NY, USA) and R Studio version 4.1.2 software. The mean ± standard deviation was used to characterize continuous and categorical variables and was analyzed using *t*-test and/or analysis of variance. Non-normally distributed measures are presented as M (Q1, Q3), and comparisons between the two groups were conducted using the rank-sum test. Sociodemographic factors are presented as percentages (%), and the Chi-squared test was used for comparison between the two groups. Subsequently, little's MACR test (Missing Completely at Random) indicated that there were missing values for household income and expenditure, which were considered missing at random and interpolated using the expectation maximum algorithm. Finally, factor analysis was used to construct dietary patterns, and binary logistic regression was applied to analyze the relationship between dietary pattern scores and DKD, DR, and DPN. A two-sided p-value < 0.05 was considered a statistically significant difference.

Results

The Current Survey and Dietary Characteristics of Type 2 Diabetic Microvascular Complications

In this study, the study population comprised 645 (52.6%) men and 582 (47.4%) women residing in both urban (777, 63.3%) and rural (450, 36.7%) areas. The participants had a mean age of 51.08 (57.37-63.97) years and had been diagnosed with T2DM for an average of 3.58 (7.00-12.08) years. The mean HbA1c level was 6.40 (7.20-8.50%). The prevalence of microvascular complications among patients with T2DM was 55.3%, with DKD, DR, and DPN having prevalence rates of 17.9%, 11.6%, and 37.1%, respectively, in urban areas and 27.6%, 14.7%, and 39.6%, respectively, in rural areas. A statistically significantly lower prevalence of microvascular complications was observed in rural areas compared with urban areas ($p < 0.05$). Regarding dietary characteristics, the intake of coarse grains, potatoes, pulses, and eggs was higher in rural areas compared with urban areas, whereas the intake of refined grains, fresh vegetables, fresh fruits, dairy and its products, animal meat, aquatic products, and nuts was lower in rural areas compared with urban areas, with all differences being statistically significant ($p < 0.05$) (Table I).

Dietary Pattern Construction

The inclusion of all food groups in the factor analysis model, with a Kaiser-Meyer-Olkin statistic of 0.643 and Bartlett's spherical test (χ^2 = 1,053.096, $p < 0.001$), indicated its suitability for factor analysis. The model revealed six factors with characteristic roots > 1, and their respective factor contributions were 15.42%, 9.99%, 8.23%, 8.16%, 7.56%, and 7.28%. Altogether, they explained 56.64% of the total dietary variation (Table II, Figure 1). Subsequent tests for the presence of covariance among the six dietary patterns showed a tolerance significantly > 0.1 and variance inflation factors < 10, indicating no covariance. This study named the dietary patterns according to the top food groups with higher factor loadings in each. The first factor was characterized by a high intake of livestock, poultry, and aquatic products, which was named the 'animal protein' dietary pattern. The second factor was characterized by a high intake of coarse grains, potatoes, legumes, and

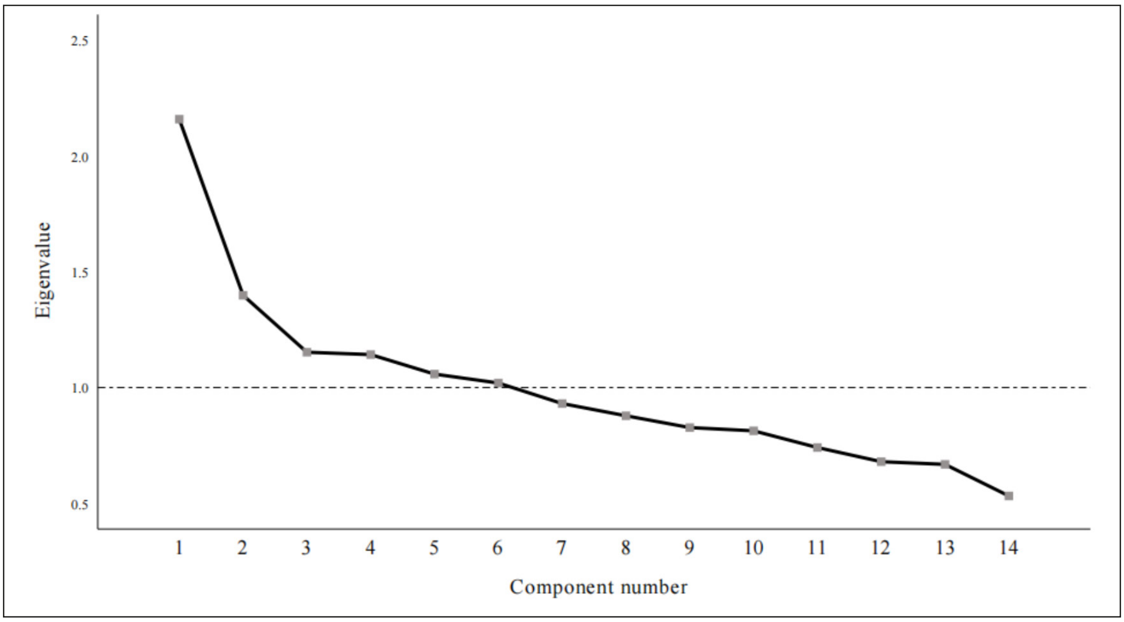

Figure 1. Factor analysis lithotripsy for determining the number of dietary patterns.

Table I. Comparison of general information of type 2 diabetes patients in urban and rural areas.

	Urban (n = 777)	Rural (n = 450)	Total (n = 1,227)	t/Z/χ^2	*p*-value
Age (years)	51.44 (57.58, 64.08)	50.35 (56.95, 63.72)	51.08 (57.37, 63.97)	-0.463	0.643
Sex				3.358	0.067
Man	393 (50.6%)	252 (56.0%)	645 (52.6%)		
Woman	384 (49.4%)	198 (44.0%)	582 (47.4%)		
Education				35.791	< 0.001
Primary school and below	162 (20.8%)	153 (34.0%)	315 (25.7%)		
Middle school and high school	512 (65.9%)	271 (60.2%)	783 (63.8%)		
College degree or above	103 (13.3%)	26 (5.8%)	129 (10.5%)		
Occupation				3.977	0.137
Technical post	115 (14.8%)	77 (17.1%)	192 (15.6%)		
Administrative post	512 (65.9%)	271 (60.2%)	783 (63.8%)		
Service and other positions	150 (19.3%)	102 (22.7%)	252 (20.5%)		
Smoking				0.364	0.546
No	548 (70.5%)	310 (68.9%)	858 (69.9%)		
Yes	229 (29.5%)	140 (31.1%)	369 (30.1%)		
Drinking				0.009	0.923
No	558 (71.8%)	322 (71.6%)	800 (71.7%)		
Yes	219 (28.2%)	128 (28.4%)	347 (28.3%)		
Hypoglycemic drug therapy				46.310	< 0.001
None	131 (16.9%)	30 (6.7%)	161 (13.1%)		
Oral medication alone	517 (66.5%)	379 (84.2%)	896 (73.0%)		
Oral medication combined with insulin therapy	129 (16.6%)	41 (9.1%)	170 (13.9%)		
Annual per capita household income (¥)	10,285.71 (18,000.00, 28,000.00)	3,500.00 (6,000.00, 10,000.00)	6,000.00 (12,000.00, 21,714.50)	-17.460	< 0.001
Annual per capita household expenditure (¥)	8,491.50 (14,000.00, 19,644.25)	3,712.50 (5,661.00, 10,000.00)	5,142.86 (10,000.00, 16,983.00)	-15.416	< 0.001
Duration of diabetes (years)	3.54 (7.42, 12.33)	3.56 (6.58, 11.52)	3.58 (7.00, 12.08)	-1.093	0.274
Refined grains (g)	374.43 ± 249.22	297.94 ± 190.86	346.38 ± 232.41	6.03	< 0.001
Coarse grains (g)	58.37 ± 77.81	71.24 ± 95.20	63.09 ± 84.79	-2.435	0.015
Potatoes (g)	42.60 ± 75.89	60.03 ± 105.19	48.99 ± 88.14	-3.08	0.002
Legumes and their products (g)	43.64 ± 68.58	58.17 ± 80.08	48.97 ± 73.31	-3.224	< 0.001
Fresh vegetables (g)	405.23 ± 299.55	340.92 ± 276.65	381.64 ± 292.89	3.726	< 0.001
Fresh fruits (g)	94.53 ± 151.36	59.34 ± 109.04	81.62 ± 138.36	4.706	< 0.001
Dairy (g)	105.79 ± 136.81	65.83 ± 93.72	91.13 ± 124.24	6.051	< 0.001
Livestock (g)	47.85 ± 77.24	30.44 ± 56.19	41.46 ± 70.73	4.54	< 0.001
Poultry (g)	11.87 ± 24.35	9.46 ± 36.28	10.99 ± 29.30	1.391	0.165
Aquatic products (g)	10.69 ± 22.61	6.22 ± 28.12	9.05 ± 24.86	2.877	0.004
Eggs (g)	48.82 ± 38.17	69.07 ± 63.46	56.24 ± 49.92	-6.156	< 0.001
Nuts (g)	19.36 ± 38.87	13.72 ± 41.93	17.29 ± 40.09	2.382	0.017
Fruit and vegetable juices (ml)	5.97 ± 38.62	3.36 ± 14.76	5.02 ± 32.02	1.683	0.093
Sugary drinks (ml)	2.71 ± 17.15	2.93 ± 21.99	2.79±19.06	-0.198	0.843
BMI (kg/m^2)	23.60 (25.80, 28.00)	23.40 (25.60, 27.80)	23.60 (25.70, 27.90)	-1.428	0.153
Waist circumference (cm)	89.34 ± 8.91	88.55 ± 9.54	89.05 ± 9.15		

Table continued

Table I *(continued)*. Comparison of general information of type 2 diabetes patients in urban and rural areas.

	Urban (n = 777)	Rural (n = 450)	Total (n = 1,227)	t/Z/χ^2	p
Systolic blood pressure (mmhg)	118.17 (129.33, 141.67)	122.33 (132.67, 146.00)	120.33 (130.67, 143.67)	-3.896	< 0.001
Diastolic blood pressure (mmhg)	71.33 (78.00, 84.67)	73.58 (79.67, 86.67)	72.00 (78.67, 85.00)	-2.947	0.003
FPG (mmol/L)	6.71 (8.07, 9.93)	6.46 (7.95, 10.00)	6.64 (8.04, 9.95)	-1.104	0.269
HbA_{1c} (%)	6.30 (7.20, 8.30)	6.40 (7.30, 8.80)	6.40 (7.20, 8.50)	-1.179	0.238
ALT (U/L)	14.00 (19.000, 26.00)	13.00 (17.50, 24.00)	14.00 (18.00, 25.00)	-2.428	0.015
AST (U/L)	16.00 (19.00, 23.00)	15.00 (18.00, 23.00)	16.00 (19.00, 23.00)	-2.051	0.040
GGT (U/L)	17.00 (24.00, 37.00)	16.00 (21.00, 30.25)	16.00 (23.00, 34.00)	-4.014	< 0.001
TG (mmol/L)	1.33 (1.96, 2.88)	1.15 (1.69, 2.35)	1.25 (1.83, 2.67)	-4.915	< 0.001
TC (mmol/L)	3.90 (4.61, 5.32)	3.70 (4.41, 5.10)	3.85 (4.53, 5.23)	-3.345	< 0.001
LDL-C (mmol/L)	2.09 (2.73, 3.33)	1.99 (2.62, 3.19)	2.05 (2.69, 3.29)	-1.528	0.114
HDL-C (mmol/L)	0.93 (1.10, 1.29)	0.97 (1.16, 1.36)	0.95 (1.11, 1.31)	-3.538	< 0.001
Scr (μmol/L)	61.00 (71.00, 81.00)	59.00 (68.50, 79.00)	60.00 (70.00, 80.00)	-2.136	0.033
UA (mmol/L)	278.00 (327.00, 400.50)	227.00 (282.50, 340.25)	257.00 (314.00, 377.00)	-9.200	< 0.001
UACR (mg/g)	5.03 (2.70, 16.39)	10.32 (3.92, 31.22)	6.32 (3.02, 21.46)	-6.426	< 0.001
eGFR (ml/min/1.73 m^2)	93.60 (81.44, 100.78)	95.60 (87.66, 104.43)	94.46 (83.49, 102.26)	-3.368	< 0.001
DKD				15.811	< 0.001
No	638 (82.1%)	326 (72.4%)	964 (78.6%)		
Yes	139 (17.9%)	124 (27.6%)	263 (21.4%)		
DR				2.442	0.118
No	687 (88.4%)	384 (85.3%)	1,071 (87.3%)		
Yes	90 (11.6%)	66 (14.7%)	156 (12.7%)		
DPN				0.750	0.386
No	489 (62.9%)	272 (60.4%)	761 (62.0%)		
Yes	288 (37.1%)	178 (39.6%)	466 (38.0%)		
Number of microvascular complications				13.072	0.004
0	367 (47.2%)	181 (40.2%)	548 (44.7%)		
1	310 (39.9%)	180 (40.0%)	490 (39.9%)		
2	93 (12.0%)	79 (17.6%)	172 (14.0%)		
3	7 (0.9%)	10 (2.2%)	17 (1.4%)		

Body mass index (BMI), fasting plasma glucose (FPG), hemoglobin A1 c (HbA1c), total cholesterol (TC), triglyceride (TG), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), uric acid (UA), urinary albumin-to-creatinine ratio (UACR), glomerular filtration rate (GFR), Diabetic kidney disease (DKD), diabetic peripheral neuropathy (DPN), Diabetic retinopathy (DR), gamma-glutamyl transferase (GGT), aspartate aminotransferase (AST), alanine aminotransferase (ALT).

their products and was named the 'coarse grains and plant protein' dietary pattern. The third factor, named 'nuts and fruits' dietary pattern, was characterized by a high intake of nuts and fresh fruits. The fourth factor, named 'refined grains and vegetables' dietary pattern, was characterized by a high intake of refined grains and fresh vegetables. The fifth factor was characterized by a high intake of dairy and its products, which was named the 'dairy' dietary pattern. Finally, the sixth factor was characterized by a high intake of fruit juices and sugary drinks, which was named the 'added sugar' dietary pattern (Figure 2).

Association Between Different Dietary Pattern Scores and the Risk of Diabetic Kidney Disease

The patients were classified into four equal groups based on their dietary patterns. Those without combined DKD were assigned a value of 0, whereas those with combined DKD were assigned a value of 1. Model 3 was adjusted for the

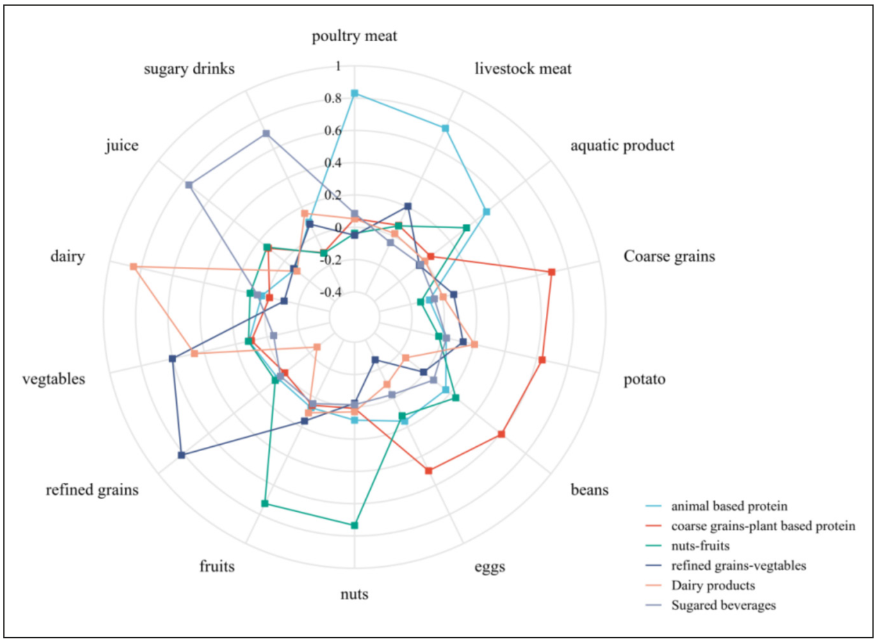

Figure 2. Factor analysis radar map for determining types of dietary patterns.

other five dietary patterns and confounders, such as age, duration of diabetes, residential area, educational level, occupation, medication, annual per capita household income and expenditure, smoking status, alcohol consumption, total energy of physical activity, exercise intensity, daily sleep duration, BMI, waist circumference, systolic and diastolic blood pressure, and FPG, HbA1c, TC, TG, LDL-C, HDL-C, and UA levels. The risk of DKD was lower by 43.3% in the highest quartile of the 'nuts and fruits' dietary pattern compared with the lowest quartile, with a statistically significant difference ($p < 0.05$) (Table III).

Association Between Different Dietary Pattern Scores and the Risk of Diabetic Retinopathy

Univariate conditional logistic regression (model 1) analyses without correction for any factor showed no significant relationship between the

Table II. Factor load of various foods in different dietary patterns.

	Animal protein	Coarse grains and plant protein	Nuts and fruits	Refined grains and vegetables	Dairy	Added sugars
Poultry	0.831[a]	0.054	-0.037	-0.049	0.053	0.086
Livestock	0.742[a]	0.075	0.071	0.206	0.018	-0.044
Aquatic products	0.490[a]	0.047	0.331	-0.042	0.001	-0.033
Coarse grains	-0.080	0.697[a]	-0.136	0.074	0.007	-0.049
Potatoes	0.026	0.636[a]	-0.021	0.134	0.206	0.028
Legumes and their products	0.167	0.608[a]	0.246	-0.009	-0.151	0.070
Eggs	0.160	0.501[a]	0.123	-0.262	-0.093	-0.022
Nuts	0.083	0.010	0.735[a]	-0.022	0.031	-0.013
Fresh fruits	0.067	0.051	0.726[a]	0.159	0.103	0.040
Refined grains	0.052	-0.002	0.073	0.816[a]	-0.258	0.032
Fresh vegetables	0.115	0.100	0.119	0.602[a]	0.462	-0.041
Dairy and its products	0.035	-0.015	0.108	-0.108	0.849[a]	0.062
Fruit and vegetable juices	-0.081	0.128	0.139	-0.073	-0.099	0.757[a]
Sugary drinks	0.096	-0.113	-0.117	0.083	0.157	0.706[a]

There are 14 food groups in total, and each number represents the factor loading of a different food group. [a]: Absolute value factor loading capacity ≥ 0.400.

Table III. Binary Logistic regression analysis of dietary pattern scores and DKD risk.

Dietary patterns	OR of T2DM for quartiles of dietary patterns				
	Q1 (referent)	Q2	Q3	Q4 (highest)	*p*-value
Animal protein					
Model 1	1.000	0.811 (0.555, 1.185)	0.745 (0.508, 1.094)	0.815 (0.558, 1.190)	0.471
Model 2		0.826 (0.552, 1.236)	0.827 (0.551, 1.240)	0.861 (0.577, 1.285)	0.758
Model 3		0.892 (0.569, 1.397)	0.97 (0.614, 1.531)	1.106 (0.696, 1.759)	0.845
Coarse grains and plant protein					
Model 1	1.000	0.840 (0.576, 1.224)	0.657 (0.444, 0.974)#	0.880 (0.605, 1.280)	0.212
Model 2		0.873 (0.590, 1.293)	0.635 (0.422, 0.956)	0.708 (0.472, 1.061)	0.125
Model 3		0.868 (0.563, 1.339)	0.662 (0.421, 1.040)	0.643 (0.406, 1.019)	0.175
Nuts and fruits					
Model 1	1.000	0.436 (0.296, 0.642)*	0.647 (0.451, 0.928)#	0.424 (0.287, 0.626)*	**< 0.001**
Model 2		0.422 (0.279, 0.637)*	0.671 (0.457, 0.984)#	0.432 (0.288, 0.650)*	**< 0.001**
Model 3		0.421 (0.267, 0.666)*	0.736 (0.476, 1.137)	0.567 (0.359, 0.894)#	**< 0.001**
Refined grains and vegetables					
Model 1	1.000	0.690 (0.468, 1.019)	0.897 (0.617, 1.303)	0.802 (0.548, 1.173)	0.283
Model 2		0.625 (0.419, 0.933)#	0.821 (0.557, 1.208)	0.783 (0.525, 1.168)	0.148
Model 3		0.742 (0.477, 1.154)	0.989 (0.640, 1.528)	0.905 (0.577, 1.420)	0.527
Dairy					
Model 1	1.000	0.969 (0.668, 1.405)	0.765 (0.521, 1.124)	0.718 (0.487, 1.059)	0.237
Model 2		0.864 (0.581, 1.283)	0.768 (0.513, 1.151)	0.702 (0.467, 1.057)	0.357
Model 3		0.859 (0.556, 1.327)	0.836 (0.533, 1.311)	0.799 (0.501, 1.273)	0.792
Added sugars					
Model 1	1.000	1.080 (0.735, 1.558)	1.040 (0.760, 1.532)	1.024 (0.694, 1.510)	0.983
Model 2		0.958 (0.635, 1.446)	0.879 (0.571, 1.351)	0.858 (0.568, 1.297)	0.879
Model 3		1.069 (0.675, 1.691)	0.927 (0.577, 1.490)	0.918 (0.583, 1.445)	0.905

According to the scores of each dietary pattern, the patients were equally divided into four groups, namely, the 1st quartile (Q1), the 2nd quartile (Q2), the 3rd quartile (Q3) and the 4th quartile (Q4). Model 1: Uncorrected; Model 2: Correcting for other five dietary patterns; Model 3: On the basis of Model 2, adjusted for age, duration of diabetes, residential area, education level, occupation, medication, annual per capita household income and expenditure, smoking, alcohol consumption, total energy of physical activity, exercise intensity, daily sleep duration, BMI, waist circumference, systolic and diastolic blood pressure, FPG, HbA_{1c}, TC, TG, LDL-C, HDL-C, and UA. *Compared with Q1, $p<0.001$; #Compared with Q1, $p < 0.05$.

risk of DR and 'refined grains and vegetables' dietary pattern. After adjustment for the other five dietary patterns and for confounders, such as age, duration of diabetes, residential area, educational level, occupation, medication, annual per capita household income and expenditure, smoking status, alcohol consumption, total energy of physical activity, exercise intensity, daily sleep duration, BMI, waist circumference, systolic and diastolic blood pressure, and FPG, HbA1c, TC, TG, LDL-C, HDL-C, and UA levels, the significant positive correlation between the 'refined grains and vegetables' dietary pattern and the risk of DR was observed. Moreover, compared to the lowest quartile, the risk of DR for the first quartile was higher [model 3, odds ratio (OR) = 1.820; 95% confidence interval (CI), 1.088-3.054; $p < 0.05$] (Table IV).

Association Between Different Dietary Pattern Scores and the Risk of Diabetic Peripheral Neuropathy

After reclassifying the absence of combined DPN as 0 and the presence of combined DPN as 1, model 3 was adjusted for the remaining five dietary patterns and controlled for potential confounding variables, including age, duration of diabetes, residential area, educational level, occupation, medication, annual per capita household income and expenditure, smoking status, alcohol consumption, total energy of physical activity, exercise intensity, daily sleep duration, BMI, waist circumference, systolic and diastolic blood pressure, and FPG, HbA1c, TC, TG, LDL-C, HDL-C, and UA levels. The highest quartile of the 'animal protein' dietary pattern was associated with a lower risk of DPN compared to the lowest quartile of the dietary score, with a statistically significant difference observed ($p < 0.05$). Specifically, the risk of DPN was reduced by 42.8% (OR = 0.572; 95% CI, 0.388-0.843; $p < 0.05$) (Table V).

Discussion

The results of this study showed that the prevalence of microvascular complications in patients with T2DM was 55.3%, which was higher in urban than in rural areas, and the prevalence of DKD, DR, and DPN were 21.4%, 12.7%, and 38.0%, respectively. The risk of DKD was reduced by the 'nuts and fruits' dietary pattern, and the risk of DPN was reduced by the 'animal protein' dietary pattern.

The 'nuts and fruits' dietary pattern is characterized by high levels of polyunsaturated fatty acids, dietary fiber, and micronutrients. Ample evidence[24,25] supports the protective effects of nuts and fruits against macrovascular complications in patients with T2DM; however, few studies in the literature have been conducted on their effects on DKD. Nut intake has a nonlinear relationship with UACR. When compared to the individuals consuming 1-6 servings per week, those who consumed no nuts, 2-3 servings per month, and ≥ 1 serving per day experienced 86%, 24%, and 117% increases in UACR levels, respectively[26]. The renoprotective effects of nuts can be attributed to their high polyunsaturated fatty acid and dietary fiber contents. Omega-3 polyunsaturated fatty acids, which are abundant in nuts, improve insulin sensitivity, delay vascular calcification, and reduce lipotoxic damage to glomerular cells[27,28]. Studies[29] have also demonstrated an inverse relationship between dietary fiber intake and albuminuria risk, with individuals consuming > 26 g/d of fiber having a 26% lower risk than

Table IV. Binary Logistic regression analysis of dietary pattern scores and DR risk.

Dietary patterns	OR of T2DM for quartiles of dietary patterns				
	Q1 (referent)	Q2	Q3	Q4 (highest)	*p*-value
Animal protein					
Model 1	1.000	1.268 (0.782, 2.055)	1.126 (0.688, 1.842)	1.273 (0.785, 2.063)	0.733
Model 2		1.260 (0.760, 2.090)	1.072 (0.642, 1.790)	1.196 (0.724, 1.975)	0.793
Model 3		1.166 (0.681, 1.996)	1.014 (0.587, 1.752)	1.310 (0.754, 2.275)	0.719
Coarse grains and plant protein					
Model 1	1.000	0.965 (0.608, 1.533)	0.969 (0.610, 1.539)	0.734 (0.450, 1.198)	0.596
Model 2		0.964 (0.600, 1.551)	1.002 (0.621, 1.615)	0.779 (0.464, 1.306)	0.756
Model 3		0.951 (0.578, 1.565)	1.056 (0.64, 1.743)	0.709 (0.408, 1.232)	0.508
Nuts and fruits					
Model 1	1.000	1.169 (0.720, 1.896)	1.266 (0.785, 2.040)	1.098 (0.673, 1.790)	0.800
Model 2		1.085 (0.650, 1.809)	1.195 (0.723, 1.975)	0.989 (0.594, 1.645)	0.862
Model 3		1.195 (0.694, 2.057)	1.39 (0.809, 2.387)	1.172 (0.681, 2.016)	0.697
Refined grains and vegetables					
Model 1	1.000	1.553 (0.961, 2.511)	1.070 (0.642, 1.784)	1.405 (0.863, 2.288)	0.211
Model 2		1.567 (0.962, 2.552)	1.045 (0.621, 1.758)	1.344 (0.811, 2.227)	0.214
Model 3		1.820 (1.088, 3.045)#	1.167 (0.675, 2.020)	1.609 (0.937, 2.761)	0.083
Dairy					
Model 1	1.000	1.035 (0.635, 1.688)	1.128 (0.697, 1.824)	1.226 (0.763, 1.970)	0.834
Model 2		1.134 (0.681, 1.889)	1.177 (0.713, 1.941)	1.279 (0.778, 2.103)	0.810
Model 3		1.222 (0.717, 2.082)	1.294 (0.759, 2.206)	1.420 (0.830, 2.429)	0.636
Added sugars					
Model 1	1.000	0.600 (0.363, 0.992)	0.974 (0.619, 1.532)	0.925 (0.585, 1.463)	0.186
Model 2		0.585 (0.345, 0.992)	0.976 (0.592, 1.610)	0.953 (0.589, 1.543)	0.162
Model 3		0.612 (0.351, 1.068)	1.043 (0.615, 1.768)	0.981 (0.590, 1.629)	0.218

According to the scores of each dietary pattern, the patients were equally divided into four groups, namely, the 1st quartile (Q1), the 2nd quartile (Q2), the 3rd quartile (Q3) and the 4th quartile (Q4). Model 1: Uncorrected; Model 2: Correcting for other five dietary patterns; Model 3: On the basis of Model 2, adjusted for age, duration of diabetes, residential area, education level, occupation, medication, annual per capita household income and expenditure, smoking, alcohol consumption, total energy of physical activity, exercise intensity, daily sleep duration, BMI, waist circumference, systolic and diastolic blood pressure, FPG, HbA_{1c}, TC, TG, LDL-C, HDL-C, and UA. #Compared with Q1, $p < 0.05$.

those consuming ≤ 26 g/d of fiber. As nuts can provide 5-10% of daily fiber requirements, they can be considered beneficial to the kidneys[30]. The effect of fruits on diabetes has been examined in various studies[31-33], with inconsistent findings. Two prospective cohort studies, namely, the Nurse's Health Study[31] (6,358 cases) and a study[32] conducted in 30 communities in Finland (4,304 cases), have shown a significantly lower risk of developing diabetes among individuals with the highest fruit consumption compared to those with the lowest intake [hazard ratio (HR) = 0.82; 95% CI, 0.72-0.92 and HR, 0.69, 95% CI, 0.50-0.93]. However, an EPIC-InterAct prospective cohort study[33] found no significant association between fruit intake and the risk of T2DM. The inconsistencies in the results can be attributed to variations in ethnicity, geography, and methods of dietary information collection. The above-mentioned studies have mostly focused on Western populations, combining fresh fruit and processed products (e.g., dried fruit, fruit juices) in their analyses. In contrast, the present study collected data on fresh fruit and fruit juice intake separately, which may have provided more reliable evidence. The findings of the current study are consistent with those of a previous study[34], which indicates that a reduced intake of fresh fruit is related to an increased risk of albuminuria in rural Chinese populations. Furthermore, a prospective cohort study[35] of 500,000 Chinese patients with T2DM, followed up for 7 years, indicated that patients who consumed fruit ≥ 3 days per week had a significantly lower risk of concurrent DKD compared to those who consumed fruit < 1 day per week (HR = 0.69). However, the exact mechanism underlying the relationship between fresh fruit consumption and DKD risk remains unclear. Current studies[36,37] have suggested that the bioactive components in fruits, such as polyphenolic

Table V. Binary Logistic regression analysis of dietary pattern scores and DPN risk.

	OR of T2DM for quartiles of dietary patterns				
Dietary patterns	**Q1 (referent)**	**Q2**	**Q3**	**Q4 (highest)**	***p*-value**
Animal protein					
Model 1	1.000	0.701 (0.508, 0.968)#	0.737 (0.534, 1.016)	0.495 (0.355, 0.691)*	**< 0.001**
Model 2		0.634 (0.452, 0.891)#	0.698 (0.499, 0.977)#	0.470 (0.332, 0.666)*	**< 0.001**
Model 3		0.590 (0.408, 0.854)#	0.842 (0.583, 1.214)	0.572 (0.388, 0.843)#	**0.006**
Coarse grains and plant protein					
Model 1	1.000	0.818 (0.591, 1.130)	0.810 (0.586, 1.121)	0.748 (0.540, 1.037)	0.342
Model 2		0.768 (0.549, 1.074)	0.765 (0.546, 1.071)	0.674 (0.475, 0.957)#	0.150
Model 3		0.742 (0.516, 1.065)	0.686 (0.476, 0.988)#	0.623 (0.424, 0.916)#	0.082
Nuts and fruits					
Model 1	1.000	1.077 (0.778, 1.491)	0.973 (0.701, 1.349)	0.986 (0.711, 1.367)	0.930
Model 2		1.058 (0.747, 1.499)	1.088 (0.768, 1.541)	1.073 (0.760, 1.516)	0.968
Model 3		1.161 (0.793, 1.698)	1.152 (0.785, 1.692)	1.232 (0.840, 1.807)	0.750
Refined grains and vegetables					
Model 1	1.000	0.872 (0.631, 1.206)	0.769 (0.554, 1.066)	0.889 (0.643, 1.229)	0.474
Model 2		0.842 (0.604, 1.173)	0.760 (0.543, 1.063)	0.894 (0.637, 1.253)	0.440
Model 3		0.815 (0.569, 1.169)	0.754 (0.523, 1.087)	0.897 (0.619, 1.299)	0.459
Dairy					
Model 1	1.000	0.853 (0.616, 1.180)	0.758 (0.546, 1.051)	0.922 (0.667, 1.273)	0.392
Model 2		0.754 (0.535, 1.063)	0.705 (0.500, 0.994)#	0.825 (0.587, 1.159)	0.267
Model 3		0.818 (0.565, 1.185)	0.683 (0.470, 0.992)#	0.765 (0.524, 1.118)	0.248
Added sugars					
Model 1	1.000	1.056 (0.764, 1.462)	1.100 (0.796, 1.522)	0.836 (0.601, 1.163)	0.378
Model 2		0.931 (0.660, 1.315)	0.857 (0.600, 1.226)	0.707 (0.498, 1.004)	0.249
Model 3		0.916 (0.632, 1.328)	0.874 (0.596, 1.280)	0.844 (0.578, 1.233)	0.837

According to the scores of each dietary pattern, the patients were equally divided into four groups, namely, the 1st quartile (Q1), the 2nd quartile (Q2), the 3rd quartile (Q3) and the 4th quartile (Q4). Model 1: Uncorrected; Model 2: Correcting for other five dietary patterns; Model 3: On the basis of Model 2, adjusted for age, duration of diabetes, residential area, education level, occupation, medication, annual per capita household income and expenditure, smoking, alcohol consumption, total energy of physical activity, exercise intensity, daily sleep duration, BMI, waist circumference, systolic and diastolic blood pressure, FPG, HbA_{1c}, TC, TG, LDL-C, HDL-C, and UA. #Compared with Q1, $p < 0.05$.

compounds, water-soluble vitamins, and soluble dietary fibre, may reduce urinary protein. These bioactive components have antioxidative properties, modulate the composition and metabolic activity of the intestinal microflora[38,39], and inhibit podocyte apoptosis[40]. The 'nuts and fruits' dietary pattern found in this study may contribute to the reduced risk of DKD by complementing the renal benefits of nuts and fruits. The intake of dietary fibres, phenolic compounds, and unsaturated fatty acids from this dietary pattern may partially explain this benefit.

In the 'animal protein' dietary pattern, livestock and aquatic products provide high-quality protein and significant amounts of B vitamins and polyunsaturated fatty acids. Diets rich in animal proteins can have immunomodulatory effects and enhance the host's immune defense[41]. Such diets can also increase feelings of fullness, ameliorate insulin resistance, and reduce chronic inflammatory responses in patients with T2DM[42]. Furthermore, dietary sources of vitamins B6 and B12 have a clear protective effect against DPN, both of which can increase sensory conduction velocity in the median and peroneal nerves and reduce pain sensitivity levels. This potential therapeutic effect has been confirmed in various randomized controlled trials[43,44]. Li et al[45] analyzed the dietary patterns of 2,031 patients with diabetes using rank regression and found that inadequate intake of poultry and fish increased the risk of poor glycemic control. Huang et al[46] identified three dietary patterns (high-fat meat, traditional Chinese snacks, and fish and vegetables) through factor analysis and found that an increased intake of omega-3 polyunsaturated fatty acids was negatively correlated with fasting blood glucose and glycated hemoglobin levels. Fish, a rich source of polyunsaturated fatty acids, improves glycemic control and lipid metabolism in patients with T2DM. Moreover, it improves endothelial function and delays the progression of diabetic microvascular complications[47,48]. Tao et al[49] investigated 1,062 patients with diabetes and found that an increased intake of alpha-linolenic acid (a major omega-3 polyunsaturated fatty acid) was inversely associated with the prevalence of peripheral neuropathy. This can be explained by the fact that omega-3 polyunsaturated fatty acids reduce plasma glutamate and sphingomyelin concentrations, ultimately protecting nerve fibers from lipotoxic stress[50,51]. Both livestock and aquatic products are rich in bioactive components that ameliorate neuropathies. Therefore, the reduced risk of DPN associated with the 'animal protein' dietary pattern in this study may be partly due to the intake of high-quality protein, unsaturated fatty acids, and micronutrients found in these foods.

Limitations

This study has some limitations. First, the study design was cross-sectional, which limits the ability to determine the causal relationship between dietary patterns and diabetic microvascular complications. Second, dietary information was collected through self-reporting, which is subject to a recall bias. However, the outcome variable in this study was the chronic complications of diabetes, and the dietary characteristics assessed in the past year represented the long-term dietary habits of the respondents. Third, the population of this survey was limited to the Shanxi region, and the representative nature and generalizability of the findings may be inadequate. We were unable to successfully extract separate dietary patterns for rural and urban areas. This study relied on the China Chronic Disease and its Risk Factor Surveillance System and utilized a multi-stage stratified random sampling approach to select four surveillance sites. This method minimizes the possibility of selection bias to a certain extent while still ensuring representation to some extent. Future studies should expand the scope and sample size of the survey, refine the indicators for food information collection, and establish cohorts to further explore the relationship between dietary patterns and microvascular complications, especially differences between urban and rural areas.

Conclusions

The results of this study indicate that dietary patterns are associated with microvascular complications in Chinese adults with T2DM. More specifically, the 'nuts and fruits' dietary pattern lowers the risk of DKD, whereas the 'animal protein' dietary pattern is associated with a reduced risk of DPN. Nevertheless, no dietary pattern is found to decrease the risk of DR. Overall, this study has important clinical implications for T2DM management by highlighting the potential benefits of adhering to 'nuts and fruits' and 'animal protein' dietary patterns to prevent microvascular complications.

Conflict of Interest
The Authors declare that they have no conflict of interests.

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Informed Consent
All subjects who participated in the study gave their informed consent.

Ethics Approval
The study met the standards for the ethical treatment of participants. The China DiaChronic Study was approved by the Ethical Review Committee (Approval No.: 2018-010) and was registered in the Chinese Clinical Trial Registry (ChiCTR1800014432).

Authors' Contributions
All authors made a significant contribution to the work reported. Y Wang and Y.-J. Liu conceived and designed the study. Y.-J. Liu wrote the main manuscript text and conducted statistical analysis. Y Wang and L.-X. Xu revised and critically reviewed the manuscript. Y Wang, J Yang, and Y Zhao organized and supervised this project. J Qiao, N Li, Y Li, D.-Q. Lv, and W.-Y. Sun collected data and performed data entry. The work presented here has not been published previously and is not being considered for publication elsewhere. All authors have read and approved the manuscript.

Availability of Data and Materials
The datasets generated for this study are available on request to the corresponding author.

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