Healthy adult vegetarians have better renal function than matched omnivores: a cross sectional study in China.

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Research article

Keywords: Vegetarian, Dietary pattern, Renal function, Kidney, Estimated glomerular filtration rate, Urea nitrogen, Serum creatinine, Uric acid

DOI: https://doi.org/10.21203/rs.2.17471/v2

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Abstract

Background Appropriate diet is an important determinant of kidney health. However, the association between vegetarian diets and renal function is unclear.

Object We aimed to study the association between vegetarian diets and renal function in healthy adults.

Design A total of 269 vegetarians (aged 34.5±8.7 years) and 269 sex- and age-matched nonvegetarian omnivores were enrolled in this cross-sectional study. Basic characteristics as well as daily dietary intakes were assessed by face-to-face interviews. Blood samples were collected, and renal function was assessed by measuring blood urea nitrogen (BUN), creatinine (Cr), uric acid (UA) and estimated glomerular filtration rate (eGFR). Blood pressure, fasting blood glucose and blood lipid profiles were also assessed.

Results The average age of the vegetarians was 35.4±8.6 years, 82.2% of whom were female. We evaluated the association between vegetarian diets and renal function by using multivariate analysis. Compared with omnivores, vegetarians had lower BUN ($\beta = -0.63$, 95% CI: -0.88 to -0.38), SCr ($\beta = -2.07$, 95% CI: -4.21 to -0.06), UA ($\beta = -15.17$, 95% CI: -27.81 to -2.53) and higher eGFR levels ($\beta = 4.09$, 95% CI: 0.23 to 7.96) after adjusting for sex, age, BMI, physical activity, alcohol consumption, smoking status, LDL, HDL, systolic pressure and fasting blood glucose. Further analysis of food composition and renal function showed that dietary fiber intake was significantly negatively associated with BUN ($\beta = -0.02$, 95% CI:(-0.03, 0.00)), SCr ($\beta = -0.14$, 95% CI:(-0.25, 0.04)), and UA ($\beta = -0.72$, 95% CI:(-1.36, 0.07)) and positively associated with eGFR ($\beta = 0.20$, 95% CI:(0.00, 0.40)).

Conclusions Healthy adult vegetarians have better renal function than omnivores, and the higher dietary fiber intake associated with vegetarian diets may contribute to the protective effect on renal function.

1. Background

As a common, real-world dietary pattern, the vegetarian diet is an attractive target for study. Previous studies have suggested that vegetarian diets are associated with a reduced risk of obesity, cardiovascular disease, metabolic syndrome and some types of cancer due to their higher content of unsaturated fat, fiber, folic acid, vitamin C, vitamin E and many phytochemicals [1-4]. Moreover, because of the relatively lower intake and unique source of protein, a vegetarian diet may theoretically have some potential effects on renal function [5,6]. Nevertheless, the association between vegetarian diets and kidney function are controversial on account of the limited quantity of related studies. The most recent cross-sectional study among 55,113 participants revealed a lower prevalence of CKD in vegetarians than in omnivores [7]. A study of a population in the Middle East and North Africa reported that the lacto-vegetarian dietary pattern might be protective against the occurrence of CKD after 6.1 years of follow-up [8]. Another study in Taiwan showed that there was no difference in renal function between 102 Buddhist nun vegetarians and a matched control group of omnivores [9]. Some prospective studies reported that a vegetarian diet has a protective effect against renal diseases such as kidney stones and kidney cancer and may reduce
renal disease mortality, but the relationship between vegetarian diets and renal function parameters were not mentioned [10-12].

Chronic kidney disease (CKD) is a worldwide public health problem that is associated with poor prognosis and high mortality [13,14]. Dietary management plays an important role in the prevention and treatment of CKD [15]. Most of the previous data regarding diet and kidney health were focused on the association between dietary patterns and CKD morbidity. We aimed to fill this gap by focusing on healthy adults without eGFR impairment to explore the relationship between a vegetarian dietary pattern and renal function parameters. We analyzed whether a vegetarian diet was associated with renal function despite the influence of blood pressure and glycolipid metabolism. The roles of the duration of vegetarian dietary habits and nutrients in food have also been discussed. Our results may provide significant observational evidence for the dietary management of renal function.

2. Methods

2.1 Population

A total of 538 young (34.5±8.7 years) healthy Chinese adults included 269 vegetarians and 269 sex- and age-matched (± 1 year) omnivores were recruited for this study through online and offline approaches. All subjects were volunteers. The vegetarian subjects were recruited through advertisements in the Vegetarian Society of China, some vegetarian restaurants in Shanghai or other publicity in media, and word of mouth via subjects. Once being included in our study, the vegetarian subjects was asked to recommended one matched omnivore among her or his friends by the following criteria: 1) same sex; 2) same age or ± 1 year;3) similar lifestyle and social class. The recruitment criteria of participants including: 1) adoption of a vegetarian diet for at least 12 months (for vegetarians); 2) living in Shanghai for more than 6 months; 3) being aged between 18 and 60 years; 4) can understand the contents of the questionnaires; and 5) no history of pregnancy or breastfeeding within the previous 12 months (for female participates). The exclusion criteria of subjects including: 1) subjects who had been diagnosed with any renal disease, acute illness or severe nutritional malabsorption. All the subjects were invited to Xinhua Hospital between March 2015 and May 2016 to participate in this study (see flowchart Figure 1) after providing written informed consent. The study was approved by the Ethics Committee of Shanghai Jiao Tong University School of Medicine.

2.2 Laboratory tests

After 10-12 hours of fasting, a venous blood from each participant was drawn and then sent to the Clinical Laboratory Center of Shanghai Xinhua Hospital for laboratory tests. Data of fasting blood glucose, blood lipid profiles including TC, TGs, LDL, HDL, LDL/HDL ratio, and renal function parameters, including BUN, SCr, and UA were collected. eGFR was used to evaluate renal function in terms of excretion and filtration and was calculated based on the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) from serum creatinine. Higher eGFR values indicate better renal function, mild renal impairment was
defined by eGFR<90 mL/minute/1.73 m² and the presence of CKD was defined as eGFR<60 mL/minute/1.73 m² [16]. Blood pressure was also measured by automatic blood pressure machine (OMRON, HEM-759P, Japan).

2.3 Dietary and lifestyle variables assessments

Habitual dietary intakes were assessed using face-to-face 24-hour recall questionnaire conducted by trained dietitians. To help subjects recall and estimate their dietary intakes, dietitians provided food images, oral descriptions, and food models as a part of the 24 hour dietary recall method. Data-entry and calculate of 24-hour dietary recall questionnaires were using Nutrition Calculator v2.5 software developed by the Institute for Nutrition and Food Safety of the Chinese Center for Disease Control and Prevention and Beijing B-win Technology Co. Ltd.

All vegetarians in our study claimed that they had follow a vegetarian diet by consuming no meat, poultry and aquatic products at all meals daily and persistently for over a year. Those who did not consume any animal products were defined as “vegans”, while those who consumed eggs and/or dairy products were “lacto-ovo vegetarians”. Among the 269 vegetarians, there were 70 vegans (26.0%) and 199 lacto-ovo vegetarians (74.0%). Subjects who did not reject consuming animal products were defined as omnivores.

All participants were required to complete general condition questionnaires via face-to-face interviews. Basic characteristics such as age; sex; income; education level; marital status; tobacco use; alcohol consumption; work intensity; and the frequency, time, and type of physical activity were recorded.

2.4 Physical examination

Height and weight were measured using digital scales to calculate body mass index (BMI). We also used a body composition analyzer (Biospace Inbody 720, Korea) to detect muscle mass to identify the components of body protein that could affect renal function indicators, such as creatinine. All the measurements were performed by professional dietitians while subjects were minimally clothed without shoes.

2.5 Statistical analysis

Data analysis was performed by using Statistical Program for Social Sciences 25.0 (SPSS, IBM, USA). Continuous variables are presented as the means ± standard deviations (SDs) (e.g., age, physical activity, sedentary time, BMI, blood pressure, alcohol consumption, TC, TG, LDL-C, HDL-C, LDL-C/HDL-C ratio, BUN, SCr, UA, eGFR and daily dietary intakes including energy, protein, protein intake/weight, protein energy supply ratio, calcium, phosphorus, potassium and sodium). Categorical variables (e.g., sex, marital status, regular physical examination, ethnicity, education level, working intensity, income, alcohol use, eGFR mild impairment) were presented by proportions. To compare the differences between vegetarian group and omnivore group, paired t tests were performed for continuous data, Wilcoxon matched-pairs signed-ranks tests were performed for ordinal variables, and McNemar tests were performed for matched categorical
variables. Differences between vegan group and lacto-ovo vegetarian group were also assessed. We performed two-independent-sample t tests for continuous data and used Wilcoxon rank-sum tests for ordinal variables. \( \chi^2 \) tests were performed for categorical variables.

Multivariable adjusted \( \beta \) coefficients [95% confidence intervals (CIs)] for the associations of vegetarian dietary patterns [omnivore(reference), total vegetarian (lacto-ovo vegetarian and vegan), lacto-ovo vegetarian, vegan] with renal function parameters (BUN, SCr, UA, eGFR) were estimated by using linear regression. The covariates were sex, age, BMI, skeletal muscle mass, physical activity, alcohol consumption, smoking status, blood pressure, blood lipid profiles, fasting blood glucose and vegetarian duration. The associations between dietary intake compositions and renal function parameters were also estimated using multiple-linear regression. The covariates were sex, age, BMI, skeletal muscle mass, physical activity, alcohol consumption, smoking status, blood pressure, blood lipid profiles fasting blood glucose and vegetarian duration.

All P values were calculated based on two-sided tests, and the significance level for each test was set at P < 0.05.

3. Results

3.1 Basic characteristics of vegetarians and omnivores

The basic characteristics of study participants are shown in Table 1. In our study, the mean age of vegetarians was 35.4±8.6 years, and the mean duration of vegetarian dietary habits was 5.4±5.0 years. The proportion of alcohol users was lower in the vegetarian group, and the vegetarian group was characterized by a lower consumption of alcohol. Vegetarians spent more time being physically active (1.9±2.5 hours/week vs. 1.4±2.0 hours/week) and tended to have a lower BMI (20.9±2.6 kg/m² vs. 22.4±3.5 kg/m²) and a higher skeletal muscle mass (22.3±4.1 kg vs. 23.3±4.8 kg). Compared with omnivores, vegetarians had a lower systolic pressure (108.0±12.7 mmHg vs. 111.6±15.4 mmHg) and lower fasting blood glucose (4.6±0.6 mmol/L vs. 4.8±0.4 mmol/L), as well as better blood lipid profiles, including lower levels of TC and LDL at 4.1±0.8 mmol/L and 2.5±0.6 mmol/L, respectively, as well as lower LDL/HDL ratios (2.1±0.6 vs. 2.2±0.7).

3.2 Daily diet intake

Table 2 details the daily dietary intake of nutrients of the participants in each of the different dietary patterns. The 24-h dietary recall results demonstrated a significant difference between vegetarians and omnivores. The dietary structure of vegetarians was characterized by lower energy intake (1501.1±514.2 kcal/d vs. 1757.3±588.9 kcal/d), lower energy supply ratio of protein and fat intake (protein: 12.2±3.2% vs. 15.7±4.3%; fat: 25.48±8.60% vs 33.01±9.93%), and well as higher energy supply ratio of carbohydrate intake (60.49±9.66% vs. 49.94±11.85%). In addition, the consumption of dietary fiber was higher in vegetarians, especially in vegans. Regarding mineral substances, vegetarians consumed less dietary calcium, phosphorus and sodium than omnivores (all P values <0.05). Among vegetarians, vegans...
consumed more dietary energy and protein and had a higher intake of calcium and phosphorus but a lower intake of sodium than lacto-ovo vegetarians (all P values <0.05).

3.3 Renal function parameters

Figure 2 demonstrates the renal function parameters of omnivores and vegetarians. No subjects had been defined as CKD, and the proportion of mild eGFR impairment was not different between vegetarians and omnivores (13.8% vs. 11.2%) or within vegetarians. The eGFR was higher in vegetarians (109.2±16.6 mL/minute/1.73 m²) than in omnivores (106.2±16.4 mL/minute/1.73 m²). Vegetarians also had lower levels of BUN (3.6±1.0 mmol/L vs. 4.7±5.9 mmol/L), SCr (67.8±10.0 μmol/L vs. 69.5±12.1 μmol/L) and UA (254.6±62.9 μmol/L vs. 272.5±64.3 μmol/L), which are the final metabolites and the representative parameters of renal excretion and filtration. Among vegetarians, the renal function parameters showed no differences between the vegan and lacto-ovo vegetarian groups.

As shown in Table 3, we design five multiple-linear regression models to explore the association between vegetarian dietary patterns and renal function parameters. In multiple-linear regression analysis using an unadjusted model, vegetarian diet was associated with lower BUN ($\beta = -0.71$, 95% CI:(-0.88, -0.53)), lower SCr ($\beta = -1.91$, 95% CI:(-3.72, -0.10)), lower UA ($\beta = -18.41$, 95% CI:(-29.11, -7.70)) and higher eGFR ($\beta = 3.06$, 95% CI:(0.26, 5.85)). After adjusting for sex, age, BMI and skeletal muscle mass, vegetarian diet was associated with lower BUN ($\beta = -0.68$, 95% CI:(-0.85, -0.51)), lower SCr ($\beta = -2.04$, 95% CI:(-3.51, -0.57)), lower UA ($\beta = -10.17$, 95% CI:(-19.28, -1.05)) and higher eGFR ($\beta = 3.59$, 95% CI:(0.92, 6.28)). In model 3, physical activity, alcohol consumption and smoking status were also controlled in addition to the variables included in model 2. After adjusting for LDL and HDL, systolic blood pressure and fasting blood glucose in model 4, vegetarian diet was negatively associated with BUN ($\beta = -0.63$, 95% CI:(-0.88, -0.38)), SCr ($\beta = -2.04$, 95% CI:(-4.10, 0.02)), and UA ($\beta = -15.15$, 95% CI:(-27.81, -2.50)) and positively associated with eGFR ($\beta = 4.04$, 95% CI:(0.30, 7.78)). After adjusting for vegetarian duration, vegetarian diet was remained found to be significant associated with lower BUN, SCr, UA level and higher eGFR level. In multiple-linear regression analysis, no association was found between vegetarian duration and renal function parameters. Regarding different types of vegetarian diets, both lacto-ovo vegetarian diets and vegan diets were associated with lower SCr, BUN, and UA level and significantly positively associated with higher eGFR levels after adjusting for different confounders.

We designed a multiple-linear regression model to explore the association between dietary intake composition and renal function parameters. When exploring the contribution of dietary composition to renal function parameters, multiple-linear regression results showed that dietary fiber was significantly negatively associated with BUN ($\beta = -0.02$, 95% CI:(-0.03, 0.00)), SCr ($\beta = -0.12$, 95% CI:(-0.23, 0.02)), and UA ($\beta = -0.70$, 95% CI:(-1.34,-0.06)) and positively associated with eGFR ($\beta = 0.22$, 95% CI:(0.06, 0.41)). Energy intake, fat energy supply ratio, protein energy supply ratio, and protein intake/weight were positively associated with BUN level, and carbohydrate energy supply ratio was negatively associated with BUN level, while no convincing association was found between these factors and SCr, UA and eGFR. To further explore the contribution about different sourced protein to the renal function, we divided dietary protein
into plant-sourced-protein and animal-sourced-protein, and the association between different sourced protein and renal function have been discussed separately. However, we did not detect any association between plant-sourced protein vs. animal-sourced protein and renal function parameters.

4. Discussion

We found that among healthy adults, vegetarians, including lacto-ovo vegetarians and vegans, have better renal function than omnivores. Moreover, it is the higher dietary fiber intake that is mainly associated with better renal function. This is the first study indicating that healthy adult vegetarians have better renal function parameters, apart from the influence of blood pressure, fasting blood glucose and blood lipid levels, than omnivores.

Hyperlipemia, hypertension and diabetes are well recognized as factors that influence renal function and renal diseases [17-19]. Many studies have demonstrated that compared with omnivores, vegetarians have significantly lower blood pressure, cholesterol levels, and glucose levels [2,3]. We observed lower systolic pressure, lower fasting blood glucose and better blood lipid profile levels in vegetarians, which could be an important reason for the better renal function of vegetarians. However, after adjusting for LDL and HDL, systolic pressure and fasting blood-glucose level, the vegetarian diet remained significantly associated with higher eGFR, suggesting that the vegetarian diet may have a direct influence on protecting renal function.

Previous researches reported that a 60%-80% caloric restriction (20%-40% less than the ad libitum—fed group) may show obvious effects of higher eGFR [20,21]. However, we did not detect the association between less energy intake and higher eGFR. Although the vegetarians had less energy intake in our study, the degree and duration of caloric limitation may not meet the effective standard to obtain optimal benefits. We did not find convincing association between physical activity and eGFR. There is a debate as to whether physical inactivity is associated with reduced kidney function according to previous studies [22,23]. The association between physical activity and renal function remains to be further explored.

According to the results of the multiple-linear regression in our study, the higher dietary fiber consumption of vegetarians may contribute to better renal function. CKD is often accompanied by a chronic inflammatory state characterized by elevated serum CRP, IL-6 and TNF-alpha levels [24]. High fiber intake has been proven to reduce oxidative stress status by affecting bacterial fermentation of proteins in the colon [25-26]. Some small-scale studies have reported that increasing fiber intake in CKD patients may reduce serum creatinine levels and improve eGFR [27-28]. A study among 1110 community-dwelling male participants aged 70–71 years from Sweden demonstrated that high dietary fiber intake was associated with better kidney function and lower inflammation [29].

We did not find a relationship between protein intake and eGFR. Previous studies have confirmed the effectiveness of low-total-protein intake in the prevention and treatment of renal dysfunction [15,30,31]. However, in the context of a vegetarian diet, it is difficult to explore whether the lower protein intake was associated with better renal function due to the change in both the amount and source of dietary protein.
On the one hand, some studies have suggested that a low-protein vegan-vegetarian diet is a suitable option in the management of CKD patients [6,32,33]. On the other hand, because of the lower bioavailability of vegetable proteins, a vegetarian diet may lead to a decrease in glomerular filtration rate and increase the risk of protein-energy malnutrition [34,35]. What’s more, historical studies showing greater propensity of animal-sourced protein, particularly red meat to be associated with lower eGFR and/or kidney injury. [36,37] However, no convincing association was found between different sourced protein and renal function parameters in our study. One possible explanation is we failed to investigate the effect of some sources of protein such as red and processed meat, nuts and legumes, which are studied have inversely or positively related to risk of incident CKD. Our rough classification of protein sources may confuse the effect. In our study, all the participants, whether vegetarians or not, had normal protein intake that met the requirements of the dietary recommended intakes of China. Healthy adults have strong buffering and compensatory capabilities, and these capabilities may also result in inconspicuous changes in renal metabolites and function caused by acceptable differences in protein consumption.

A few studies have shown that plant phytochemicals, such as green tea polyphenols, soy isoflavones, allicin, bitter melon extract, and platonic acid, have a strong effect on oxidative stress and help protect metabolic stability and renal excretion as well as filtration [38-40]. According to our previous study among vegetarians in Shanghai, vegetarian diet was characterized by an adequate consumption of whole grains, tubers, vegetables, fruits, legumes and nuts, which are foods rich in phytochemicals and anti-oxidants [41]. Vegetarian diets may contain more phytochemicals and less saturated fat and cholesterol due to the plant-based nature of the diet, resulting in better metabolic status and milder metabolic burden as well as renal filtration burden in vegetarians [1].

We did not detect an association between vegetarian duration and renal function. Previous studies have rarely reported the role of vegetarian diet duration. According to a 24-year follow-up of 14,686 middle-aged adults, a higher adherence to plant-based and vegetarian diets was associated with a slower annual eGFR decline [42]. This result probably indicates that maintaining a vegetarian diet can have lasting beneficial effects on renal health; thus, we suspect that a longer duration of vegetarian diet may be beneficial for the maintenance and stability of kidney function. However, a study in Taiwan found no association between vegetarian duration and renal function, which was consistent with our results [7]. Since some previous studies have confirmed that dietary fiber can improve renal function in the short term [43]. One possible explanation is the kidney benefits of gut microbiome changes associated with dietary fiber occur in a short time frame, as opposed to requiring many years of the sustained diet to manifest with benefits on kidney function. However, the gut microbiome is constantly changing, which requires long-term maintenance of vegetarian diet to maintain the stability of gut microbiome. There is a lack of research to study the beneficial effects of dietary fiber in the CKD population in the long term. To the limited previous data, more evidence should be collected to prove the influence of vegetarian diet duration on renal function outcomes.
Some limitations of this study should be mentioned. First, the small vegetarian population in China introduced practical limitations preventing random sampling, and the relatively small sample size of vegans will require additional studies in the future. Second, due to the cross-sectional design, we could not determine the causal relationship between vegetarian diets and renal function. Third, dietary patterns may change over time, and this analysis relied on a single measurement of diet at baseline; thus, there may be dietary variations that we did not analyze. In addition, the potential for uncontrolled confounding factors, such as genetic factors and unobserved lifestyle choices, remains. Concerns should be raised that, participants in our study were young and healthy without kidney diseases, the difference in kidney injury between vegetarians and non-vegetarians may not be detected. The association between dietary pattern and kidney injury remains to be further researched, and our finding should be explained carefully in the clinical treatment of chronic kidney disease. These could be shortcomings of our study, we will do additional studies in the future.

5. Conclusions

In conclusion, a vegetarian diet has potential benefits for renal function that are not completely accounted for by the influence of glycolipid metabolism and blood pressure status. A higher intake of dietary fiber may lead to better renal function. This information may be important to advise the public about the prevention of kidney disease.

List Of Abbreviations

BUN, blood urea nitrogen;
SCr, serum creatinine;
UA, blood uric acid;
eGFR, estimated glomerular filtration rate;
CKD, chronic kidney disease;
BMI, body mass index;
TC, total cholesterol;
TGs, total triglycerides;
LDL, low-density lipoprotein cholesterol;
HDL, high-density lipoprotein cholesterol;
Ref, reference;
Cl, confidence interval;
BMI, body mass index

Declarations

Acknowledgements: We thank the dietitians from nutrition department of Xinhua Hospital and nutrition department of Shanghai Jiao Tong University, School of Medicine, for assistance with the field investigation and measurements.

Author’s contribution: SXH designed the research; CJF and TQY assisted the research design and field survey; WB, CXY and XKJ conducted the research; CXY performed the statistical analysis; CJF provided advice and verification for statistical analysis; XKJ and SXH wrote the manuscript; SXH had primary responsibility for final content. All authors contributed to the discussion of analyses, critically reviewed the manuscript, and approved the final manuscript. All authors declare no relevant conflicts of interest.

Funding: This work is supported by the Danone nutrition research and education fund (DIC2016-07) and Shanghai Key Laboratory of Pediatric Gastroenterology and Nutrition (17DZ2272000). The funders had no role in the design of the study, the collection, analysis and interpretation of the data, or preparation of the manuscript.

Availability of data and materials: All data generated or analyzed during this study are included in this article and its supplementary information files.

Ethics approval and consent to participate: All participants provided written informed consent. The study was approved by the Ethics Committee of Shanghai Jiao Tong University School of Medicine.

Consent for publication: Not applicable.

Competing interests: All authors declare no relevant competing interests.

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Tables

Table 1 Basic Characteristics of vegetarians and omnivores
| Variables                  | Vegans | Lacto-ovo vegetarians | Total vegetarians | Omnivores |
|---------------------------|--------|-----------------------|-------------------|-----------|
| (Females, %)              | 74.3   | 85.4                  | 82.2              | 82.2      |
| (years)                   | 37.2±9.2 | 34.8±8.3            | 35.4±8.6           | 34.8±9.4  |
| Vegetarian age (years)    | 5.4±4.5 | 5.4±5.2              | 5.4±5.0           |           |
| n=70                      | n=199  | n=269                |                   | n=269     |
| (years)                   | 3000   | 17.1                 | 18.7              | 26.1      |
| (you~8000)                | 67.2   | 68.2                 | 67.9              | 65.3      |
| 8000                      | 15.7   | 12.6                 | 13.4              | 8.6       |
| (years)                   | 5.4±4.5 | 5.4±5.2              | 5.4±5.0           |           |
| (Females, %)              | 21.4   | 13.1                 | 15.3              | 17.7      |
| (years)                   | 18.6   | 15.2                 | 16.0              | 17.7      |
| Education (%)             | 60     | 71.7                 | 68.7              | 64.6      |
| (Females, %)              | 98.6   | 93.5                 | 95.1              | 83.4      |
| (years)                   | 0      | 5.5                  | 4.1               | 12.4      |
| Monthly or rarely         | 1.4    | 1                    | 0.8               | 4.2       |
| Weekly or daily           | 14.3   | 8                    | 9.7               | 8.2       |
| Drinking (%)              | 20.5±2.4 | 21.1±2.7            | 20.9±2.6          | 22.4±3.5  |
| (kg/m²)                   | 2.0±2.9 | 1.8±2.3              | 1.9±2.5           | 1.4±2.0   |
| Physical activity (hrs/week) | 2.2±4.8 | 22.2±3.8           | 22.3±4.12         | 23.3±4.8  |
| Weight (kg)               | 22.7±4.8 | 22.2±3.8            | 22.3±4.12         | 23.3±4.8  |
| Tensiol pressure (mmHg)   | 108.6±12.3 | 107.8±12.8         | 108.0±12.72       | 111.6±15.4|
| Systolic pressure (mmHg)  | 69.9±9.4 | 69.8±9.0             | 69.9±9.1          | 70.4±11.0 |
| Fasting blood glucose (mmol/L) | 4.6±0.4 | 4.7±0.7             | 4.6±0.62          | 4.8±0.4   |
| (mmol/L)                  | 4.0±0.8 | 4.1±0.8             | 4.1±0.82          | 4.6±0.8   |
| (mmol/L)                  | 2.5±0.6 | 2.6±0.6             | 2.5±0.62          | 2.9±0.7   |
| (mmol/L)                  | 1.3±0.2 | 1.3±0.3             | 1.3±0.3           | 1.4±0.3   |
| /HDL                      | 2.2±0.6 | 2.1±0.6             | 2.1±0.62          | 2.2±0.7   |

1. Total vegetarians: lacto-ovo vegetarians and vegans

2. Statistical significance when comparing vegetarians and omnivores, P<0.05

3. Statistical significance when comparing vegans and lacto-ovo vegetarians, P<0.05
Table 2 Daily dietary intakes of vegetarians and omnivores

| Variables                        | Vegans          | Lacto-ovo vegetarians | Total vegetarians | Omnivores |
|----------------------------------|-----------------|-----------------------|-------------------|-----------|
|                                  | n=70            | n=199                 | n=269             | n=269     |
| Energy (kcal/d)                  | 1507.5±555.6    | 1498.8±500.3²         | 1501.1±514.2³     | 1757.3±588.9 |
| Carbohydrates                    | 233.2±103.1     | 225.2±82.7            | 227.3±88.3        | 217.0±78.8 |
| Carbohydrate energy supply (%)   | 61.6±12.0       | 60.1±8.7              | 60.5±9.7³         | 49.9±11.9 |
| Fiber (g/d)                      | 38.7±8.7        | 43.7±21.4²            | 42.4±21.31³       | 65.7±33.0 |
| Energy supply (%)                | 23.3±9.5        | 26.2±8.2²             | 25.48±8.60³       | 33.0±9.9 |
| Protein (g/d)                    | 48.7±22.1       | 45.1±19.1²            | 46.0±19.9³        | 70.5±33.9 |
| Protein energy ratio (%)         | 12.9±3.8        | 12.0±2.9²             | 12.2±3.2³         | 15.7±4.3 |
| Protein intake (g/kg)            | 0.9±0.4         | 0.8±0.4²              | 0.8±0.4³          | 1.2±0.5  |
| Fiber (g/d)                      | 17.29±9.11      | 14.63±9.3²            | 15.3±9.3³         | 11.83±6.90 |
| Phosphorus (mg/d)                | 496.2±316.3     | 441.6±250.4²          | 455.8±269.5³      | 539.5±340.1 |
| Potassium (mg/d)                 | 841.5±367.0     | 768.4±331.2²          | 787.4±341.7³      | 989.0±378.6 |
| Magnesium (mg/d)                 | 2118.1±996.1    | 1741.3±762.3          | 1839.4±844.0      | 1943.3±826.5 |
| Zinc (mg/d)                      | 2389.1±1166.2   | 2780.0±1263.4²        | 2678.3±1248.6³    | 3767.6±1584.7 |

¹total vegetarians: lacto-ovo vegetarians and vegans

²Statistical significance when comparing vegans and lacto-ovo vegetarians, P<0.05

³Statistical significance when comparing vegetarians and omnivores, P<0.05

Table 3 Multiple-linear regression for the association between vegetarian dietary patterns and renal function parameters

| Parameters                        | Vegans          | Lacto-ovo vegetarians | Total vegetarians | Omnivores |
|-----------------------------------|-----------------|-----------------------|-------------------|-----------|
|                                  | n=70            | n=199                 | n=269             | n=269     |
| Energy (kcal/d)                   | 1507.5±555.6    | 1498.8±500.3²         | 1501.1±514.2³     | 1757.3±588.9 |
| Carbohydrates                     | 233.2±103.1     | 225.2±82.7            | 227.3±88.3        | 217.0±78.8 |
| Carbohydrate energy supply (%)    | 61.6±12.0       | 60.1±8.7              | 60.5±9.7³         | 49.9±11.9 |
| Protein (g/d)                     | 48.7±22.1       | 45.1±19.1²            | 46.0±19.9³        | 70.5±33.9 |
| Protein energy ratio (%)          | 12.9±3.8        | 12.0±2.9²             | 12.2±3.2³         | 15.7±4.3 |
| Protein intake (g/kg)             | 0.9±0.4         | 0.8±0.4²              | 0.8±0.4³          | 1.2±0.5  |
| Fiber (g/d)                       | 17.29±9.11      | 14.63±9.3²            | 15.3±9.3³         | 11.83±6.90 |
| Phosphorus (mg/d)                 | 496.2±316.3     | 441.6±250.4²          | 455.8±269.5³      | 539.5±340.1 |
| Potassium (mg/d)                  | 841.5±367.0     | 768.4±331.2²          | 787.4±341.7³      | 989.0±378.6 |
| Magnesium (mg/d)                  | 2118.1±996.1    | 1741.3±762.3          | 1839.4±844.0      | 1943.3±826.5 |
| Zinc (mg/d)                       | 2389.1±1166.2   | 2780.0±1263.4²        | 2678.3±1248.6³    | 3767.6±1584.7 |

¹total vegetarians: lacto-ovo vegetarians and vegans

²Statistical significance when comparing vegans and lacto-ovo vegetarians, P<0.05

³Statistical significance when comparing vegetarians and omnivores, P<0.05
|       | Omnivores | Total vegetarians\(^2\) | Lacto-ovo vegetarians | Vegans | \(\beta\) 95% CIs | \(\beta\) 95% CIs | \(\beta\) 95% CIs |
|-------|-----------|--------------------------|-----------------------|--------|-------------------|-----------------|----------------|
| BUN   | Model 1   | 0 (Ref)                  | -0.71 (-0.88, -0.53)  | -0.76 (-0.95, -0.57) | -0.56 (-0.84, -0.27) |
|       | Model 2   |                          | -0.68 (-0.85, -0.51)  | -0.71 (-0.90, -0.52) | -0.58 (-0.87, -0.30) |
|       | Model 3   |                          | -0.72 (-0.96, -0.49)  | -0.71 (-0.96, -0.46) | -0.74 (-1.13, -0.36) |
|       | Model 4   |                          | -0.63 (-0.88, -0.38)  | -0.59 (-0.86, -0.32) | -0.64 (-1.05, -0.22) |
|       | Model 5   |                          | -0.66 (-0.95, -0.38)  | -0.66 (-0.98, -0.35) | -0.52 (-1.04, 0.00) |
| Cr    | Model 1   | 0 (Ref)                  | -1.91 (-3.72, -0.10)  | -2.08 (-4.03, -0.12) | -1.43 (-4.43, 1.57) |
|       | Model 2   |                          | -2.04 (-3.51, -0.57)  | -1.61 (-3.12, -0.10) | -3.70 (-6.08, -1.32) |
|       | Model 3   |                          | -2.95 (-4.85, -1.05)  | -2.46 (-4.38, -0.55) | -5.41 (-8.70, -2.11) |
|       | Model 4   |                          | -2.04 (-4.10, 0.02)   | -1.58 (-3.65, 0.48)  | -3.17 (-6.24, -0.09) |
|       | Model 5   |                          | -2.47 (-4.83, -0.11)  | -2.41 (-4.81, -0.01) | -3.67 (-8.17, -0.86) |
| UA    | Model 1   | 0 (Ref)                  | -18.41 (-29.11, -7.70) | -21.72 (-33.19, -10.25) | -9.00 (-26.01, 8.03) |
|       | Model 2   |                          | -10.17 (-19.28, -1.05) | -11.87 (-21.54, -2.19) | -5.69 (-20.30, 8.95) |
|       | Model 3   |                          | -17.21 (-28.76, -5.65) | -16.47 (-28.77, -4.17) | -19.30 (-37.77, -0.82) |
|       | Model 4   |                          | -15.15 (-27.81, -2.50) | -16.29 (-29.61, -2.97) | -14.88 (-35.18, 5.42) |
|       | Model 5   |                          | -18.00 (-32.52, -3.48) | -18.73 (-34.25, -3.21) | -19.96 (-45.61, 5.68) |
| eGFR  | Model 1   | 0 (Ref)                  | 3.06 (0.26, 5.85)     | 2.65 (-0.26, 5.56)  | 4.20 (-0.37, 8.78)  |
|       | Model 2   |                          | 3.59 (0.92, 6.28)     | 2.66 (-0.08, 5.39)  | 7.42 (3.02, 11.81)  |
|       | Model 3   |                          | 5.94 (2.48, 9.41)     | 4.51 (1.15, 7.87)   | 12.29 (6.25, 18.33) |
|       | Model 4   |                          | 4.04 (0.30, 7.78)     | 2.69 (-0.92, 6.30)  | 8.31 (2.38, 13.85)  |
|       | Model 5   |                          | 4.55 (0.25, 8.84)     | 4.17 (-0.03, 8.37)  | 7.70 (0.53, 15.94)  |

1 Model 1: Unadjusted regression; Model 2: Adjusted for sex, age, BMI and skeletal muscle mass on the basis of Model 1; Model 3: Adjusted for physical activity, alcohol consumption and smoking status on the basis of Model 2; Model 4: Adjusted for LDL, HDL, systolic pressure and fasting blood glucose in addition to the adjustments in Model 3; Model 5: Adjusted for vegetarian duration on the basis of Model 4.

2 total vegetarians: lacto-ovo vegetarians and vegans.

Figures
Figure 1

Flowchart of study participants
Figure 2

Renal function parameters of omnivores and vegetarians 1 A: eGFR of omnivores and vegetarians; B: BUN of omnivores and vegetarians; C: SCr of omnivores and vegetarians; D: UA of omnivores and vegetarians; values are means±SD. * Statistical significance when comparing vegetarians and omnivores, P<0.05