The Effects of Dietary Nutrients On Serum Liquids in Chinese Dietary: A Community-Based Population Study

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Research

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Abstract

Background

To examine the association between dietary nutrients (protein, carbohydrates, total fats, saturated fatty acids [SFA], monounsaturated fatty acids [MUFA], polyunsaturated fatty acids [PUFA], and cholesterol) and various serum lipids in Chinese adults.

Methods

As a part of Prospective Urban and Rural Epidemiology (PURE) study, 46,285 Chinese participants were recruited. Dietary nutrients from various foods were computed using the Chinese Food Composition Table databases. Blood were collected to test total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C).

Results

42,054 participants in PURE-China study were included. Mean TC, LDL-C, HDL-C, and TG were 4.68 ± 0.99 mmol/L, 2.63 ± 0.76 mmol/L, 1.36 ± 0.33 mmol/L, and 1.55 ± 1.09 mmol/L in our study, respectively. Subjects consuming higher proteins were more likely to have higher TC, TG, LDL-C (all $P_{trend} < 0.001$). High carbohydrate intake may play a role on reduction of TC ($P_{trend} < 0.001$), TG ($P_{trend} = 0.031$), LDL-C ($P_{trend} < 0.001$) and HDL-C ($P_{trend} < 0.001$). Higher fat intake was associated with increase of TC, LDL-C, and HDL-C (all $P_{trend} < 0.001$). Unlike SFAs and MUFAs, those consuming higher PUFAs are likely to have higher TG ($P_{trend} < 0.001$), but have stable LDL-C ($P_{trend} = 0.136$).

Conclusions

High carbohydrate intake could decrease significantly various lipids, while high-fat and high-protein intake might have harmful impacts on profile of serum lipids. Subjects consuming higher SFAs and MUFAs were more likely to have higher levels of TC and LDL-C, but the intake of PUFAs has no influence on LDL-C level.

Background

The atherosclerotic cardiovascular disease (ASCVD) is the leading cause of death and disability in the world [1, 2]. Increased LDL cholesterol level is the major atherosclerotic factor, which have been identified by considerable amounts of observational and intervention studies [3, 4]. In addition, decreased high-density lipoprotein cholesterol (HDL-C) can contribute to the development of ASCVD [5]. However, the findings are still inconsistent in other studies [6, 7]. Thereby, correcting lipid profile was recommended as one of the most important strategies to prevent and control ASCVD risk in many countries [4, 8, 9].

Low-carbohydrate (LC) diet is recommended as a popular weight-loss approach compared with the conventional low-fat (LF) diet [10, 11]. Several previous studies using systematic review and meta-analysis provided supportive evidence that LC diet produced greater weight loss, greater reduction of total cholesterol (TC) and triglycerides (TG), as well as greater increase of HDL-C compared with LF diet, but significant increase or lack of reduction in LDL-C was observed after consuming LC diet [12]. As we know, LDL-C plays an important role for ASCVD morbidity and

mortality, so the benefits of LC diet must be balanced with possible detrimental effect of increase LDL-C. Major types of dietary fat have been evaluated for preventing from ASCVD in moderate numbers of observational studies and clinical trials, suggesting that saturated fatty acid (SFA) intake should be replaced with polyunsaturated fatty acids (PUFAs) intake rather than monounsaturated fatty acids (MUFAs) or carbohydrate intake [13, 14], though a recent meta-analysis did not support high consumption of polyunsaturated fatty acids and low consumption of total saturated fats [15]. However, most relevant studies were conducted in Europe and North America. It is not known whether their findings could be extrapolated to other countries, especially developing countries, where dietary patterns vary more than developed countries.

Along with the development of economy and improvement of living conditions, dyslipidemia prevalence has shown a gradual increasing trend in China [16, 17]. However, few studies have assessed dietary nutrient effects in Chinese populations. A cross-sectional study in a nationally representative sample of 46,239 adults aged at 20 years or older demonstrated that age-standardized levels of total cholesterol (TC), HDL-C, and LDL-C and TG were 4.72, 1.30, 2.68, and 1.57 mmol/L, respectively, but the effects of dietary intake on serum lipids were not evaluated [17]. In current study, we aim to examine the levels of lipids in China and evaluated the effects of three macro-nutrients (total fats, carbohydrates, protein) and three types of fats (SFA, MUFAs, PUFAs) on blood lipid measures (TC, TG, LDL-C, HDL-C, TC to HDL-C ratio, TG to HDL-C ratio) using data involving twelve administrative regions in China with 1:1 urban-to-rural recruitment ratio, based on an international prospective urban and rural epidemiology (PURE) study [18, 19].

Methods

Study design and population selection

PURE study is a worldwide epidemiological study that recruited 153,996 adults from 628 urban and rural communities in 17 different economic-income levels countries and details of the study population and methods used in the PURE study have been published elsewhere [3, 18, 20]. Our analyses used baseline data from PURE-China [19, 21–23]. A total of 46,285 individuals were enrolled from 45 urban and 70 rural communities, of which 45,587 completed Food Frequency Questionnaires (FFQ) and had energy intake between 500 to 5000 kcal per day.

Data Collection

Individual data including socio-demographic data, self-reported medical history, lifestyle behaviors (tobacco use, alcohol consumption, and physical activities), antihypertensive and anti-diabetic medication were collected via a structured questionnaire. Physical examination was conducted to collect weight, height, and systolic/diastolic blood pressure for each participant by trained physicians. Blood samples were drawn by venipuncture after overnight fasting and processed at the field center and shipped to the study center lab in Beijing to test serum lipids, including TC, LDL-C, HDL-C, and TG. Dyslipidemia was defined to meet any one criteria as below: 1) $TC \geq 6.22$ mmol/L; 2) $LDL-C \geq 4.14$ mmol/L; 3) $HDL-C < 1.04$ mmol/L; 4) $TG \geq 2.26$ mmol/L; 5) use of lipid-lowering medications[24].

A semi-quantitative Chinese FFQ was used to obtain food consumption with satisfactory outcomes of reproducibility and validity [25]. Total fats, carbohydrates, protein, SFA, MUFAs, and PUFAs from various foods were computed using the Chinese Food Composition Table database [25, 26].

Statistical Analyses

All statistical analyses were performed with SAS 9.4 (SAS Institute Inc, Cary, North Carolina, USA). The data are presented as means $\pm$ standard deviation (SD) for continuous variables or percent for categorical variables. Participants were categorized into quartiles of each nutrient intake (total fats, carbohydrates, protein, SFAs, MUFAs, PUFAs, and cholesterol intake), based on percentage of energy intake provided by specific nutrients. The primary outcomes of this study are concentrations of blood lipids (TC, TG, LDL-C, HDL-C, TC to HDL-C ratio, and TG to HDL-C ratio). Multilevel linear regression with random-effect models to account for center was used to assess the effects of dietary nutrients with blood lipid concentrations. Potential confounding variables included age, sex, education levels, urban or rural locations, smoking status, and taking lipid-lowering medications, as in our PURE global paper [27]. In order to compare the strength of associations between the various nutrients and serum lipids using common units, standardized coefficients were computed, representing standard deviation (SD) change in serum lipids per one SD increase in nutrient intake.

Results

As published before [19, 21–23], 46,285 residents participated in PURE study from 115 communities (45 urban, 70 rural) from 2005 to 2009, while 45,587 completed FFQ and had energy intake between 500 to 5000 kcal per day. 42,292 participants had lipid test records. Data were available for analysis for 42,054 participants with reasonable TC (1.0–20.0 mmol/L), TG (0.2–30.0 mmol/L), LDL-C (0.1–10.0 mmol/L), and HDL-C (0.1–10.0 mmol/L). Overall, the average age was 51.1 ± 9.7 years (range from 35 to 70 years), 20,402 (48.5%) came from urban communities, and women comprised 58.6% of the total number of participants.

Mean TC was 4.68 ± 0.99 mmol/L (urban vs. rural: 4.84 vs. 4.54 , $P < 0.01$), LDL-C level was 2.63 ± 0.76 mmol/L (2.76 vs. 2.50 , $P < 0.01$), HDL-C level was 1.36 ± 0.33 mmol/L (1.36 vs. 1.36 , $P = 0.85$), and TG was 1.55 ± 1.09 mmol/L (1.59 vs. 1.52 , $P < 0.01$). The prevalence of dyslipidemia was 31.4% for overall study population, indicating 33.5% for urban areas and 29.4% for rural areas ($P < 0.01$). The percent of energy intake from protein (16.56 ± 2.67 vs. 14.15 ± 2.47) and fat intake (20.09 ± 7.43 vs. 15.44 ± 7.37) among urban people were much higher than rural subjects, while much lower for carbohydrate intake (63.35 ± 9.24 vs. 70.41 ± 9.13). Whatever the percent of energy intake from SFA, MUFAs, and PUFAs, higher levels were observed in urban areas than rural areas (SFA: 6.54 ± 2.56 vs. 4.86 ± 2.63 ; MUFAs: 7.61 ± 2.74 vs. 6.06 ± 2.90 ; PUFAs: 4.87 ± 2.99 vs. 3.51 ± 2.33). More detailed comparison between rural and urban areas as well as between females and males have been presented in Table 1.

Table 1
General characteristics of study participants in urban and rural PURE-China

Variables ¹	Urban (N = 20,402)		Rural (N = 21,652)		Significance		
	Females	Males	Females	Males	Sex	Urbanization	Sex×urbanization
	(n = 12,214)	(n = 8,188)	(n = 12,412)	(n = 9,240)			
Age, years	52.3 ± 9.7	52.5 ± 10.1	49.3 ± 9.2	50.6 ± 9.5	< 0.001	< 0.001	< 0.001
Body mass index, kg/m ²	24.8 ± 3.6	25.2 ± 3.5	24.5 ± 3.7	23.8 ± 3.7	< 0.001	< 0.001	< 0.001
College or higher education, %	13.0	21.0	0.7	2.4	< 0.001	< 0.001	< 0.001
Current cigarette smoking, %	2.3	44.6	3.5	55.0	< 0.001	< 0.001	0.682
Current alcohol drinking, %	5.4	41.0	3.8	47.7	< 0.001	< 0.001	< 0.001
History of stroke, %	2.0	3.0	1.3	1.7	< 0.001	< 0.001	0.330
History of CHD, %	6.6	5.8	4.9	3.1	< 0.001	< 0.001	< 0.001
History of other heart diseases, %	1.6	1.1	1.2	0.8	< 0.001	0.001	0.862
Hypertension ² , %	40.2	47.8	42.2	43.6	< 0.001	0.322	< 0.001
Regular use of AHM, %	17.4	15.9	10.7	9.6	< 0.001	< 0.001	0.612
Diabetes mellitus ³ , %	11.2	12.7	7.0	6.3	0.444	< 0.001	< 0.001
Regular use of ADM, %	5.0	4.8	1.8	1.2	< 0.001	< 0.001	0.003

Note: CHD, coronary heart diseases, included angina/heart attack/ coronary artery diseases; AHM, antihypertensive medication; ADM, antidiabetic medication; TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; TG, triglycerides;

¹ Sum may not always add up to total because of missing values; ² Hypertension was defined as self-reported hypertension diagnosis by physicians or self-reported regular use of antihypertensive medication or systolic/diastolic blood pressure at recruitment ≥ 140/90 mmHg or both; ³ Diabetes mellitus was defined as self-reported diabetes diagnosis by physicians or self-reported regular use of antidiabetic medication or fasting glucose at recruitment ≥ 7.0 mmol/L; ⁴ Dyslipidemia was defined to meet any one criteria as below: 1) TC ≥ 6.22; 2) LDL-C ≥ 4.14; 3) HDL-C < 1.04; 4) TG ≥ 2.26; 5) use of lipid-lowering medications.

Variables ¹	Urban (N = 20,402)		Rural (N = 21,652)		Significance		
	Females	Males	Females	Males	Sex	Urbanization	Sex×urbanization
	(n = 12,214)	(n = 8,188)	(n = 12,412)	(n = 9,240)			
Systolic blood pressure, mmHg	130.5 ± 22.7	134.5 ± 21.0	134.5 ± 23.6	135.7 ± 21.2	< 0.001	< 0.001	< 0.001
Diastolic blood pressure, mmHg	80.9 ± 12.8	83.6 ± 12.2	83.2 ± 13.9	84.3 ± 13.7	< 0.001	< 0.001	< 0.001
Fasting glucose, mmol/L	5.66 ± 1.60	5.71 ± 1.70	5.48 ± 1.51	5.43 ± 1.39	0.458	< 0.001	0.002
Dyslipidemia ⁴ , %	30.4	38.1	28.6	30.5	< 0.001	< 0.001	< 0.001
TC, mmol/L	4.91 ± 1.00	4.73 ± 1.05	4.59 ± 0.94	4.47 ± 0.90	< 0.001	< 0.001	0.001
TG, mmol/L	1.52 ± 1.00	1.69 ± 1.28	1.52 ± 1.03	1.51 ± 1.09	< 0.001	< 0.001	< 0.001
LDL-C, mmol/L	2.82 ± 0.79	2.67 ± 0.81	2.53 ± 0.71	2.46 ± 0.69	< 0.001	< 0.001	< 0.001
HDL-C, mmol/L	1.41 ± 0.32	1.30 ± 0.32	1.38 ± 0.34	1.34 ± 0.34	< 0.001	0.852	< 0.001
Ratio for TC vs. HDL-C	3.6 ± 1.2	3.4 ± 1.0	3.4 ± 1.0	3.5 ± 1.0	< 0.001	< 0.001	< 0.001
Ratio for TG vs. LDL-C	1.16 ± 1.10	1.44 ± 2.37	1.20 ± 1.10	1.26 ± 1.41	< 0.001	0.002	0.001
Protein intake (gram/day)	75.7 ± 26.0	85.4 ± 27.5	65.6 ± 23.9	74.3 ± 25.9	< 0.001	< 0.001	0.042
Carbohydrate intake (gram/day)	288.0 ± 100.4	337.3 ± 120.3	327.5 ± 111.6	369.8 ± 123.9	< 0.001	< 0.001	0.006
Fat intake (gram/day)	42.4 ± 23.1	45.4 ± 23.2	32.5 ± 21.0	36.6 ± 22.4	< 0.001	< 0.001	0.002

Note: CHD, coronary heart diseases, included angina/heart attack/ coronary artery diseases; AHM, antihypertensive medication; ADM, antidiabetic medication; TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; TG, triglycerides;

¹ Sum may not always add up to total because of missing values; ² Hypertension was defined as self-reported hypertension diagnosis by physicians or self-reported regular use of antihypertensive medication or systolic/diastolic blood pressure at recruitment ≥ 140/90 mmHg or both; ³ Diabetes mellitus was defined as self-reported diabetes diagnosis by physicians or self-reported regular use of antidiabetic medication or fasting glucose at recruitment ≥ 7.0 mmol/L; ⁴ Dyslipidemia was defined to meet any one criteria as below: 1) TC ≥ 6.22; 2) LDL-C ≥ 4.14; 3) HDL-C < 1.04; 4) TG ≥ 2.26; 5) use of lipid-lowering medications.

After adjusted for above-mentioned covariates, standardized coefficients (β) with 95% CI showing the standard deviance (SD) change in various serum liquids per one SD increase in nutrient intake are presented in Fig. 1. Overall, total fats had positive associations with all serum liquids levels, except for HDL-C (β , -0.007; 95% CI, -0.017 to 0.004; $P = 0.223$; see to Fig. 1A). Total carbohydrates had negative associations with all risk markers, but only TG to HDL-C ratio did not reach statistical significance (β , -0.004; 95% CI, -0.015 to 0.008; $P = 0.538$; see to Fig. 1B). Total fats were related positively not only with TC (β , 0.042; 95% CI, 0.032 to 0.052; $P < 0.001$) and LDL-C (β , 0.032; 95% CI, 0.022 to 0.042; $P < 0.001$), but also with HDL-C (β , 0.029; 95% CI, 0.019 to 0.040; $P < 0.001$); however, no significance was found for TG, TC to HDL-C ratio, and TG to HDL-C ratio (Fig. 1C). Generally, SFAs and MUFAs had stronger associations with TC and LDL-C, in comparison with the associations of PUFAs. Unlike SFAs and MUFAs, PUFAs had no impacts on increasing HDL-C (β , -0.001; 95% CI, -0.009 to 0.011; $P = 0.790$; See Fig. 1D, 1E, and 1F). Like total fats, positive significance was observed in TC, LDL-C, and HDL-C with cholesterol intake, but it failed for other liquids (Fig. 1G).

After adjustment for covariates, we found that higher protein and fat intake was associated with higher TC (both $P_{trend} < 0.001$), but higher carbohydrates related with lower TC ($P_{trend} < 0.001$), which were illustrated in Fig. 2A-2C. Figure 2D-2F indicated that TG were associated positively with protein intake and negatively with carbohydrates (both $P_{trend} < 0.001$), while no significance with fat intake ($P_{trend} = 0.140$). Similar trends were observed for LDL-C and TC levels (all $P_{trend} < 0.001$; Fig. 2G-2I). HDL-C levels can increase along with fat intake increase, but decrease with carbohydrate intake increase (both $P_{trend} < 0.001$), but not related with protein intake ($P_{trend} = 0.123$; Fig. 2J-2L). Regarding TC to HDL-C ratio illustrated in Fig. 2M-2O, positive and negative associations were shown for protein intake ($P_{trend} < 0.001$) and fat intake ($P_{trend} < 0.001$), respectively, but stable trend for carbohydrate intake ($P_{trend} = 0.249$). Figure 2P-2R presented that higher fat intake had lower TG to HDL-C ratio ($P_{trend} = 0.013$), was marginally associated with protein intake ($P_{trend} = 0.050$), and no related with carbohydrate intake ($P_{trend} = 0.300$).

Figure 3 presented the adjusted means of various serum liquid concentrations by quartiles in daily intake of SFAs, MUFAs, and PUFAs. Similar increase trends in TC levels were observed by the increase of three fatty acids ($P_{trend} < 0.001$, Fig. 3A-3C). Only positive associations of TG levels were shown with PUFAs ($P_{trend} < 0.001$, Fig. 3F), but no significance for SFAs ($P_{trend} = 0.768$, Fig. 3D) and MUFAs ($P_{trend} = 0.686$, Fig. 3E). Those consuming higher SFAs and MUFAs were more likely to have higher LDL-C levels (both $P_{trend} < 0.001$, Fig. 3G-3H), but stable LDL-C were observed in those with high and low PUFA intake ($P_{trend} = 0.136$, Fig. 3I). Nice dose-response trends of HDL-C levels were presented in all three fatty acids ($P_{trend} < 0.001$, Fig. 3J-3L). Negative relationship between TC to HDL-C ratio and three fatty acids, such as SFAs ($P_{trend} = 0.010$, Fig. 3M), MUFAs ($P_{trend} = 0.003$, Fig. 3N), and PUFAs ($P_{trend} = 0.015$, Fig. 3O). Inverse associations of TG to HDL-C ratio with SFAs ($P_{trend} = 0.010$, Fig. 3P) and MUFAs ($P_{trend} = 0.003$, Fig. 3Q) were observed, but only marginally significant with PUFAs ($P_{trend} = 0.061$, Fig. 3R). Regarding cholesterol intake categorized by quartiles, similar analyses were performed with six serum liquids in Fig. 4. Nice dose-response increase trends of TC, LDL-C, and TC to HDL-C were found with the increase daily cholesterol intake (all $P_{trend} < 0.001$; see Fig. 4A, 4C, 4E), while slight decrease trends for TG, HDL-C, and TG to HDL-C ($P < 0.05$; see Fig. 4B, 4D, 4F).

Discussions

Surprisingly, high carbohydrate intake seemed to play a beneficial role on serum liquid profile in Chinese dietary structure, though HDL-C levels also decrease slightly. The higher total fat intake and intake of two types of fats including SFAs and MUFAs, the higher most serum liquids including TC, LDL-C, and HDL-C, except for TG. However,

those consuming higher PUFA intake had higher TG levels, while stable LDL-C levels were observed in various intake levels of PUFAs.

Several previous epidemiological studies reported serum lipid and lipoproteins levels in China [16, 17, 28, 29]. Our study was conducted from 2005 to 2009, documenting more significant increase in the means of TC at 4.68 mmol/L, LDL-C at 2.63 mmol/L, HDL-C at 1.36 mmol/L, TG at 1.55 mmol/L than the 2002 China National Nutrition and Health Survey (TC at 3.81 mmol/L, HDL-C at 1.30 mmol/L, and TG at 1.10 mmol/L) [16]. However, similar levels of TC at 4.72 mmol/L, LDL-C at 2.68 mmol/L, HDL-C at 1.30 mmol/L, and TG at 1.57 mmol/L were reported in another national-wide epidemiological survey between 2007 and 2008 [17]. Though there are potential sampling bias and urban-rural gap, the rapid increase in serum lipids among Chinese population is inevitable. Moreover, dyslipidemia prevalence difference in urban (female 30.4% and male 38.1%) and rural residents (female 28.6% and male 30.5%) was concerned. After age- and sex-standardized using 2010 population census [30], our urban residents had the higher levels of dyslipidemia than rural residents, which consisted with the previous studies [31]. Hence, increasing burden resulted from high serum lipids levels in the Chinese general population should be obtained great attention from public health institutions and governments, especially for urban areas.

Ideal dietary regimen to reduce ASCVD risk may decrease LDL-C and raise HDL-C levels simultaneously. Previous studies have shown that higher fat intake could increase TC and LDL-C levels, but also increase HDL-C levels, thereby reduce the ratio of TC to HDL-C, including PURE-global data [27, 32]. Our study had consistent results with previous studies. Additionally, low-carbohydrate diets may have more favorable changes in HDL-C and TG levels, but less favorable changes in LDL-C levels, compared with those consuming a low-fat diet [12]. Inversely, those consuming lower carbohydrate intakes were more likely to have higher TC, TG, LDL-C and HDL-C, but had no effects on TC to HDL-C ratio, and TG to HDL-C ratio in our PURE-China population. As we know, staple food is the main food in Chinese dietary, such as rice and noodle, and wheaten food, which are high in carbohydrate and low in fat. Currently, randomized controlled trials of comparing low-carbohydrate diets to low-fat diets were conducted mainly in USA and Australia, where cooking methods might not be applicable to China. Hence, results may be much different from previous RCTs [33–35], if similar RCTs will be performed in Chinese population.

Saturated fats are main content in red meat, but not in white meat, which has been suggested to be associated with higher mortality of cardiovascular diseases [36]. Current dietary guidelines have largely focused on reducing saturated fatty acid intake and replacing it with carbohydrate and unsaturated fats [27, 37], and therefore could reduce the risk of cardiovascular diseases [14]. In our study, as one type of unsaturated fats, MUFAs have similar impacts with SFAs on serum lipid profile in Chinese dietary especially for TC and LDL-C, while another unsaturated fats (i.e. PUFAs) did not affect the levels of LDL-C. On the other hand, higher intake of PUFAs in daily dietary may increase TG levels, but SFAs and MUFAs not. In addition, higher intake of any types of fatty acids can raise the levels of HDL-C, which might neutralize adverse impacts of fatty acids, especially for SFAs and MUFAs. Current guidelines emphasize on the effects of diet on LDL-C, though TC to HDL-C ratio was recognized as a better predictor of cardiovascular disease risk [38]. In our PURE-China study, whatever saturated or unsaturated fatty acid intake was associated inversely with TC to HDL-C ratio and TG to HDL-C ratio. Hence, increasing intake of unsaturated fatty acids might be ineffective to improve serum lipid profiles in Chinese adults. Chinese cooking styles might be an important influence factor. Fussy process steps and additive agents may produce trans-fats and nullify the possible benefits of polyunsaturated fatty acids on blood lipids [27, 39]. Additionally, our study observed that high level of dietary cholesterol intake was more likely to have higher TC, LDL-C level, which consist with the PURE-global and other results [27, 40]. Recently, extensive research did not show evidence to support a role of dietary cholesterol in the development of CVD [41, 42]. As a result, the 2015–2020 Dietary Guidelines for Americans removed the

recommendations of restricting dietary cholesterol [43]. One of the most reasons is that most foods are rich in cholesterol and SFAs, which may increase the risk of CVD.

Our PURE-China study had the same limitations with global PURE [18, 44, 45]. Firstly, FFQ questionnaires were specialized for Chinese people [25], while which did not differentiate between raw and cooked vegetables. As we know, Chinese special cooking pattern were much different from the Western countries, which might introduce confounding for the evaluation between nutrients and serum lipids, especially for cooked vegetables using oil and sauce. Secondly, though our PURE-China adopted cluster sampling with 1:1 urban-to-rural recruitment ratio and involved in 12 administrative regions, our population was not representative to mean levels in China. Specially, achieving good follow-up retention is the primary goal for PURE study. Thirdly, only baseline data were analyzed, which has potential methodological limitations to detect the causality between exposure and outcome. Data from follow-up period will be analyzed further to confirm the association of dietary intake and lipid profiles, especially for CVD risk. Finally, some potential confounding factors may not be included in current study. Some studies have found that less sleep duration [46], air pollution [47] and mental stress [48] might contribute to lipid disorders. Thus, more studies, especially randomized controlled trials were needed for illustrate the real relationship between dietary intake and lipid profiles.

Conclusions

Despite these limitations, our study found that higher carbohydrate intake was unexpected to reduce the levels of serum lipids, though HDL-C also decreased, but high protein and fat intake could raise serum lipid concentrations. Both SFAs and MUFAs were associated positively with TC, LDL-C and HDL-C levels. However, the intake of PUFAs has not influence on LDL-C level. Hence, enhancing intake of unsaturated fatty acids might be useless to improve serum lipids profiles in Chinese adults due to Chinese-specific cooking styles.

List Of Abbreviations

Saturated Fatty Acids [SFA], Monounsaturated Fatty Acids [MUFA], Polyunsaturated Fatty Acids [PUFA]) Total Cholesterol (TC), Triglycerides (TG), Low-Density Lipoprotein Cholesterol (LDL-C), High-Density Lipoprotein Cholesterol (HDL-C) Atherosclerotic Cardiovascular Disease (ASCVD), Low-Carbohydrate (LC), Low-Fat (LF)

Declarations

Ethics approval and consent to participate: The protocol and informed consent were reviewed and approved by the institutional review board at Fuwai Hospital of Chinese Academy of Medical Sciences and Beijing Hypertension League Institute.

Consent for publication: Not applicable.

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests No.

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Figures

Figure 1

Standardized coefficients and 95% CIs for the association between nutrient intake and serum lipids. Bars are 95% CIs. Data are adjusted for age, sex, education levels, urban or rural locations, smoking status, and taking lipid-lowering medications. Data are shown for (A) total protein, (B) total carbohydrates, (C) total fats, (D) saturated fatty acid (SFA), (E) monounsaturated fatty acid (MUFA), (F) polyunsaturated fatty acid (PUFA), (G) cholesterol. Note: SD,

standard deviance; TC, total cholesterol; TG, triglycerides; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acid.

Figure 2

Adjusted means of serum lipid concentrations by daily protein, carbohydrate and fat intake. Bars are 95% CIs. Data are adjusted for age, sex, education levels, urban or rural locations, smoking status, and taking lipid-lowering medications. Data are shown for (A) total cholesterol (TC) by protein intake, (B) TC by carbohydrate intake, (C) TC by fat intake, (D) TG by protein intake, (E) TG by carbohydrate intake, (F) TG by fat intake, (G) LDL-C by protein intake, (H) LDL-C by carbohydrate intake, (I) LDL-C by fat intake, (J) HDL-C by protein intake, (K) HDL-C by carbohydrate intake, (L) HDL-C by fat intake, (M) TC to HDL-C ratio by protein intake, (N) TC to HDL-C ratio by

carbohydrate intake, (O) TC to HDL-C ratio by fat intake, (P) TG to HDL-C ratio by protein intake, (Q) TG to HDL-C ratio by carbohydrate intake, (R) TG to HDL-C ratio by fat intake Note: TC, total cholesterol; TG, triglycerides; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol.

Figure 3

Adjusted means of serum lipid concentrations by daily SFA, MUFA, PUFA intake Bars are 95% CIs. Data are adjusted for age, sex, education levels, urban or rural locations, smoking status, and taking lipid-lowering medications. Data are shown for (A) TC by SFAs quartiles, (B) TC by MUFAs quartiles, (C) TC by PUFAs quartiles, (D) TG by SFAs quartiles, (E) TG by MUFAs quartiles, (F) TG by PUFAs quartiles, (G) LDL-C by SFAs quartiles, (H) LDL-C by MUFAs quartiles, (I) LDL-C by PUFAs quartiles, (J) HDL-C by SFAs quartiles, (K) HDL-C by MUFAs quartiles, (L) HDL-C by PUFAs quartiles, (M) TC to HDL-C ratio by SFAs quartiles, (N) TC to HDL-C ratio by MUFAs quartiles, (O) TC

to HDL-C ratio by PUFAs quartiles, (P) TG to HDL-C ratio by SFAs quartiles, (Q) TG to HDL-C ratio by MUFAs quartiles, (R) TG to HDL-C ratio by PUFAs quartiles Note: TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acid.

Figure 4

Adjusted means of serum lipid concentrations by daily cholesterol intake Note: TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol.