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Association between dietary patterns and chronic kidney disease in elderly patients with type 2 diabetes: a community-based cross-sectional study

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Abstract

Background Chronic kidney disease (CKD) is prevalent among elderly patients with type 2 diabetes mellitus (T2DM). The association between dietary patterns and CKD in elderly T2DM patients remains understudied. This study aimed to investigate the relationship between dietary patterns and CKD in elderly Chinese patients with T2DM.

Methods This community-based cross-sectional study included 5,713 elderly T2DM patients (aged ≥ 65 years) from Xiangcheng District, Suzhou, China. Dietary intake was assessed using a validated food frequency questionnaire, and dietary patterns were identified using factor analysis. Each participant was assigned a score for each identified dietary pattern, with higher scores indicating a greater alignment of their diet with the respective pattern. Quartiles of these pattern scores were utilized as the primary exposures in the analysis. CKD was defined as albuminuria, reduced estimated glomerular filtration rate (eGFR), or both. Logistic regression models assessed CKD prevalence across quartiles of dietary pattern scores, expressed as adjusted odds ratios (ORs) with 95% confidence intervals (CIs).

Results CKD prevalence was 45.7%. Four dietary patterns were identified: "traditional southern", "high-protein", "balanced" and "imbalanced". A balanced dietary pattern, featured with high intake of fruits, dairy products, eggs, snacks, crab and shellfish, and fish and shrimp, was associated with lower CKD prevalence. The adjusted ORs for CKD across ascending quartiles were 0.99 (95% CI: 0.85–1.16), 0.89 (95% CI: 0.76–1.04), and 0.73 (95% CI: 0.62–0.86). The imbalanced dietary pattern, characterized by high intake of green leafy vegetables, refined grains, and red meat but low dietary diversity, was associated with increased CKD prevalence, with ORs of 1.01 (95% CI: 0.86–1.18), 1.15 (95% CI: 0.98–1.35), and 1.25 (95% CI: 1.07–1.46) across quartiles. No significant associations were observed for "traditional southern" or "high-protein" dietary patterns.

Conclusions Dietary patterns were associated with CKD prevalence in elderly Chinese T2DM patients. A "balanced dietary pattern", consistent with local dietary customs, was associated with a lower risk of CKD. Further longitudinal and intervention studies are needed to confirm these associations.

Keywords Diabetes mellitus, type 2, Aged, Chronic kidney disease, Dietary pattern

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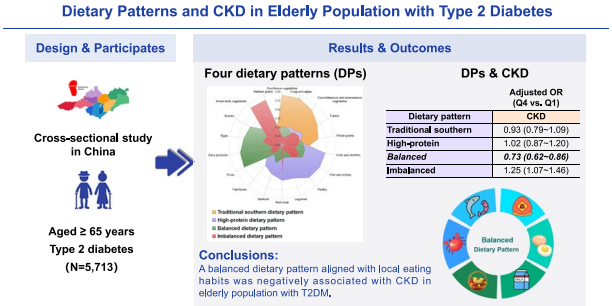
Graphical Abstract



Introduction

The prevalence of diabetes mellitus (DM) is dramatically increasing globally, posing a serious public health problem worldwide [1]. Chronic kidney disease (CKD) is prevalent in elderly diabetic patients and is the most common cause of kidney failure, affecting quality of life and overall survival, and placing a heavy burden on society [2, 3]. The pathogenesis of CKD in patients with diabetes is multifactorial and includes both genetic and environmental factors. Emerging evidence suggests that diet, physical activity, alcohol consumption, smoking, and obesity are associated with the progression of CKD [4–7].

Several studies in large populations have shown that a healthy diet is fundamental for reducing the risk of chronic diseases [8]. However, most studies on the relationship between diet and chronic diseases have focused on specific foods and could not provide a comprehensive understanding of the ideal dietary pattern for health outcomes. Dietary patterns include the amount, proportion, type or combination of different foods, beverages and nutrients in the diet and the frequency of their habitual consumption [9]. The major evidence of exploring the association between dietary patterns and CKD in diabetic patients comes from the western diets [10–12]. It is important to note that many of these studies have focused on healthy, young, or middle-aged individuals, rather than high-risk subjects such as elderly diabetic patients. The relationship between dietary patterns and chronic kidney disease in diabetic patients remains controversial. For example, adherence to a Mediterranean diet characterized by high intakes of vegetables, fruits, nuts, grains, legumes, fish, and olive oil, has been correlated with a reduced risk of CKD and kidney-related mortality [13, 14]. In contrast, a Western dietary pattern, characterized by a high consumption of soft drinks, fast food, refined grains, red meat, and processed foods, has been associated with an elevated risk of CKD [15, 16]. Additionally, the China Health and Nutrition Survey (CHNS) found that the "Traditional Southern" dietary pattern was significantly associated with an increased risk of kidney disease, while "modern" dietary pattern was linked to a reduced risk of CKD [17].

Compared with the study population mentioned above, studies focused on older adults with type 2 diabetes mellitus (T2DM) were relatively limited, and the current results are still controversial. Therefore, we conducted a large-scale community-based study to identify the association between dietary patterns and CKD in elderly patients with type 2 diabetes.

Subjects and methods

Study population

The Elderly Diabetes Cohort is an ongoing community-based prospective study designed to identify factors related of cardiovascular disease (CVD) in elderly Chinese T2DM patients aged ≥ 65 years, which was set up in Xiangcheng District, Suzhou, Jiangsu Province. 6011 elderly patients with T2DM were initially recruited between 2020 and 2021. T2DM was diagnosed according to the 2018 American Diabetes Association (ADA) criteria [18], which included any of the following: fasting plasma glucose ≥ 7.0 mmol/L, 2-h plasma glucose ≥ 11.1 mmol/L during 75 g oral glucose tolerance test (OGTT), HbA1c ≥ 6.5%, or random plasma glucose ≥ 11.1 mmol/L in patients with classic symptoms of hyperglycemia. Diagnosed diabetes was confirmed based on either a self-reported physician diagnosis or current use of glucose-lowering medications. After excluding subjects with missing data on urinary albumin creatinine ratio (UACR) ($n = 234$), blood biochemical data ($n = 43$), and incomplete questionnaire information ($n = 21$), 5,713

participants were included in the final analysis (Fig. 1). All participants were invited to participate in the annual health checkup at 11 primary care clinics. Personal and health information was collected using questionnaires.

The study was approved by the ethical committee of Zhongshan Hospital Fudan University and registered at Clinicaltrials.gov (Identifier number: NCT04544527). The consent information was obtained from each participant and the study was conducted according to the Declaration of Helsinki.

Dietary assessment

Food frequency questionnaire (FFQ) was used to collect habitual dietary intake data over the past 12 months. The FFQ has been validated in Chinese population,15 containing 18 common food groups, including refined grains, whole grains, legumes, cruciferous vegetables, fungi and algae, cucurbitaceous and solanaceous vegetables, tubers, green leafy vegetables, red meat, poultry, dairy products, eggs, fruits, snacks, fish and shrimp, crab and shellfish, seafood, and fast foods (Table S1). The content of the questionnaire was adapted to the local situation in Xiangcheng District and its reliability and validity were verified. Five frequency levels were adopted: never or rarely, 1–2 days/week, 3–4 days/week, 5–6 days/week, and daily, which were transformed to 0, 1, 2, 3, and 4 days/week, respectively.

Covariates

Demographic and lifestyle information were also obtained using questionnaires, including age, sex, education level (illiteracy, primary, or junior high school and higher), income level (< 30000 or ≥ 30000 yuan/year), physical activity (< 30, or ≥ 30 min per day), smoking status (never, past, or current smoker), alcohol consumption (never, past drinker, or current drinker), use of medications (e.g., hypoglycemic agents, and antihypertensives), history of disease (cardiovascular disease, hypertension etc.), residence area and regions (urban, rural, or urban–rural fringe). Physical activity was assessed by asking participants about their average daily exercise time (in minutes), with the following categories: ≤ 15 min, 16–30 min, 31–60 min, 61–90 min, and > 90 min [19]. For analysis, participants were categorized into two groups based on whether they engaged in more than 30 min per day of physical activity or 30 min or less per day. Body height, weight, and blood pressure were measured by trained nurses, following standard protocols. Height was measured to the nearest 0.5 cm with shoes and hats removed and standing naturally. Weight was measured to the nearest 0.1 kg. Body mass index (BMI) was calculated

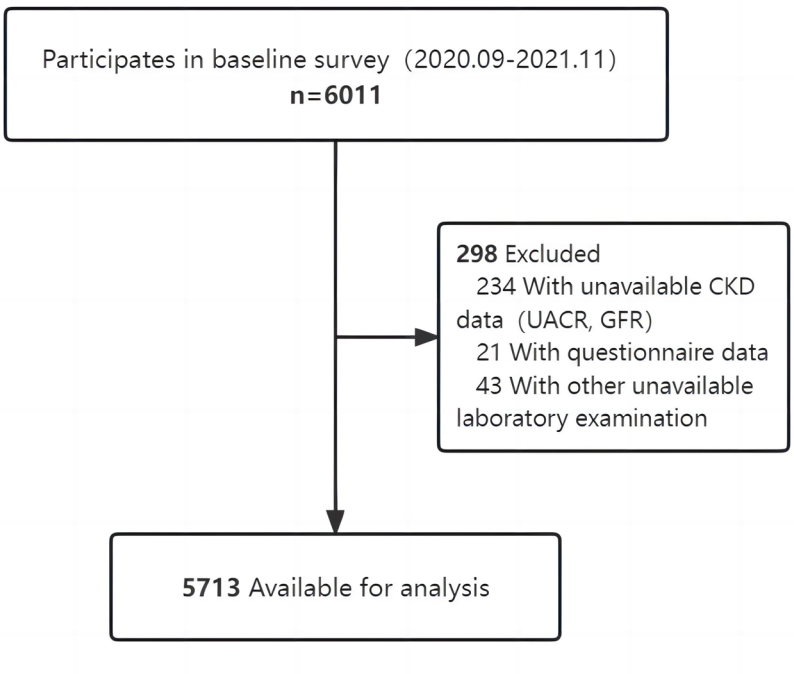


Fig. 1 Flowchart of participant selection. Abbreviations: CKD, chronic kidney disease; GFR, glomerular filtration rate; UACR, Urinary albumin-to-creatinine ratio

as weight (kilogram)/height (square meters). Waist circumference was measured at the midpoint between the last rib and the iliac crest to the nearest millimeter. Systolic and diastolic blood pressures were measured at least twice at the seated position using an automated digital blood pressure machine (Omron HBP-1120U) and the mean of two readings was used for the analyses [20, 21]. Hypertension was defined as the use of antihypertensive medication in the past 2 weeks or a measured blood pressure of 140/90 mmHg or higher at the time of physical examination. Glycemic control of diabetes was defined as glycosylated hemoglobin A1c (HbA1c) < 7.0% among those with diabetes during the survey. CVD was defined as history of coronary artery disease, congestive heart failure, stroke, or peripheral vascular disease. Overweight and obesity were defined as a BMI of 24.0 to 27.9 and 27.9 or higher, respectively [22].

Blood and urine samples were collected according to according to a standardized protocol. HbA1c was measured in whole blood samples using automated, nonporous ion-exchange high-performance liquid chromatography (HPLC) on a hemoglobin analyzer (D-10, Bio-Rad). A single first-morning midstream urine sample was collected from each participant on the day of the interview. Urinary creatinine was measured by an enzymatic assay, and urine albumin was assessed by a nephelometric method in the same urine sample using a Roche Cobas 6000 biochemistry autoanalyzer.

Assessment of CKD

CKD was defined as the presence of albuminuria or estimated glomerular filtration rate (eGFR) < 60 mL/min/1.73 m2. Albuminuria was defined as a urine albumin-to-creatinine ratio (UACR) of 30 mg/g or higher. eGFR was computed using serum creatinine, sex, and age, according to the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) formula [23].

Statistical analyses

Dietary patterns were derived from 18 food groups using factor analysis with principal component method (Table S2) [24–26]. The identified factors were rotated by orthogonal transformation (varimax rotation) to obtain a simpler structure with greater interpretability [27]. The number of factors (dietary patterns) to be retained was chosen based on the following criteria: components with an eigenvalue ≥ 1.0; the examination of the scree plot (Supplemental Fig. 1); explained ≥ 10% of the total variance and interpretability. Food items with absolute factor loadings ≥ 0.20 were considered to be the main contributors to a dietary pattern [28]. Each food intake characteristics and the overall dietary pattern were analyzed by the positive and negative factor loadings and magnitudes, and the extracted dietary patterns were classified and named according to their clinical significance or the magnitude of their food contribution. Factor scores for each dietary pattern were calculated by summing and weighting the observed intakes of food groups. Each participant received a score for each identified dietary pattern, reflecting how closely their diet resembled the pattern, with a higher score representing closer resemblance. In our analysis, the factor (dietary pattern) scores and their quartiles were used in further analyses, with quartile 1 (Q1) representing the lowest consumption of each pattern and Q4 representing the highest intake of the food pattern. Q1 for each model was used as the reference group.

Continuous variables were expressed as median (interquartile range [IQR]) or mean ± standard deviation (SD) and compared using the nonparametric Mann–Whitney U test or an independent sample t-test, as appropriate. Categorical variables are summarized as numbers (percentages) and compared using the chi-square test or Fisher's exact test, as appropriate. We did not perform imputation for less than 5% of the randomly missing data. We investigated the association between dietary patterns and CKD by using logistic regression models. Logistic regression was used to estimate odds ratios (ORs) and 95% confidence intervals (95% CIs) adjusted for potential confounders. Associations were expressed as adjusted ORs with 95% CIs, using the lowest quartile score (Q1) as a reference. Backward elimination was used to identify potential confounders for inclusion in the multivariate models, retaining those associated with CKD ($P < 0.05$). Covariates included in multivariable models were age, sex, body mass index, education level, income level, smoking status, alcohol consumption, physical activity, systolic blood pressure, diastolic blood pressure, use of ACEI or ARB, cardiovascular disease, diabetes duration, HbA1c, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, total cholesterol, and triglyceride levels. All statistical analyses were performed using SPSS statistical software version 22.0, R software (http://www.r-project.org/) and EmpowerStats (http://www.empowerstats.com, X&Y Solutions, Inc., Boston, MA). Statistical significance was set at $P < 0.05$ (two-sided).

Results

Subject characteristics at baseline

Table 1 lists the baseline characteristics of the study population. Among the 5,713 participants included in this study, 3,205 (56.1%) were female and 2,508 (43.9%) were male, with a mean age of 71.6 ± 5.0 years. Significant gender differences were observed in educational level (junior high school and higher: females 5.5% vs. males 27.8%, $P < 0.001$) and annual income (< 30,000 yuan/

Table 1 Basic characteristics of the study population

Variables	Total (*n* = 5713)	Female (*n* = 3205, 56.1%)	Male (*n* = 2508, 43.9%)	*P* value
Age (years)	71.6 ± 5.0	71.7 ± 5.0	71.5 ± 5.0	0.25
Junior high school and higher, n (%)	873 (15.3)	176 (5.5)	697 (27.8)	< 0.001
Income < 30,000 yuan/year, n (%)	4568 (80.0)	2797 (87.3)	1771 (70.6)	< 0.001
Residence area, n (%)				< 0.001
Rural	2073 (36.3)	1178 (36.8)	895 (35.7)	
Urban	3389 (59.3)	1857 (57.9)	1532 (61.1)	
Urban–rural fringe	251 (4.4)	170 (5.3)	81 (3.2)	
BMI (kg/m^2)	24.9 ± 3.2	25.0 ± 3.4	24.8 ± 3.0	< 0.001
< 24.0	2176 (38.2)	1234 (38.6)	942 (37.7)	
24.0–28.0	2589 (45.5)	1383 (43.3)	1206 (48.3)	
≥ 28.0	928 (16.3)	577 (18.1)	351 (14.0)	
Waist circumference (cm)	89.2 ± 9.4	88.5 ± 9.5	90.2 ± 9.1	< 0.001
Systolic blood pressure (mmHg)	144.8 ± 19.8	146.6 ± 19.8	142.5 ± 19.4	< 0.001
< 140	2261 (39.8)	1171 (36.8)	1090 (43.7)	
≥ 140	3416 (60.2)	2012 (63.2)	1404 (56.3)	
Diastolic blood pressure (mmHg)	80.1 ± 10.4	79.6 ± 10.3	80.6 ± 10.4	< 0.001
< 90	4687 (82.6)	2672 (83.9)	2015 (80.8)	
≥ 90	990 (17.4)	511 (16.1)	479 (19.2)	
Diabetes duration (years)	9.0 (4.1, 14.5)	10.0 (4.3, 15.0)	8.2 (4.0, 14.3)	0.002
Family history of diabetes mellitus, n (%)	1368 (23.9)	808 (25.2)	560 (22.3)	0.01
Hypoglycemic agents, n (%)	5538 (96.9)	3103 (96.8)	2435 (97.1)	0.61
Cardiovascular disease, n (%)	606 (10.6)	323 (10.1)	283 (11.3)	0.15
Hypertension, n (%)	4315 (75.5)	2458 (76.7)	1857 (74)	0.02
Hypertension duration (years)	13.0 (10.0, 20.0)	14.0 (10.0, 20.0)	13.0 (8.0, 20.0)	0.01
Antihypertensive drugs, n (%)	4196 (73.4)	2393 (74.7)	1803 (71.9)	0.02
ACEI or ARB, n (%)	2112 (37.0)	1177 (36.7)	935 (37.3)	0.69
Smoking status, n (%)				< 0.001
Never	4174 (73.1)	3200 (99.8)	974 (38.8)	
Current	1010 (17.7)	5 (0.2)	1005 (40.1)	
Past	529 (9.3)	0 (0)	529 (21.1)	
Alcohol consumption, n (%)				< 0.001
Never	4714 (82.5)	3195 (99.7)	1519 (60.6)	
Current	763 (13.4)	10 (0.3)	753 (30.0)	
Past	236 (4.1)	0 (0)	236 (9.4)	
Physical activity, n (%)				< 0.001
< 30 min/d	3686 (64.5)	2189 (68.3)	1497 (59.7)	
≥ 30 min/d	2027 (35.5)	1016 (31.7)	1011 (40.3)	
HbA1c (%)	7.4 ± 1.5	7.3 ± 1.4	7.4 ± 1.5	< 0.001
< 7.0	2709 (47.4)	1575 (49.1)	1134 (45.3)	
≥ 7.0	3002 (52.6)	1630 (50.9)	1372 (54.7)	
Fasting plasma glucose (mmol/L)	8.3 ± 2.4	8.2 ± 2.4	8.3 ± 2.4	< 0.001
Lipid profile				
HDL-C (mmol/L)	1.4 ± 0.3	1.4 ± 0.3	1.3 ± 0.3	< 0.001
LDL-C (mmol/L)	2.8 ± 0.9	2.9 ± 0.9	2.7 ± 0.9	< 0.001
TG (mmol/L)	1.7 ± 1.4	1.9 ± 1.6	1.5 ± 1.1	< 0.001
TC (mmol/L)	4.8 ± 1.1	5.0 ± 1.1	4.5 ± 1.0	< 0.001
Uric acid (μmol/L)	326.6 ± 97.2	312.5 ± 97.1	344.6 ± 94.3	< 0.001
eGFR (mL/min/1.73m^2)	83.2 ± 17.6	85.3 ± 18.0	80.5 ± 16.7	< 0.001

Table 1 (continued)

Variables	Total ($n=5713$)	Female ($n=3205$, 56.1%)	Male ($n=2508$, 43.9%)	*P* value
UACR (mg/g)	22.4 (10.5, 57.3)	26.9 (13.3, 66.6)	17.1 (7.8, 44.9)	< 0.001
CKD, n (%)	2611 (45.7)	1616 (50.4)	995 (39.7)	< 0.001

Continuous variables were expressed as median (interquartile range [IQR]) or means ± standard deviation (SD). Categorical variables were described as number (%). *P*-values were calculated using t-test or Mann–Whitney U test for continuous variables, and chi-squared test for categorical variables. A *P*-value < 0.05 was considered statistically significant

Abbreviations: *CKD* Chronic kidney disease, *BMI* Body mass index, *ACEI* Angiotensin-converting enzyme inhibitor, *ARB* Angiotensin receptor blocker, *HDL-C* High-density lipoprotein cholesterol, *LDL-C* Low-density lipoprotein cholesterol, *TC* Total cholesterol, *TG* Triglyceride, *eGFR* estimated glomerular filtration rate, *UACR* Urinary albumin-to-creatinine ratio

year: females 87.3% vs. males 70.6%, $P<0.001$). Regarding residence, 36.3% lived in rural areas, 59.3% in urban areas, and 4.4% in urban–rural fringes, with significant gender differences ($P<0.001$). Female participants had a higher mean systolic blood pressure (146.6 ± 19.8 vs. 142.5 ± 19.4 mmHg, $P<0.001$), longer diabetes duration (median: 10.0 vs. 8.2 years, $P=0.002$), and higher prevalence of hypertension (76.7% vs. 74.0%, $P=0.02$). Lifestyle differences were notable, with females having a much lower prevalence of current smoking (0.2% vs. 40.1%, $P<0.001$) and alcohol consumption (current drinkers: 0.3% vs. 30.0%, $P<0.001$). Physical inactivity (< 30 min/d) was more common in females (68.3%) than males (59.7%) ($P<0.001$). Metabolic parameters also showed significant gender differences: females had higher total cholesterol (5.0 ± 1.1 vs. 4.5 ± 1.0 mmol/L, $P<0.001$), higher eGFR (85.3 ± 18.0 vs. 80.5 ± 16.7 mL/min/1.73m^2, $P<0.001$), and higher UACR (26.9 vs. 17.1 mg/g, $P<0.001$). The prevalence of CKD was significantly higher in females compared to males (50.4% vs. 39.7%, $P<0.001$).

Dietary pattern

From the principal component analysis, four principal components (interpreted as dietary patterns) accounted for 45.8% of the total variance in the dietary intake (Fig. 2 and Table S2). The descriptive labeling

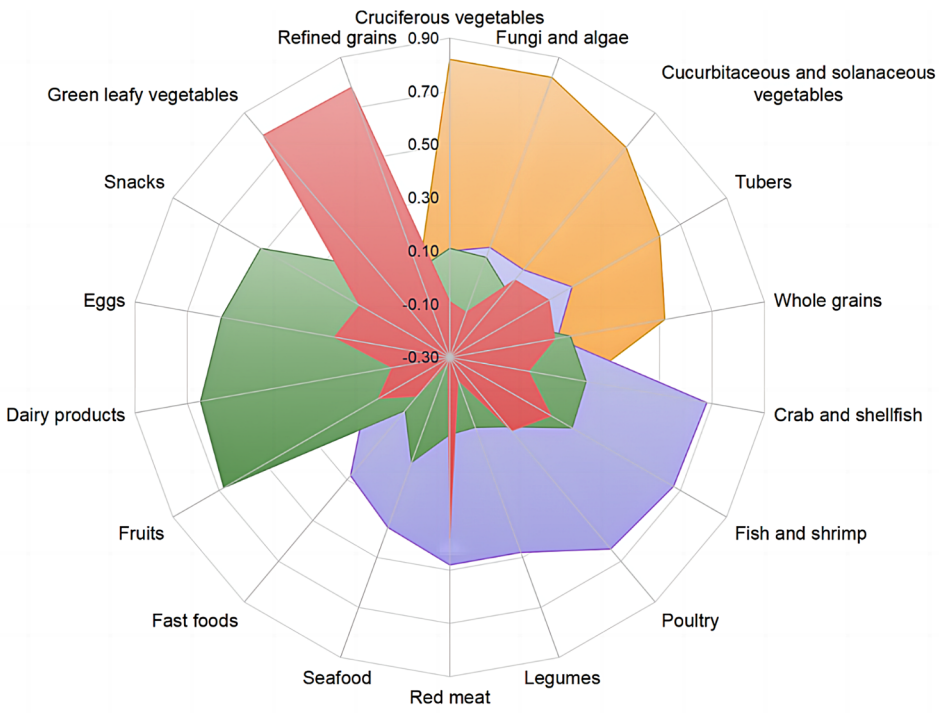


Fig. 2 Food composition of the identified dietary patterns

was determined by identifying the foods that exhibited the strongest association with the respective dietary patterns. The first factor, labelled as "traditional southern dietary pattern", was featured with high intakes of cruciferous vegetables, fungi and algae, cucurbitaceous and solanaceous vegetables, tubers, whole grains, crab and shellfish and fast foods. The "high-protein dietary pattern" was characterized by high consumption of crab and shellfish, fish and shrimp, poultry, legumes, red meat, seafood, fast foods, eggs and tubers. The third factor, labelled as "balanced dietary pattern", had high loadings on fruits, dairy products, egg, snacks, crab and shellfish, fish and shrimp. The fourth pattern was referred to as "imbalanced dietary patterns" in view of the marked consumption of green leafy vegetables, refined grains, and red meat, and low consumption of legumes and seafood. The average consumption of each food group across quartiles was listed in Table S3.

Characteristics according to dietary patterns

The prevalence of CKD and characteristics of study participants by dietary patterns were shown in Table 2 and Table S4. Among the 5,713 participants, four distinct dietary patterns were identified: traditional southern ($n=1,121$), high-protein ($n=1,372$), balanced ($n=1,479$), and imbalanced ($n=1,741$) dietary patterns. Significant differences were observed in renal function parameters across these dietary patterns (all $P<0.001$). The balanced dietary pattern group showed the highest mean eGFR (84.8 ± 16.9 mL/min/1.73m^2) and lowest median UACR (19.8 [9.6, 51.5] mg/g), while the imbalanced dietary pattern group exhibited the lowest mean eGFR (81.6 ± 18.4 mL/min/1.73m^2) and highest median UACR (24.3 [10.9, 62.4] mg/g). The prevalence of CKD varied significantly among dietary patterns, with the highest prevalence observed in the imbalanced dietary pattern group (50.0%) and the lowest in the balanced dietary pattern group (41.0%).

Dietary patterns and CKD in elderly patients with type 2 diabetes

Table 3 shows the effect of adherence to the dietary patterns on CKD in elderly patients with type 2 diabetes. Multivariable logistic regression analysis was performed to assess the association between adherence to different dietary patterns and CKD, albuminuria, and eGFR < 60 mL/min/1.73 m^2 in elderly patients with type 2 diabetes.

For the balanced dietary pattern, high adherence (Q4 vs. Q1) in Model 2 showed a reduced risk of CKD (OR = 0.73, 95% CI: 0.62–0.86, $P<0.001$) and eGFR < 60 mL/min/1.73 m^2 (OR = 0.59, 95% CI: 0.46–0.76, $P<0.001$), with significant trends across quartiles (P for trend < 0.001 for both endpoints). Similarly, high adherence (Q4 vs. Q1) was associated with a reduced risk of albuminuria in the fully adjusted model (OR = 0.77, 95% CI: 0.65–0.91, $P=0.002$). The imbalanced dietary pattern was associated with increased odds of CKD (OR = 1.08, 95% CI: 1.02–1.14, $P=0.008$), with the highest risk in the fourth quartile (Q4 vs. Q1: OR = 1.25, 95% CI: 1.07–1.46, $P=0.006$). For specific renal outcomes, the imbalanced pattern was associated with increased risk of reduced eGFR (OR = 1.14, 95% CI: 1.04–1.25, $P=0.005$). The traditional southern and high-protein dietary patterns showed no significant associations with overall CKD risk in the fully adjusted model (Model 2).

Discussion

To our knowledge, this study is the first to identify dietary patterns associated with CKD in elderly patients with type 2 diabetes in China. Four distinct dietary patterns were identified, collectively explaining 45.8% of the dietary variance in the study population and reflecting the predominant dietary habits of elderly individuals in the Xiangcheng District, Suzhou. After adjustment for potential confounders, adherence to a balanced dietary pattern, characterized by elevated loadings of fruits, dairy products, eggs, snacks, crab, shellfish, fish, and shrimp, was significantly associated with reduced odds of CKD. In contrast, an imbalanced dietary pattern was associated with increased odds of CKD. No significant associations

Table 2 Prevalence of CKD among 5713 participants by dietary patterns in Xiangcheng District

Variables	Total	Traditional southern dietary pattern	High-protein dietary pattern	Balanced dietary pattern	Imbalanced dietary pattern	*P* value
	(*n* = 5713)	(*n* = 1121)	(*n* = 1372)	(*n* = 1479)	(*n* = 1741)	
eGFR (mL/min/1.73m^2)	83.2 ± 17.6	82.8 ± 17.7	83.7 ± 16.9	**84.8 ± 16.9**	81.6 ± 18.4	< 0.001
UACR (mg/g)	22.4 (10.5, 57.3)	22.0 (10.5, 55.5)	23.1 (10.6, 58.8)	**19.8 (9.6, 51.5)**	24.3 (10.9, 62.4)	< 0.001
CKD, n (%)	2611 (45.7)	504 (45.0)	630 (45.9)	**606 (41.0)**	871 (50.0)	< 0.001

Continuous variables were expressed as median (interquartile range [IQR]) or means ± standard deviation (SD). Categorical variables were described as number (%)

Abbreviations: *CKD* Chronic kidney disease, *eGFR* estimated glomerular filtration rate, *UACR* Urinary albumin-to-creatinine ratio

Table 3 Multivariable logistic regression between adherence to the dietary patterns and CKD in elderly patients with type 2 diabetes

Endpoints	Traditional southern dietary pattern									
	Total		Q1	Q2		Q3		Q4		*P* for trend
	OR(95% CI)	*P* value		OR(95% CI)	*P* value	OR(95% CI)	*P* value	OR(95% CI)	*P* value	
CKD										
n (%)	2611 (45.7)		669 (46.8)	633 (44.3)		662 (46.4)		647 (45.3)		
Crude model	0.96 (0.91, 1.01)	0.13	1.00 (Ref)	0.90 (0.78, 1.05)	0.18	0.98 (0.85, 1.14)	0.79	0.94 (0.81, 1.09)	0.4	0.58
Model 1	0.96 (0.91, 1.01)	0.1	1.00 (Ref)	0.93 (0.80, 1.08)	0.35	0.99 (0.85, 1.15)	0.85	0.93 (0.80, 1.08)	0.37	0.47
Model 2	0.95 (0.89, 1.00)	0.06	1.00 (Ref)	0.91 (0.78, 1.07)	0.25	0.99 (0.84,1.16)	0.9	0.93 (0.79, 1.09)	0.37	0.52
Albuminuria										
n (%)	2335 (40.9)		582 (40.8)	559 (39.1)		600 (42)		594 (41.6)		
Crude model	0.99 (0.94, 1.05)	0.82	1.00 (Ref)	0.94 (0.80, 1.09)	0.38	1.05 (0.91, 1.22)	0.5	1.03 (0.89, 1.20)	0.66	0.43
Model 1	0.99 (0.93, 1.04)	0.59	1.00 (Ref)	0.95 (0.81, 1.10)	0.48	1.05 (0.90, 1.22)	0.55	1.02 (0.87, 1.18)	0.84	0.63
Model 2	0.97 (0.92, 1.03)	0.34	1.00 (Ref)	0.91 (0.78, 1.08)	0.28	1.05 (0.89, 1.23)	0.55	1.02 (0.94, 1.10)	0.99	0.7
eGFR < 60 mL/min/1.73 m^2										
n (%)	661 (11.6)		181 (12.7)	154 (10.8)		170 (11.9)		156 (10.9)		
Crude model	0.94 (0.87, 1.03)	0.17	1.00 (Ref)	0.84 (0.67, 1.05)	0.13	0.93 (0.75, 1.17)	0.55	0.84 (0.67, 1.06)	0.14	0.23
Model 1	0.96 (0.88, 1.04)	0.3	1.00 (Ref)	0.93 (0.73, 1.17)	0.52	0.99 (0.79, 1.25)	0.96	0.89 (0.70, 1.12)	0.31	0.38
Model 2	0.97 (0.89, 1.06)	0.47	1.00 (Ref)	0.97 (0.76, 1.25)	0.84	1.02 (0.80, 1.29)	0.9	0.91 (0.71, 1.17)	0.47	0.5
Endpoints	**High-protein dietary pattern**									
	Total		**Q1**	**Q2**		**Q3**		**Q4**		***P* for trend**
	OR(95% CI)	***P* value**		**OR(95% CI)**	***P* value**	**OR(95% CI)**	***P* value**	**OR(95% CI)**	***P* value**	
CKD										
n (%)	2611 (45.7)		670 (46.9)	679 (47.5)		652 (45.7)		610 (42.7)		
Crude model	0.93 (0.88, 0.98)	0.005	1.00 (Ref)	1.03 (0.89, 1.19)	0.74	0.95 (0.82, 1.10)	0.5	0.84 (0.73, 0.98)	0.02	0.01
Model 1	0.98 (0.93, 1.04)	0.48	1.00 (Ref)	1.11 (0.96, 1.29)	0.17	1.07 (0.92, 1.25)	0.38	0.98 (0.84, 1.14)	0.78	0.55
Model 2	1.00 (0.94, 1.06)	0.95	1.00 (Ref)	1.13 (0.97, 1.33)	0.12	1.11 (0.95, 1.30)	0.2	1.02 (0.87, 1.20)	0.83	0.94
Albuminuria										
n (%)	2335 (40.9)		584 (40.9)	603 (42.2)		598 (41.9)		550 (38.5)		
Crude model	0.95 (0.90, 1.00)	0.04	1.00 (Ref)	1.06 (0.91, 1.23)	0.47	1.04 (0.90, 1.21)	0.6	0.90 (0.78, 1.05)	0.19	0.13
Model 1	1.00 (0.95, 1.06)	0.98	1.00 (Ref)	1.14 (0.98, 1.32)	0.1	1.17 (1.00, 1.36)	0.05	1.04 (0.89, 1.22)	0.59	0.72
Model 2	1.02 (0.96, 1.08)	0.55	1.00 (Ref)	1.17 (1.00, 1.38)	0.05	1.23 (1.04, 1.44)	0.01	1.10 (0.94, 1.30)	0.25	0.33
eGFR < 60 mL/min/1.73 m^2										
n (%)	661 (11.6)		205 (14.4)	176 (12.3)		131 (9.2)		149 (10.4)		
Crude model	0.85 (0.78, 0.92)	0.001	1.00 (Ref)	0.84 (0.68, 1.04)	0.12	0.60 (0.48, 0.76)	< 0.001	0.69 (0.55, 0.87)	0.002	< 0.001
Model 1	0.86 (0.79, 0.94)	0.001	1.00 (Ref)	0.89 (0.71, 1.11)	0.3	0.64 (0.50, 0.81)	< 0.001	0.72 (0.57, 0.92)	0.01	0.002

Table 3 (continued)

Model 2	0.87 (0.79, 0.95)	0.003	1.00 (Ref)	0.90 (0.71, 1.13)	0.37	0.65 (0.51, 0.84)	< 0.001	0.73 (0.57, 0.94)	0.01	0.004
Endpoints	**Balanced dietary pattern**									
	Total		**Q1**	**Q2**		**Q3**		**Q4**		***P* for trend**
	OR(95% CI)	***P* value**		**OR(95% CI)**	***P* value**	**OR(95% CI)**	***P* value**	**OR(95% CI)**	***P* value**	
CKD										
n (%)	2611 (45.7)		701 (49.1)	684 (47.9)		654 (45.8)		572 (40.0)		
Crude model	0.87 (0.82, 0.92)	< 0.001	1.00 (Ref)	0.95 (0.82, 1.10)	0.53	0.88 (0.76, 1.02)	0.08	0.69 (0.60, 0.80)	< 0.001	< 0.001
Model 1	0.87 (0.82, 0.91)	< 0.001	1.00 (Ref)	0.95 (0.82, 1.10)	0.48	0.85 (0.74, 0.99)	0.04	0.69 (0.59, 0.80)	< 0.001	< 0.001
Model 2	**0.88 (0.83, 0.93)**	**< 0.001**	1.00 (Ref)	0.99 (0.85, 1.16)	0.89	0.89 (0.76, 1.04)	0.15	**0.73 (0.62, 0.86)**	**< 0.001**	< 0.001
Albuminuria										
n (%)	2335 (40.9)		620 (43.4)	612 (42.9)		593 (41.5)		510 (35.7)		
Crude model	0.89 (0.84, 0.93)	< 0.001	1.00 (Ref)	0.98 (0.84, 1.13)	0.76	0.93 (0.80, 1.07)	0.31	0.72 (0.62, 0.84)	< 0.001	< 0.001
Model 1	0.88 (0.84, 0.93)	< 0.001	1.00 (Ref)	0.98 (0.85, 1.14)	0.82	0.90 (0.78, 1.05)	0.19	0.72 (0.62, 0.84)	< 0.001	< 0.001
Model 2	**0.90 (0.85, 0.95)**	**< 0.001**	1.00 (Ref)	1.03 (0.88, 1.21)	0.69	0.95 (0.81, 1.11)	0.52	**0.77 (0.65, 0.91)**	**0.002**	< 0.001
eGFR < 60 mL/min/1.73 m^2										
n (%)	661 (11.6)		199 (13.9)	178 (12.5)		153 (10.7)		131 (9.2)		
Crude model	0.83 (0.76, 0.90)	< 0.001	1.00 (Ref)	0.88 (0.71, 1.09)	0.25	0.74 (0.59, 0.93)	0.01	0.62 (0.49, 0.79)	< 0.001	< 0.001
Model 1	0.82 (0.75, 0.90)	< 0.001	1.00 (Ref)	0.83 (0.66, 1.04)	0.11	0.73 (0.58, 0.92)	0.01	0.60 (0.47, 0.77)	< 0.001	< 0.001
Model 2	**0.81 (0.74, 0.88)**	**< 0.001**	1.00 (Ref)	0.84 (0.66, 1.06)	0.14	0.74 (0.58, 0.94)	0.01	**0.59 (0.46, 0.76)**	**< 0.001**	< 0.001
Endpoints	**Imbalanced dietary pattern**									
	Total		**Q1**	**Q2**		**Q3**		**Q4**		***P* for trend**
	OR(95% CI)	***P* value**		**OR(95% CI)**	***P* value**	**OR(95% CI)**	***P* value**	**OR(95% CI)**	***P* value**	
CKD										
n (%)	2611 (45.7)		621 (43.5)	643 (45.0)		659 (46.1)		688 (48.1)		
Crude model	1.07 (1.01, 1.13)	0.01	1.00 (Ref)	1.06 (0.92, 1.23)	0.41	1.11 (0.96, 1.29)	0.15	1.21 (1.04, 1.40)	0.01	0.01
Model 1	1.08 (1.02, 1.14)	0.006	1.00 (Ref)	1.08 (0.93, 1.25)	0.34	1.14 (0.98, 1.32)	0.1	1.25 (1.07, 1.45)	0.004	0.005
Model 2	1.08 (1.02, 1.14)	0.008	1.00 (Ref)	1.01 (0.86, 1.18)	0.9	1.15 (0.98, 1.35)	0.09	1.25 (1.07, 1.46)	0.006	0.005
Albuminuria										
n (%)	2335 (40.9)		568 (39.8)	570 (39.9)		589 (41.2)		608 (42.5)		
Crude model	1.04 (0.99, 1.10)	0.15	1.00 (Ref)	1.01 (0.87, 1.17)	0.94	1.06 (0.92, 1.23)	0.42	1.12 (0.97, 1.30)	0.13	0.14
Model 1	1.04 (0.99, 1.10)	0.12	1.00 (Ref)	1.01 (0.87, 1.17)	0.92	1.07 (0.92, 1.24)	0.39	1.14 (0.98, 1.32)	0.1	0.11
Model 2	1.04 (0.98, 1.10)	0.22	1.00 (Ref)	0.93 (0.79, 1.09)	0.38	1.07 (0.91, 1.25)	0.41	1.12 (0.95, 1.31)	0.17	0.16
eGFR < 60 mL/min/1.73 m^2										
n (%)	661 (11.6)		148 (10.4)	161 (11.3)		170 (11.9)		182 (12.7)		
Crude model	1.10 (1.01, 1.20)	0.03	1.00 (Ref)	1.10 (0.87, 1.39)	0.47	1.17 (0.93, 1.48)	0.19	1.27 (1.00, 1.59)	0.046	0.04

Table 3 (continued)

Model 1	1.13 (1.03, 1.23)	0.01	1.00 (Ref)	1.16 (0.91, 1.49)	0.23	1.28 (1.00, 1.63)	0.05	1.37 (1.08, 1.74)	0.010	0.007
Model 2	1.14 (1.04, 1.25)	0.005	1.00 (Ref)	1.21 (0.94, 1.55)	0.15	1.33 (1.04, 1.71)	0.03	1.41 (1.11, 1.81)	0.006	0.004

Abbreviations: *OR* Odds ratio, *Q* Quartile, *Ref* Reference, *CKD* Chronic kidney disease, *eGFR* estimated glomerular filtration rate, *UACR* Urinary albumin-to-creatinine ratio

Model 1: Adjusted for age, sex and body mass index

Model 2: Adjusted for age, sex, body mass index, education level, income level, smoking status, alcohol consumption, physical activity, systolic blood pressure, diastolic blood pressure, use of ACEI or ARB, cardiovascular disease, diabetes duration, HbA1c, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, total cholesterol, triglyceride

were observed between CKD and adherence to either the "traditional southern dietary pattern" or the "high-protein dietary pattern".

Most prior population-based studies on diet and CKD have concentrated on individual dietary components or nutrients [25]. However, dietary intakes are complex and involve intricate nutrient interactions, which are not captured by single-component analyses. By identifying dietary patterns, we account for the synergistic effects of multiple nutrients as well as cultural and lifestyle factors, enabling a more comprehensive understanding of dietary influences on CKD. This method also enhances the relevance of findings for clinical practice and public health initiatives, as dietary patterns are more pragmatic targets for dietary guidelines [29]. Although there is growing advocacy for adherence to healthy dietary patterns globally, most of the currently recommended patterns are Western-oriented and may not adequately align with the dietary habits or cultural preferences of Chinese individuals, especially elderly populations. Tailored dietary recommendations are therefore essential to address nutritional disparities and optimize health outcomes in specific populations.

Previous studies have reported that adherence to established healthy dietary patterns, such as the Dietary Approaches to Stop Hypertension (DASH) diet or the Mediterranean diet, is associated with a reduced risk of CKD [30, 31]. The DASH diet emphasizes high consumption of fruits, vegetables, and low-fat or skim dairy products, while limiting saturated fats, cholesterol, and sugary items [32]. Similarly, the Mediterranean diet is characterized by high intake of vegetables, fruits, whole grains, legumes, nuts, and olive oil, alongside low consumption of red and processed meat [33]. Several components of the "balanced dietary pattern" identified in our study overlap with these widely recognized dietary models, but it also incorporates unique regional characteristics that align with the cultural and dietary habits of elderly patients with type 2 diabetes in the Xiangcheng District of Suzhou. These regional differences emphasize the influence of the unique geographical and cultural environment on dietary practices and the importance of tailoring dietary recommendations to specific populations.

Healthy dietary patterns have consistently been linked to a reduced incidence of CKD, largely through mechanisms involving dietary fiber and antioxidants [16, 34, 35]. Diets rich in fruits and vegetables provide essential antioxidants, such as vitamins C and E and carotenoids, which reduce oxidative stress and systemic inflammation—both major contributors to CKD progression [10, 17]. Additionally, a diet high in fruits and low in animal protein reduces the endogenous acid load, alleviating nephron stress and supporting long-term kidney health [36]. Evidence from a large cross-sectional study of 56,476 individuals with metabolic syndrome in China demonstrated that adherence to dietary patterns rich in vegetables, fruits, and grains, as well as milk and dairy, was associated with reduced levels of blood urea nitrogen, creatinine, and uric acid and improved eGFR [37]. Dietary fiber, a key component of plant-based foods including vegetables, fruits, whole grains, nuts, legumes, and seeds, plays a significant role in mitigating CKD risk [38, 39]. Sufficient fiber intake confers a range of health benefits, such as promoting gut microbiota diversity, strengthening the intestinal barrier, reducing systemic inflammation, and improving bowel function. Importantly, adequate fiber intake has been associated with decreased production of uremic toxins, which are implicated in CKD progression and increased mortality [38, 40].

The meat-seafood-egg dietary pattern, characterized by a high intake of protein and saturated fat, is not recommended for individuals with mild kidney insufficiency, as elevated consumption of meat, fish, eggs, and other non-dairy protein sources may accelerate CKD progression [41]. Experimental studies have demonstrated that a low-protein diet can mitigate renal damage by inhibiting endogenous uric acid synthesis and improving renal tubular injury, as compared to a standard protein diet (18% protein), in streptozotocin-induced diabetic rats [42]. In our study, the high-protein dietary pattern was not significantly associated with CKD, while the balanced dietary pattern exhibited a lower factor loading for aquatic protein sources such as freshwater fish, shrimp, crab, and shellfish, with values around 0.2. This indicates that protein intake in the balanced dietary pattern is relatively lower compared to the high-protein dietary pattern, possibly contributing to the protective effect observed.

Interestingly, our finding that snacks, as a component of the balanced dietary pattern, were associated with a lower prevalence of CKD among elderly patients with type 2 diabetes was counterintuitive. Previous evidence suggests that snacks—particularly those representative of Western dietary patterns—are often high in energy, carbohydrates, fats, and sodium, while being low in potassium and calcium, all of which are linked to an increased risk of metabolic syndrome, gout, and other chronic diseases [43–46]. However, other studies have indicated that snacking can also be associated with higher dietary quality and greater intake of key nutrients such as vitamins, potassium, and magnesium [47, 48]. The heterogeneity of snack composition makes it essential to account for nutritional content when assessing their health effects. Properly selected snacks do not inherently degrade diet quality; rather, they can increase opportunities for

healthy, low-energy food choices and contribute positively to dietary diversity. Additionally, balanced snacking can significantly enhance daily micronutrient and macronutrient intake [49].

The snacks consumed in our study population in the Xiangcheng District, Suzhou, exemplify traditional "Su Cuisine" and are characterized by their fragrance, sweetness, fine texture, loose consistency, and ingredients like glutinous rice—hallmarks of local dietary habits. Located adjacent to Yangcheng Lake, a major freshwater lake in Jiangsu Province and one of the most significant fishing areas in China, the Xiangcheng District benefits from abundant biological resources [50]. Yangcheng Lake provides a diverse array of aquatic species, traditionally referred to as the "Six Treasures of Yangcheng Lake," including species such as salmon, turtles, whitefish, eels, shrimp, and crabs. Among these, the Chinese mitten crab, often referred to as the "King of Crabs," is renowned for its exceptional taste, unique aroma, and high nutritional value. It is a rich source of minerals such as zinc, iron, copper, and phosphorus and provides high-quality protein [51]. These foods align with the local cultural and geographical context while offering considerable dietary and nutritional value, which may contribute to the unique dietary patterns observed in this study.

In our study, adherence to the "imbalanced dietary pattern" was positively associated with a higher risk of CKD. This pattern was characterized by a prominent consumption of green leafy vegetables, refined grains, and red meat, along with low intake of legumes and seafood, and an overall lack of diversity in other dietary components. These findings are partially consistent with previous studies, which have demonstrated a positive association between high red meat consumption and the risk of CKD. For instance, the Atherosclerosis Risk in Communities (ARIC) study, which followed 12,000 participants over a median of 23 years, reported that 2,632 individuals developed CKD, with red and processed meat intake being significantly associated with an increased risk of CKD (HR = 1.19, 95% CI: 1.03–1.36) [52]. Recent research has pointed to trimethylamine N-oxide (TMAO)—a metabolite generated by gut microbial metabolism of dietary red meat—as a potential mediator of the adverse effects of red meat consumption on cardiovascular and kidney health [53].

In this study, we investigated the association between diet and CKD among elderly patients with type 2 diabetes in China. The strengths of our study include its large sample size, population-based design, and the availability of detailed epidemiological and clinical data, which allowed for extensive adjustment for potential confounders. Unlike previous studies, we focused on a specific population of elderly diabetic patients with CKD, who may differ from populations studied in other dietary guidelines. This population-specific focus provides new insights into dietary management tailored for elderly Chinese diabetic patients with CKD. Importantly, we identified dietary patterns that not only align with the cultural and regional dietary habits in China but may also serve as healthy, practical options for this high-risk group. These findings provide valuable, real-world evidence to inform dietary recommendations aimed at improving the renal health of elderly Chinese diabetic patients.

This study has several limitations that should be acknowledged. First, the focus on elderly patients with type 2 diabetes in a specific region may restrict the generalizability of the findings to other populations; however, this allowed us to identify dietary patterns particularly relevant to this demographic, providing valuable insights for targeted approaches. Second, the use of self-reported dietary data through food frequency questionnaires is subject to recall bias, and the identification of dietary patterns via factor analysis limits reproducibility. Additionally, while rigorous adjustments were made for potential confounders, residual confounding cannot be entirely excluded, particularly given the lack of detailed nutrient-level data (e.g., energy, protein, and fat intake). Lastly, the cross-sectional design precludes causal inference, highlighting the need for future longitudinal studies to confirm these associations.

Conclusions

In summary, our study demonstrated that dietary patterns aligned with local eating habits are associated with CKD in elderly Chinese patients with type 2 diabetes. A balanced dietary pattern, featuring high intake of fruits, dairy products, eggs, snacks, crab and shellfish, and fish and shrimp, was associated with a lower prevalence of CKD, while an imbalanced dietary pattern was linked to an increased risk. Further large-scale, long-term studies and randomized controlled trials are needed to clarify the associations between diet and CKD in elderly diabetic patients in China.

Abbreviations

CKD	Chronic kidney disease
T2DM	Type 2 diabetes mellitus
BMI	Body mass index
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
ACEI	Angiotensin-converting enzyme inhibitor
ARB	Angiotensin receptor blocker
HDL-C	High-density lipoprotein cholesterol
LDL-C	Low-density lipoprotein cholesterol
TC	Total cholesterol
TG	Triglyceride
eGFR	Estimated glomerular filtration rate
UACR	Urinary albumin-to-creatinine ratio
FFQ	Food frequency questionnaire
CVD	Cardiovascular disease

HbA1c	Glycosylated hemoglobin A1c
OR	Odds ratio
CI	Confidence interval

Supplementary Information

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Supplementary Material 1.

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Authors' contributions
Xiaomu Li, Xiaoying Li and Fang Zhou conceived and designed this work. Ling Cao, Peng Yu, Lei Zhang and Qiuming Yao conducted research, researched data and analyzed the data. Ling Cao interpreted the results and drafted the manuscript. Xiaoying Li and Xiaomu Li supervised the study, reviewed and edited the manuscript. All authors contributed to the review and revision of the manuscript and agree to be accountable for all aspects of work ensuring integrity and accuracy.

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Data availability
All data are available in the manuscript or supplementary materials. Further inquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate
The study was conducted in accordance with the Declaration of Helsinki and approved by the ethical committee of Zhongshan Hospital Fudan University (no. B2020-201). All participants were agreed to take part in the study and provided informed written consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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