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Lu, Ting Yu; Zhang, Wei Sen; Zhu, Tong; Jiang, Chao Qiang; Zhu, Feng; Jin, Ya Li; Lam, Tai Hing; Cheng, Kar Keung; Xu, Lin

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Associations of meat, fish and seafood consumption with kidney function in middle-aged to older Chinese: a cross-sectional study based on the Guangzhou Biobank Cohort Study

Ting Yu Lu,[1] Wei Sen Zhang,[2] Tong Zhu,[2] Chao Qiang Jiang,[2] Feng Zhu,[2] Ya Li Jin,[2] Tai Hing Lam,[3] Kar Keung Cheng,[4] Lin Xu [1,3,4]

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TYL and WSZ are joint first authors.

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For numbered affiliations see end of article.

Correspondence to
Professor Lin Xu;
xulin27@mail.sysu.edu.cn

ABSTRACT

Objective To examine the associations of red meat, poultry, fish and seafood and processed meat consumption with kidney function in middle-aged to older Chinese.

Design A cross-sectional study based on the Guangzhou Biobank Cohort Study.

Setting Community-based sample.

Participants 9768 participants (2743 men and 7025 women) aged 50+ years.

Primary and secondary outcome measures Primary outcome was estimated glomerular filtration rate (eGFR) derived from the Chinese-specific equation based on the Modification of Diet in Renal Disease (MDRD) equation (c-aGFR). eGFR derived from the original isotope-dilution mass spectrometry-traceable MDRD study equation, and prevalent chronic kidney disease (CKD) defined as c-aGFR<60 mL/min/1.73 m^2 were considered the secondary outcomes.

Results After adjusting for sex, age, body mass index, education, occupation, family income, smoking status, alcohol use, physical activity, daily energy intake, self-rated health and chronic disease history (diabetes, hypertension and dyslipidaemia), compared with processed meat consumption of 0–1 portion/week, those who consumed ≥3 portions/week had lower c-aGFR (β=−2.74 mL/min/1.73 m^2, 95% CI=−4.28 to −1.20) and higher risk of prevalent CKD (OR=1.40, 95% CI=1.09 to 1.80, p<0.0125). Regarding fish and seafood consumption, the associations varied by diabetes (p for interaction=0.02). Fish and seafood consumption of ≥11 portions/week, versus 0–3 portions/week, was non-significantly associated with higher c-aGFR (β=3.62 mL/min/1.73 m^2, 95% CI=−0.06 to 7.30) in participants with diabetes, but was associated with lower c-aGFR in normoglycaemic participants (β=−1.51 mL/min/1.73 m^2, 95% CI=−2.81 to −0.20). No significant associations of red meat or poultry consumption with c-aGFR nor prevalent CKD were found. Similar results were found for meat, fish and seafood consumption with eGFR.

Conclusions Higher processed meat, fish and seafood consumption was associated with lower kidney function in normoglycaemic participants. However, the associations in participants with diabetes warrant further investigation.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This is a large population-based cross-sectional study examining the associations of meat, fish and seafood consumption with kidney function, using both Chinese-specific and original estimated glomerular filtration rate and comprehensive measurements of potential confounders.
⇒ Measurement error due to variability in food intake was almost inevitable in nutritional epidemiological studies and it tends to lead to less precise estimates.
⇒ Different cooking methods may influence the associations of meat, fish and seafood consumption with eGFR, but the information was not available in our study.
⇒ Due to the relatively small sample size, subgroup analysis may not be adequately powered to assess the associations in participants with diabetes.
⇒ The causal associations of meat, fish and seafood consumption with kidney function could not be confirmed in this cross-sectional study.

INTRODUCTION

Chronic kidney disease (CKD) has become one of the major public health problems in the world due to its increasing incidence and substantial burden.[1 2] Previous studies identified major risk factors of CKD including ageing,[3] hyperglycaemia,[2] obesity[3] and high protein (especially animal protein) intake.[4] Protein restriction is recommended for patients with CKD who are metabolically stable and not on dialysis.[5] However, inconclusive evidence exists regarding the association of animal protein consumption with kidney function in the general population.[6] As a major animal protein source with universal exposure, the potential roles of meat, fish and seafood consumption in kidney function warrants exploration.

Previous studies on the associations of meat, fish and seafood consumption with kidney function showed inconclusive results. A non-systematic literature review showed that different kinds of meat consumption had various associations with kidney function, with two studies reporting higher red meat and processed meat consumption being associated with higher CKD risk, while no significant association of poultry or fish consumption with kidney function was found in two studies.[6] This review included only one study from Asian.[7] Besides, we found only one case–control study on 752 older Chinese men in Taiwan assessing the associations of meat, fish and seafood consumption with odds of prevalent CKD.[8] Given dietary patterns between the western and Asian populations differ substantially and the lack of consensus regarding the impacts of meat, fish and seafood consumption on kidney function, studies describing the associations in this understudied population are needed. Moreover, few studies described the associations of meat, fish and seafood consumption with estimated glomerular filtration rate (eGFR),[9] a well-documented surrogate marker of kidney function. As the development of CKD is a continuum, older people may have a reduced eGFR many years before they develop symptoms or complications of CKD.[1] Primary prevention strategies targeting early prevention of subclinical kidney function decline should be of significant public health value.

Therefore, we conducted a population-based cross-sectional study using data from the Guangzhou Biobank Cohort Study (GBCS) to examine the associations of red meat, poultry, fish and seafood and processed meat consumption with kidney function (eGFR) in middle-aged to older Chinese.

METHODS

Study sample

All GBCS participants were recruited from Guangzhou, China. Details of the GBCS have been reported previously.[10] Briefly, the GBCS is a three-way collaboration among Guangzhou Twelfth People's Hospital and the Universities of Hong Kong, China and Birmingham, UK. Participants of the GBCS were recruited from 'The Guangzhou Health and Happiness Association for the Respectable Elders (GHHARE)', a community social and welfare organisation. Membership is open to Guangzhou permanent residents aged 50 years or above for a nominal fee of ¥4 (≈50 US cents) per month. The baseline examination included a face-to-face computer-assisted interview by trained nurses to collect information on demographic characteristics, lifestyles, family and personal medical history. In this study, we used the first phase of baseline data from GBCS from 2003 to 2004.

Patient and public involvement

No patients or public were involved in setting the research question or the outcome measures, nor were they involved in the design and implementation of the study.

Exposures

The exposure variables were four kinds of meat, fish and seafood consumption. Information on meat, fish and seafood consumption at baseline was obtained from a validated Food Frequency Questionnaire (FFQ).[11] This FFQ contained 303 food items, including 26 types of red meat, 16 types of poultry, 37 types of fish and seafood and 10 types of processed meat. Participants were asked the amounts and frequencies of each type of meat consumed in the past 7 days, with a usual portion size specified. Given the relatively averaged distribution of sample size, with one portion equal to 50 g, red meat, and fish and seafood consumption were categorised into 0–3, 4–6, 7–10 and ≥11 portions/week. Poultry consumption was categorised into 0–1, 2–3, 4–5 and ≥6 portions/week (1 portion=50 g). Processed meat consumption was categorised into 0–1, 2 and ≥3 portions/week (1 portion=25 g).

Outcomes

Glomerular filtration rate (GFR) was considered the best overall index of kidney function.[12] However, since GFR was difficult to measure in clinical practice, the eGFR based on serum creatinine concentration and demographic and clinical variables was widely used as a diagnostic biomarker for kidney function.[13 14] Therefore, we used creatinine-based eGFR assessed at baseline as the outcome variable to measure kidney function. Since the original isotope-dilution mass spectrometry (IDMS)-traceable Modification of Diet in Renal Disease (MDRD) study equation (shown as equation (1) as below) was developed based on North-American Caucasian and Afro-Caribbean patients,[13] it may not be directly applicable in Chinese population. Thus, based on the MDRD equation, Ma *et al* constructed a calibrated equation by modifying the coefficient of each variable specifically for Chinese population in 2006 (shown as equation (2) as below) to calculate a Chinese-specific eGFR (ie, c-aGFR), which was used as the primary outcome in our study.[15] For comparison, the eGFR derived from the IDMS-traceable MDRD equation (shown as eGFR) was used as the secondary outcome. Moreover, prevalent CKD, defined as c-aGFR<60 mL/min/1.73 m^2, was considered another outcome in our analysis.[12]

$$eGFR\ (mL/min/1.73\ m^2) = 175 * S_{cr}^{-1.154} * age^{-0.203} * 1.212\ [if\ African\ American] * 0.742\ [if\ female] \quad (1)$$

$$c-aGFR\ (mL/min/1.73\ m^2) = 175 * S_{cr}^{-1.234} * age^{-0.179} * 0.79\ [if\ female] \quad (2)$$

S_{cr} is serum creatinine concentration (mg/dL).

Potential confounders

As both of dietary intake and kidney function could be influenced by sex,[16] age,[3] body mass index (BMI),[3] socioeconomic position (education, occupation and family income),[17 18] personal lifestyles (smoking status, alcohol use and physical activity),[19–21] daily energy intake,[22] self-rated health and chronic disease history (hypertension, dyslipidaemia and diabetes),[3 23] these factors were considered as potential confounders and included in our analysis.

Information on sex, age, socioeconomic position, personal lifestyles and self-rated health was collected from a face-to-face interview. BMI was calculated as weight in kilogram divided by standing height in metre squared (kg/m^2). Physical activity was assessed using Chinese versions of the International Physical Activity Questionnaire and categorised into inactive, moderate and active.[24] Daily energy intake was calculated by multiplying the intake amounts per day and the amounts of energy of each type of food based on the sixth edition of the Chinese Food Composition Tables.[25] Diabetes was defined by fasting plasma glucose of 7.0 mmol/L or above, self-reported physician-diagnosis or use of antidiabetic medications. Information on hypertension and dyslipidaemia was based on self-reports.

Statistical analyses

As c-aGFR and eGFR were non-normally distributed, Wilcoxon rank-sum test and Kruskal-Wallis test were used to assess the associations of potential confounders with c-aGFR and eGFR as appropriate. Meat, fish and seafood consumption was analysed in categories, with the lowest consumption group as the reference group, and continuously, with per portion increment. Linear regression was performed to estimate the associations of meat, fish and seafood consumption with c-aGFR and eGFR and logistic regression was used for prevalent CKD, yielding regression coefficients (β) or OR and corresponding 95% CIs as appropriate. We used three models to investigate the robustness of the associations, including a crude model, model 1 (adjusted for sex, age, education, family income, occupation, BMI, physical activity, smoking status, alcohol use, self-rated health and chronic disease history) and model 2 (additionally adjusted for daily energy intake).

Since diabetes history may influence both kidney function and dietary habits,[1] we examined the interaction with

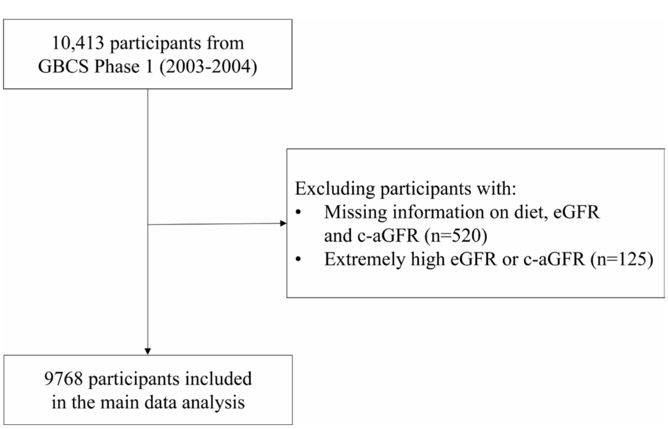

Figure 1 Flow diagram. c-aGFR, estimated glomerular filtration rate calculated by Chinese-specific Modification of Diet in Renal Disease equation; eGFR, estimated glomerular filtration rate; GBCS, Guangzhou Biobank Cohort Study.

Table 1 Associations of demographic characteristics, lifestyle factors and disease history with c-aGFR on 9768 participants of the Guangzhou Biobank Cohort Study (2003–2004)

		c-aGFR, mL/min/1.73 m^2	
	N (%)	Median (IQR)	P value
All	9768 (100.0)	85.5 (27.2)	–
Sex			<0.01
Men	2743 (28.1)	77.8 (23.9)	
Women	7025 (71.9)	88.7 (26.7)	
Age group, years			<0.01
50–59	2582 (26.4)	92.5 (26.1)	
60–69	5213 (53.4)	85.0 (26.0)	
≥70	1973 (20.2)	76.7 (25.3)	
BMI, kg/m^2			0.01
<18.5	489 (5.0)	86.8 (27.4)	
18.5–24.9	5955 (61.0)	85.9 (26.7)	
25.0–27.4	2104 (21.5)	84.6 (27.6)	
≥27.5	1220 (12.5)	84.9 (29.0)	
Family income, CNY/year			<0.01
<10 000	672 (6.8)	85.0 (26.6)	
10 000–29 999	3319 (34.0)	84.2 (26.9)	
30 000–49 999	1467 (15.0)	86.6 (28.4)	
≥50 000	1021 (10.5)	85.9 (27.2)	
Do not know	3289 (33.7)	86.3 (27.2)	
Education			<0.01
Primary or below	4896 (50.2)	86.2 (27.7)	
Secondary	3970 (40.6)	85.6 (26.9)	
College or above	902 (9.2)	81.7 (25.0)	
Occupation			<0.01
Manual	6235 (63.8)	86.6 (27.6)	
Non-manual	3053 (31.3)	83.1 (26.0)	
Others	480 (4.9)	89.8 (29.2)	
Smoking status			<0.01
Never	7856 (80.4)	86.7 (27.3)	
Former	1001 (10.3)	78.0 (24.7)	
Current	911 (9.3)	82.3 (24.9)	
Alcohol use			<0.01
Never	8169 (83.6)	86.5 (27.2)	
Former	212 (2.2)	79.9 (23.9)	
Current	1387 (14.2)	81.0 (25.7)	
Physical activity			<0.01
Inactive	148 (1.5)	76.9 (26.4)	
Moderate	3496 (35.8)	83.7 (27.4)	
Active	6124 (62.7)	86.6 (26.8)	
Self-rated health			<0.01
Good	7557 (77.4)	85.9 (26.5)	
Poor	2211 (22.6)	84.0 (30.2)	

Continued

Table 1 Continued

	N (%)	c-aGFR, mL/min/1.73 m² Median (IQR)	P value
Self-reported hypertension			<0.01
No	6639 (68.0)	87.1 (25.9)	
Yes	3129 (32.0)	81.6 (28.8)	
Self-reported dyslipidaemia			0.01
No	8886 (91.0)	85.4 (26.9)	
Yes	882 (9.0)	86.5 (29.1)	
Diabetes			<0.01
No	8316 (85.1)	85.1 (26.3)	
Yes	1452 (14.9)	88.7 (32.5)	
Daily energy intake, kcal/day			0.08
Tertile 1	3056 (31.3)	86.2 (27.2)	
Tertile 2	3488 (35.7)	85.7 (26.6)	
Tertile 3	3224 (33.0)	84.6 (27.6)	
Red meat consumption, 1 portion=50 g			0.35
0–3 portions/week	2014 (20.6)	85.4 (27.3)	
4–6 portions/week	3405 (34.9)	85.8 (27.1)	
7–10 portions/week	2726 (27.9)	85.6 (27.7)	
≥11 portions/week	1623 (16.6)	84.8 (25.8)	
Poultry consumption, 1 portion=50 g			0.21
0–1 portion/week	2397 (24.6)	85.1 (25.8)	
2–3 portions/week	2103 (21.5)	85.2 (27.7)	
4–5 portions/week	2493 (25.5)	85.9 (27.1)	
≥6 portions/week	2775 (28.4)	85.8 (28.0)	
Fish and seafood consumption, 1 portion=50 g			0.09
0–3 portions/week	2076 (21.3)	85.8 (26.9)	
4–6 portions/week	2600 (26.6)	85.5 (26.4)	
7–10 portions/week	2295 (23.5)	86.4 (28.0)	
≥11 portions/week	2797 (28.6)	84.5 (27.4)	
Processed meat consumption, 1 portion=25 g			<0.01
0–1 portion/week	7989 (81.8)	85.9 (27.3)	
2 portions/week	959 (9.8)	84.0 (26.3)	
≥3 portions/week	820 (8.4)	83.1 (25.5)	

Continued

Table 1 Continued

	N (%)	c-aGFR, mL/min/1.73 m² Median (IQR)	P value

BMI, body mass index; c-aGFR, estimated glomerular filtration rate calculated by Chinese-specific Modification of Diet in Renal Disease equation; CNY, Chinese yuan; IQR, inter-quartile range.

diabetes history on c-aGFR and eGFR by comparing fitness of the models before and after adding the interaction terms using log-likelihood ratio test and also conducted stratification analysis by diabetes. Furthermore, sensitivity analysis was performed by excluding those with evidence of kidney function impairment (ie, c-aGFR or eGFR<60 mL/min/1.73 m^2) to assess the robustness of the results. Stata/MP V.14.0 (StataCorp, College Station, Texas, USA) was used for data analyses. All tests were two-sided, and p<0.05 was considered statistically significant. We examined the associations of meat, fish and seafood consumption with c-aGFR and eGFR with Bonferroni-adjusted p value of 0.0125.

RESULTS

Basic characteristics

Of the 10 413 participants recruited from 2003 to 2004, 520 participants with incomplete information on diet, c-aGFR and eGFR, and 125 participants with c-aGFR or eGFR>200 mL/min/1.73 m^2 were excluded, giving 9768 participants in the present study (figure 1). Of the 9768 participants included, the average age was 64.6 (SD=6.0) years, 71.9% were women and the prevalence of diabetes was 14.9%. The median c-aGFR and eGFR was 85.5 (IQR=27.2) and 73.0 (21.0) mL/min/1.73 m^2, respectively (table 1, online supplemental table 1). There were 2014 (20.6%), 3405 (34.9%), 2726 (27.9%) and 1623 (16.6%) participants consuming red meat of 0–3, 4–6, 7–10 and ≥11 portions/week, and 2397 (24.6%), 2103 (21.5%), 2493 (25.5%) and 2775 (28.4%) participants consuming poultry of 0–1, 2–3, 4–5 and ≥6 portions/week, respectively. The proportion of fish and seafood consumption of 0–3, 4–6, 7–10 and ≥11 portions/week was 21.3%, 26.6%, 23.5% and 28.6%, respectively. Regarding processed meat consumption, the proportion of 0–1, 2 and ≥3 portions/week was 81.8%, 9.8% and 8.4%, respectively (table 1). Sample characteristics by groups of meat, fish and seafood consumption were shown in online supplemental tables 2-5.

Table 1 shows that participants who were men, aged 70+ and with higher BMI had lower c-aGFR (all p<0.05). Those who had lower family income, higher education level, non-manual occupation and were former smokers, alcohol users and physically inactive also had lower c-aGFR (all p<0.01). Participants with poor self-rated health and self-reported hypertension, as well as those without self-reported dyslipidaemia and diabetes had lower c-aGFR (all p<0.05). No significant association was found for daily energy intake with c-aGFR. Similar associations were found for eGFR (online supplemental table 1).

Meat, fish and seafood consumption and kidney function

After adjusting for sex, age, BMI, education, occupation, family income, smoking status, alcohol use, physical activity, daily energy intake, self-rated health and chronic disease history (diabetes, hypertension and dyslipidaemia), compared with processed meat consumption of 0–1 portion/week, those who consumed ≥3 portions/week had significantly lower c-aGFR (β=−2.74 mL/min/1.73 m^2, 95% CI=−4.28 to −1.20, p<0.0125) and higher risk of prevalent CKD (OR=1.40, 95% CI=1.09 to 1.80, p<0.0125). No associations of other kinds of meat, fish and seafood consumption with c-aGFR nor prevalent CKD were found (table 2, the full table 2 is shown as online supplemental table 6).

Subgroup analysis by diabetes

When stratified by diabetes, the significantly negative association between processed meat consumption and c-aGFR remained in participants without diabetes, but attenuated and became non-significant in those with diabetes (table 3). Compared with processed meat consumption of 0–1 portion/week, those who consumed ≥3 portions/week had lower c-aGFR (β=−2.65 mL/min/1.73 m^2, 95% CI=−4.26 to −1.03, p<0.0125). A significant interaction was found between diabetes history and consumption of fish and seafood on c-aGFR (p=0.02). In participants with diabetes, those with fish and seafood consumption of ≥11 portions/week, versus 0–3 portions/week, had non-significantly higher c-aGFR (β=3.62 mL/min/1.73 m^2, 95% CI=−0.06 to 7.30). However, in participants without diabetes, the adjusted β (95% CI) in those with fish and seafood consumption of ≥11 portions/week was −1.51 (−2.81 to −0.20) mL/min/1.73 m^2, although this result was not significant after Bonferroni adjustment (table 3).

Sensitivity analysis

A sensitivity analysis of 7994 participants with c-aGFR and eGFR≥60 mL/min/1.73 m^2 showed consistent results. Compared with those with processed meat consumption of 0–1 portion/week, the adjusted β (95% CI) in those with processed meat consumption of ≥3 portions/week was −1.91 (−3.46 to −0.37) mL/min/1.73 m^2 (online supplemental table 7). In addition, similar results were found for meat, fish and seafood consumption with eGFR (online supplemental tables 8,9).

DISCUSSION

Our findings showed that processed meat consumption was associated with lower eGFR in all participants and those without diabetes. Greater fish and seafood consumption (≥11 portions/week) was associated with higher eGFR in participants with diabetes, whereas lower eGFR in those without diabetes. Sensitivity analysis on participants with normal kidney function (c-aGFR and eGFR≥60 mL/min/1.73 m^2) showed similar results using the overall sample.

We found no association between red meat consumption and eGFR, which was inconsistent with the results of previous prospective studies showing the adverse role of red meat consumption in CKD.[7,26] The Atherosclerosis Risk in Communities Study on 11 952 participants showed that compared with the lowest quintile of red meat consumption, those in the highest consumption quintile had 19% higher risk of CKD.[26] Another study on 4881 Iranian also reported a higher risk of incident CKD in those with higher red meat consumption ($OR_{\text{quartile 4 vs quartile 1}}$ 1.73, 95% CI 1.33 to 2.24).[7] No cross-sectional study between red meat consumption and eGFR has been reported before. The discrepancies between ours and the above prospective studies may be due to different eGFR levels at baseline, that is, higher protein intake was associated with greater kidney function decline in those with impaired kidney function, but was not evident in those with normal kidney function.[27] As most participants of our study had normal kidney function, the potentially unhealthy effect of red meat intake on kidney function might not be a major concern. Another explanation may lie in different kinds of red meat consumed by Chinese from western populations.[28,29] No association was found for poultry consumption with eGFR in our analysis, which was consistent with a previous study.[26] As limited study on the association of poultry consumption and kidney function was found, further studies on specific types of red meats and poultry are needed to confirm.

The role of fish and seafood consumption in kidney function has been inconclusive, with some studies showing the prophylactic benefits of fish and seafood consumption on kidney function,[26,30,31] while others showing no association.[9,32] The discrepancy may be partly explained by the different kinds of fish and seafood included. A case–control study on 752 participants in Taiwan showed that shellfish consumption was associated with higher CKD risk, while no association was found for fish or crustacean consumption.[8] Higher shellfish consumption was associated with higher serum uric acid levels, which might subsequently lead to poorer kidney function.[33,34] To our knowledge, no studies reported the association of fish and seafood consumption with eGFR by diabetes status. One study showed that higher fish consumption was associated with a lower risk of macroalbuminuria in patients with diabetes, but not in those without diabetes.[35] One possible mechanism for the protective effects in patients with diabetes is that some nutrients of fish (such as omega-3 fatty acids) may delay the deposition of advanced glycation end products and prevent the development of diabetic nephropathy.[36] However, exact mechanisms are yet to be explored.

Previous prospective studies consistently showed that processed meat consumption was associated with a high

Table 2 Associations of meat, fish and seafood consumption with c-aGFR (mL/min/1.73 m^2) and prevalent CKD on 9768 participants of the Guangzhou Biobank Cohort Study (2003–2004)

	c-aGFR, mL/min/1.73 m^2, β (95% CI)				Prevalent CKD*, OR (95% CI)			
	Crude model	Model 1	Model 2	P for trend	Crude model	Model 1	Model 2	P for trend
Red meat consumption, 1 portion=50 g				0.83				0.76
0–3 portions/week	0.00	0.00	0.00		1.00	1.00	1.00	
4–6 portions/week	0.03 (−1.22 to 1.28)	−0.16 (−1.34 to 1.02)	−0.28 (−1.47 to 0.90)		0.96 (0.79 to 1.18)	0.97 (0.78 to 1.20)	0.99 (0.80 to 1.22)	
7–10 portions/week	0.45 (−0.86 to 1.76)	0.52 (−0.72 to 1.75)	0.35 (−0.90 to 1.59)		0.98 (0.79 to 1.21)	0.96 (0.77 to 1.20)	0.98 (0.78 to 1.23)	
≥11 portions/week	−0.82 (−2.31 to 0.67)	0.13 (−1.28 to 1.54)	−0.20 (−1.66 to 1.25)		1.002 (0.79 to 1.28)	0.92 (0.71 to 1.19)	0.96 (0.74 to 1.25)	
Per portion increment	−0.08 (−0.18 to 0.01)	0.001 (−0.09 to 0.09)	−0.02 (−0.12 to 0.07)		1.01 (0.99 to 1.02)	0.99 (0.98 to 1.02)	1.002 (0.99 to 1.02)	
Poultry consumption, 1 portion=50 g				0.10				0.95
0–1 portion/week	0.00	0.00	0.00		1.00	1.00	1.00	
2–3 portions/week	0.35 (−0.98 to 1.68)	0.54 (−0.71 to 1.79)	0.50 (−0.75 to 1.75)		1.05 (0.84 to 1.30)	1.02 (0.81 to 1.28)	1.03 (0.82 to 1.29)	
4–5 portions/week	1.38 (0.11 to 2.66)	1.49 (0.29 to 2.69)	1.37 (0.16 to 2.58)		0.89 (0.72 to 1.10)	0.86 (0.69 to 1.08)	0.88 (0.70 to 1.10)	
≥6 portions/week	0.37 (−0.87 to 1.61)	1.04 (−0.14 to 2.22)	0.82 (−0.39 to 2.04)		1.06 (0.86 to 1.29)	0.99 (0.81 to 1.23)	1.04 (0.83 to 1.29)	
Per portion increment	−0.05 (−0.17 to 0.08)	0.04 (−0.07 to 0.16)	0.01 (−0.11 to 0.13)		1.01 (0.99 to 1.03)	1.01 (0.99 to 1.03)	1.01 (0.99 to 1.03)	
Fish and seafood consumption, 1 portion=50 g				0.32				0.56
0–3 portions/week	0.00	0.00	0.00		1.00	1.00	1.00	
4–6 portions/week	−0.30 (−1.61 to 1.01)	0.20 (−1.03 to 1.43)	0.15 (−1.08 to 1.38)		1.01 (0.81 to 1.25)	0.97 (0.77 to 1.20)	0.97 (0.77 to 1.21)	
7–10 portions/week	0.49 (−0.86 to 1.84)	0.80 (−0.47 to 2.07)	0.65 (−0.63 to 1.93)		0.98 (0.78 to 1.22)	0.95 (0.75 to 1.20)	0.97 (0.77 to 1.22)	
≥11 portions/week	−1.21 (−2.50 to 0.08)	−0.45 (−1.67 to 0.76)	−0.71 (−1.95 to 0.53)		1.11 (0.90 to 1.37)	1.03 (0.82 to 1.28)	1.06 (0.85 to 1.33)	
Per portion increment	−0.09 (−0.15 to −0.03)†	−0.05 (−0.11 to 0.01)	−0.07 (−0.13 to −0.01)		1.01 (1.003 to 1.02)†	1.01 (0.99 to 1.02)	1.01 (1.0004 to 1.02)	
Processed meat consumption, 1 portion=25 g				<0.01				0.05
0–1 portion/week	0.00	0.00	0.00		1.00	1.00	1.00	
2 portions/week	−1.05 (−2.57 to 0.47)	−0.77 (−2.20 to 0.66)	−0.86 (−2.29 to 0.57)		0.92 (0.71 to 1.20)	0.85 (0.65 to 1.12)	0.86 (0.66 to 1.13)	
≥3 portions/week	−3.50 (−5.13 to −1.87)†	−2.59 (−4.13 to −1.06)†	−2.74 (−4.28 to −1.20)†		1.47 (1.16 to 1.86)†	1.37 (1.07 to 1.76)†	1.40 (1.09 to 1.80)†	
Per portion increment	−0.71 (−1.01 to −0.41)†	−0.54 (−0.82 to −0.26)†	−0.58 (−0.86 to −0.29)†		1.08 (1.04 to 1.13)†	1.07 (1.02 to 1.12)†	1.07 (1.03 to 1.12)†	

Model 1: adjusted for sex, age, education, family income, occupation, body mass index, physical activity, smoking status, alcohol use, self-rated health and chronic disease history (diabetes, hypertension and dyslipidaemia).
Model 2: additionally adjusted for daily energy intake.
*Prevalent CKD was defined as c-aGFR<60 mL/min/1.73 m^2.
†P value<0.0125.
c-aGFR, estimated glomerular filtration rate calculated by Chinese-specific Modification of Diet in Renal Disease equation; CI, confidence interval; CKD, chronic kidney disease; OR, odds ratio.

Table 3 Associations of meat, fish and seafood consumption with c-aGFR (mL/min/1.73 m^2) in 1452 participants with diabetes and 8316 participants without diabetes

	Participants with diabetes (N=1452)			Participants without diabetes (N=8316)			P for interaction
	Crude model	Model 1	Model 2	Crude model	Model 1	Model 2	
Red meat consumption, 1 portion=50 g							0.07
0–3 portions/week	0.00	0.00	0.00	0.00	0.00	0.00	
4–6 portions/week	1.57 (–2.15 to 5.29)	2.11 (–1.40 to 5.61)	1.79 (–1.73 to 5.32)	–0.21 (–1.52 to 1.11)	–0.58 (–1.82 to 0.66)	–0.67 (–1.92 to 0.58)	
7–10 portions/week	–0.32 (–4.25 to 3.60)	1.10 (–2.59 to 4.80)	0.73 (–2.99 to 4.44)	0.63 (–0.75 to 2.00)	0.49 (–0.81 to 1.79)	0.36 (–0.96 to 1.67)	
≥11 portions/week	–2.86 (–7.22 to 1.51)	–0.65 (–4.80 to 3.50)	–1.51 (–5.78 to 2.76)	–0.45 (–2.02 to 1.12)	0.34 (–1.15 to 1.83)	0.09 (–1.44 to 1.63)	
Per portion increment	–0.28 (–0.57 to 0.02)	–0.10 (–0.38 to 0.18)	–0.17 (–0.47 to 0.12)	–0.05 (–0.15 to 0.05)	0.03 (–0.07 to 0.12)	0.01 (–0.09 to 0.11)	
Poultry consumption, 1 portion=50 g							0.26
0–1 portion/week	0.00	0.00	0.00	0.00	0.00	0.00	
2–3 portions/week	2.71 (–1.28 to 6.70)	2.11 (–1.66 to 5.88)	2.04 (–1.73 to 5.81)	–0.08 (–1.48 to 1.32)	0.17 (–1.15 to 1.48)	0.13 (–1.18 to 1.45)	
4–5 portions/week	–0.09 (–3.91 to 3.73)	0.56 (–3.04 to 4.17)	0.19 (–3.44 to 3.82)	1.63 (0.29 to 2.97)	1.60 (0.33 to 2.86)	1.51 (0.23 to 2.79)	
≥6 portions/week	–0.24 (–3.99 to 3.51)	0.62 (–2.97 to 4.22)	–0.16 (–3.88 to 3.56)	0.48 (–0.82 to 1.78)	1.05 (–0.19 to 2.29)	0.90 (–0.37 to 2.18)	
Per portion increment	–0.26 (–0.63 to 0.11)	–0.13 (–0.48 to 0.22)	–0.23 (–0.60 to 0.14)	–0.01 (–0.14 to 0.12)	0.07 (–0.05 to 0.19)	0.05 (–0.08 to 0.18)	
Fish and seafood consumption, 1 portion=50 g							0.02
0–3 portions/week	0.00	0.00	0.00	0.00	0.00	0.00	
4–6 portions/week	1.17 (–2.78 to 5.13)	1.29 (–2.43 to 5.01)	1.19 (–2.53 to 4.92)	–0.52 (–1.89 to 0.86)	–0.05 (–1.35 to 1.24)	–0.10 (–1.39 to 1.20)	
7–10 portions/week	2.14 (–1.83 to 6.11)	2.43 (–1.30 to 6.16)	2.23 (–1.52 to 5.98)	0.19 (–1.23 to 1.61)	0.47 (–0.87 to 1.81)	0.32 (–1.02 to 1.67)	
≥11 portions/week	3.81 (–0.02 to 7.63)	4.00 (0.39 to 7.61)	3.62 (–0.06 to 7.30)	–2.09 (–3.44 to –0.73)*	–1.26 (–2.54 to 0.02)	–1.51 (–2.81 to –0.20)	
Per portion increment	0.18 (0.003 to 0.36)	0.20 (0.03 to 0.37)	0.18 (0.01 to 0.36)	–0.14 (–0.20 to –0.08)*	–0.09 (–0.16 to –0.03)*	–0.11 (–0.17 to –0.05)*	
Processed meat consumption, 1 portion=25 g							0.79
0–1 portion/week	0.00	0.00	0.00	0.00	0.00	0.00	
2 portions/week	–0.21 (–4.92 to 4.49)	0.45 (–3.98 to 4.88)	0.21 (–4.23 to 4.65)	–1.14 (–2.73 to 0.45)	–0.96 (–2.45 to 0.54)	–1.03 (–2.53 to 0.47)	
≥3 portions/week	–4.86 (–9.81 to 0.09)	–2.45 (–7.15 to 2.24)	–2.80 (–7.51 to 1.92)	–3.25 (–4.96 to –1.54)*	–2.53 (–4.14 to –0.92)*	–2.65 (–4.26 to –1.03)*	
Per portion increment	–1.03 (–1.99 to –0.07)	–0.55 (–1.46 to 0.36)	–0.63 (–1.54 to 0.29)	–0.65 (–0.96 to –0.34)*	–0.53 (–0.82 to –0.23)*	–0.55 (–0.85 to –0.26)*	

Model 1: adjusted for sex, age, education, family income, occupation, body mass index, physical activity, smoking status, alcohol use, self-rated health and chronic disease history (hypertension, and dyslipidaemia).
Model 2: additionally adjusted for daily energy intake.
*P value<0.0125.
c-aGFR, estimated glomerular filtration rate calculated by Chinese-specific Modification of Diet in Renal Disease equation; CI, confidence interval.

risk of CKD.[7 26] However, these studies explored the association of processed meat consumption with CKD incidence, but not with eGFR. In our analysis, higher processed meat consumption was associated with lower eGFR, and the results were generally consistent in those with and without diabetes. Given processed meat consumption varied across settings and age groups, re-evaluation of the effect of processed meat consumption on eGFR in older people may provide useful information for tailoring dietary advice. The negative association of processed meat consumption with eGFR may be due to the high sodium contents in processed meat, which may have adverse effects on blood pressure and glomerular function.[2 37 38] In addition, previous studies showed that trimethylamine N-oxide (TMAO) played a direct contributing role in the development and progression of kidney dysfunction.[39] Given that both meat and fish are important sources of TMAO,[40 41] it is possible that the inverse associations observed between processed meat, fish and seafood consumption and eGFR may, in part, be explained by the detrimental effects of TMAO. However, the exact mechanisms underlying these associations require further investigation.

The strengths of our study include the population-based design, the use of both c-aGFR and eGFR and the detailed assessment of potential confounders. However, several limitations exist in our study. First, measurement error due to variability in food intake was almost inevitable in nutritional epidemiological studies and it tends to lead to less precise estimates, although the FFQ used in our cohort has been validated in the Chinese population previously.[11] Second, different cooking methods may influence the associations of meat, fish and seafood consumption with eGFR, but the information was not available in our study. Further studies with adjustment for cooking methods are needed to reduce residual confounding and confirm the findings. Third, the specificity of Chinese food may limit the generalisability of the findings. However, similar results regarding the association of processed meat consumption with kidney function were found in studies from different settings,[7 26] indicating that generalisability might not be a major concern. Fourth, a post hoc sample size calculation showed that our subgroup analysis may not be adequately powered to assess the associations in participants with diabetes. Fifth, the causal associations of meat, fish and seafood consumption with kidney function could not be confirmed in this cross-sectional study. However, as older Chinese had a relatively stable dietary pattern, the time sequence from meat, fish and seafood consumption to eGFR assessing during physical examination was unlikely to be reversed. Moreover, since eGFR assessment was performed at GBCS baseline only, we could not assess the associations of meat, fish and seafood consumption with changes in eGFR. Further studies with repeated assessments of eGFR are needed to examine the potential effects of meat, fish and seafood consumption on changes in eGFR. Furthermore, besides eGFR, other traditional biomarkers of kidney function such as uric acid and blood urea nitrogen were not assessed. Since both meat, and fish and seafood were wide food groups including various single items, further studies exploring the associations of specific kinds of meat, fish and seafood consumption with various biomarkers of kidney function are warranted.

CONCLUSIONS

In conclusion, we found that higher processed meat consumption was associated with lower eGFR and higher risk of poor kidney function. Fish and seafood consumption was associated with lower eGFR in participants without diabetes but higher eGFR in those with diabetes. Since older people may have a reduced eGFR many years before the manifestation of CKD, our results provided evidence to advocate for low processed meat consumption targeting early prevention of subclinical kidney function decline. Further prospective cohort studies with larger sample size are needed to clarify the moderation effects of diabetes.

Author affiliations
[1]School of Public Health, Sun Yat-sen University, Guangzhou, Guangdong, China
[2]Molecular Epidemiology Research Centre, Guangzhou Twelfth People's Hospital, Guangzhou, Guangdong, China
[3]School of Public Health, The University of Hong Kong, Hong Kong, Hong Kong
[4]Institute of Applied Health Research, University of Birmingham, Birmingham, UK

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ORCID iD

Lin Xu http://orcid.org/0000-0002-0537-922X

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