Association between fruit and vegetable intake and the risk of hypertension among Chinese adults: a longitudinal study

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ORIGINAL CONTRIBUTION

Association between fruit and vegetable intake and the risk of hypertension among Chinese adults: a longitudinal study

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Abstract

Purpose Fruit and vegetable intake has been inversely associated with the risk of hypertension; however, there is inconsistent evidence on the long-term association. Given this gap in the literature, it is necessary to identify evidence from large prospective studies, especially in China, where insufficient evidence exists. Thus, we examined the association of fruit and vegetable intake with incident hypertension in Chinese adults.

Methods We conducted analyses among 5659 Chinese adults aged 18–64 years, free of cardiovascular disease, cancer, and hypertension in the 2006 wave of the China Health and Nutrition Survey. Fruit and vegetable intake was assessed using consecutive 24-h recalls. Incident hypertension was identified from the 2011 wave of the survey.

Results A total of 866 participants developed incident hypertension. The relative risks (RRs) and 95% confidence intervals (CIs) of hypertension were 0.74 (0.55–0.99), 0.65 (0.48–0.88), 0.68 (0.50–0.92), and 0.73 (0.53–0.99) comparing each quintile group of fruit and vegetable intake with the lowest quintile group. These associations attenuated for the change of intake but remained significant for the fourth quintile, of which the RR (95% CI) was 0.65 (0.47–0.89). The magnitude of association was stronger among those who were younger, female, overweight and had prehypertension. When examined separately, fruit intake was more strongly and significantly associated with lowering BP than vegetable intake. Adding body mass index to the models attenuated all associations.

Conclusions Greater long-term intake and increased intake of fruit and vegetables may reduce the risk of developing hypertension in Chinese adults.

Keywords Hypertension · Prospective studies · Fruit · Vegetable · China

Introduction

Identified as the leading risk factor for the global disease burden and mortality [1], hypertension is an important public health challenge worldwide [2] and in China [3, 4]. The estimated proportion of the world's adult hypertensive population was more than 25% in 2010, and this population is expected to increase to around 1.56 billion by 2050 [2]. The prevalence of hypertension in the Chinese adult population sextupled from 5.1% in 1959 to 29.6% in 2014 [3], and will continue to rise because of lifestyle changes, urbanization, and the accelerated process of aging [5, 6].

Among several modifiable risk factors, diet plays a prominent role in the prevention of hypertension [7]. Among dietary factors, fruit and vegetable intake (FVI) may have a protective effect against hypertension. In the United States, multi-center trials within the Dietary Approach to Stopping Hypertension (DASH) study [8], found a high FVI diet significantly lowered blood pressure (BP) after an 8-week intervention among different populations. Further, a United Kingdom (UK) based study of a 6-month interventional trial, found an increase in FVI significantly lowered BP by 4.0 (95% CI 2.0–6.0) and 1.5 (95% CI 0.2–2.7) mmHg for systolic and diastolic [9]. Furthermore, two recent meta-analyses [10, 11] showed an inverse association between FVI and hypertension, respectively. However, the nature and

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magnitude of association varied by participants' characteristics, method of dietary assessment, outcome ascertainments, and duration of cohort follow-up [10, 11]. Furthermore, insignificant associations were reported in several previous prospective studies [12, 13], case–control studies [14] and cross-sectional studies [15, 16]. For example, in the Women's Health Study (WHS) cohort with 28,082 participants and a mean of 12.9 years of follow-up, the hazard ratios (HRs) and 95% CIs of hypertension were 1.03 (0.95–1.12), 1.02 (0.94–1.11), 1.04 (0.95–1.14), and 1.03 (0.93–1.13) comparing women who consumed 2 to < 4, 4 to < 6, 6 to < 8, and ≥ 8 servings/day of total fruits and vegetables with those consuming < 2 servings/day [13].

While studies in Western countries are helpful, China-specific studies are necessary given the unique characteristics of the Chinese population which, in many cases, are vastly different culturally (e.g., dietary intake) from Western countries. Although hypertension is more common in Western countries, China has a considerably larger affected population in critical need of study [2]. This is also a very timely issue given Chinese FVI, especially for fruit, has been shown to be below the recommended dietary intake for the past several years, while the proportion of meat consumption has grown [17, 18]. This is further compounded with the fact that to date there is a gap in published studies from large prospective studies in China concerning FVI. Given this timely and critical need, we aimed to investigate the prospective association between FVI and subsequent risk of hypertension among those with 5 years of follow-up data in a large Chinese cohort.

Method

Study population

The China Health and Nutrition Survey (CHNS) is a prospective ongoing study that examines a series of economic, sociological, demographic and health questions. During nine waves of surveys from 1989 to 2011 in nine provinces, a multistage, stratified sampling design was employed to ensure adequate representation of rural and urban areas varying substantially in geography, economic development, public resources, and health indicators. Details about the study design and sampling strategies are available in the cohort profile [19]. All participants provided written informed consent and the study was approved by the institutional review committees of the University of North Carolina at Chapel Hill, the National Institute of Nutrition and Food Safety, Chinese Center for Disease Control and Prevention, and the China–Japan Friendship Hospital, Ministry of Health.

Our analysis included two waves of survey data collected in 2006 and 2011. Of 6985 participants involved in both waves of surveys, who were 18–64 years of age in 2006, and who had a least one wave of measurement for FVI and BP, 1141 participants with hypertension at baseline were excluded, defined as having a self-reported physician diagnosis of hypertension, measured systolic BP ≥ 140 mmHg or diastolic BP ≥ 90 mmHg, or any history of antihypertension treatment. We further excluded 69 participants who had cardiovascular disease or cancer, 25 participants who had a diagnosis of diabetes, 10 participants who lacked the data on weight or height, and 81 participants who reported implausible daily energy intake (< 500 or > 4000 kcal/day), leaving 5659 participants for the analysis of FVI and hypertension. Additionally, 1870 participants who lacked at least 1 year of measurement for FVI and/or BP were excluded. The sample size for the analysis of change of FVI and hypertension/BP included 3789 participants.

Assessment of fruit and vegetable intake

FVI in CHNS, as a part of the dietary assessment, was collected via three consecutive 24-h recalls. Participants recorded the exact type and weight of food they consumed during three consecutive days, which were randomly allocated in a week [20]. The categories of fruit and vegetable groups were based on a food grouping system developed specifically for the CHNS, including 162 fruit items and 256 vegetable items [21]. The average daily FVI for each year was derived from participant responses.

Ascertainment of incident hypertension

Participants were seated for 10 min prior to BP assessments. Then arterial BP was measured on the right arm using a standard mercury sphygmomanometer three times. The mean of the three BP measurements was used in analyses. Incident hypertension was ascertained from the follow-up survey in 2011 by meeting at least 1 of 4 criteria: (1) a new physician diagnosis of hypertension; (2) antihypertensive treatment; (3) systolic BP ≥ 140 mmHg; (4) diastolic BP ≥ 90 mmHg.

Assessment of covariates

Two waves of surveys collected information about age, gender, residence, measured weight and height, daily energy intake, smoking status, physical activity (PA) and intake of alcohol, sugar-sweetened beverage intake, red meat, and whole grains. Participants' residence was categorized as residing in urban or rural areas. Body mass index (BMI) was computed as weight (in kg) divided by square of height (in m). Average daily energy intake was calculated by summing the energy contained in each food daily consumed. Smoking status was categorized into never, former or current. Alcohol and sugar-sweetened beverage intake were categorized as 6 ordinal frequencies (never, no more than once a month, once or twice a month, once or twice a week, 3–4 times a week, almost every day). PA was measured by multiplying the weekly time spent in each activity by metabolic equivalent (MET) score, an indicator of the average intensity of each PA, which was assigned using previously published guidelines and practices [22, 23]. We adopt the leisure PA domain defined in the SLOTH model [24], containing 13 items of active and sedentary leisure in this study.

Data analyses

To decrease within-person variation, average of FVI in two waves was used [25]. Change of FVI was calculated by subtracting the specific mean of 2011 to the mean of 2006, respectively. FVI and change of FVI were categorized into quintiles.

First, the distribution of hypertension risk factors was compared across quintiles of FVI to identify potential confounding factors. Second, logistic models were used to estimate the relative risk (RR) and 95% confidence interval (CI) of hypertension with FVI and change of FVI across time. In addition, multivariable linear models were used to analyze the BP change per 1-SD additional change of FVI per day.

Models were first adjusted for age, gender, residence, and baseline energy intake; then additionally adjusted for lifestyle factors including smoking status, intake of alcohol, sugar-sweetened beverage, and leisure PA (multivariable model 1); and adjusted for other dietary risk factors for hypertension including the intake of red meat and whole grains (multivariable model 2). Analyses were further stratified by known hypertension risk factors including baseline age (18–44, 45–64 years), gender (male, female), BMI (< 25, ≥ 25 kg/m^2), smoking status (never, former or current), alcohol intake (never, former or current), and baseline systolic/diastolic BP (< 120/80, ≥ 120/80 mmHg). All analyses were performed with SPSS software (version 13.0; SPSS Inc.). All values are two-sided.

Results

Table 1 presents baseline characteristics of the analytical sample. Among 5659 participants who meet the selection criteria, the mean ± SD of FVI was 392.4 ± 186.3 g/day. Participants with higher FVI were more likely to be male, live in urban areas, consume more energy, be a former or current smoker, have more leisure PA, and intake more red meat and whole grains (see Table 1).

A total of 866 participants or 15.3% developed incident hypertension. After adjusting for age, gender, residence, and baseline energy intake, higher levels of FVI were shown to be associated with a decreased risk of hypertension (see Table 2): the RRs and 95% CIs of hypertension were 0.75 (0.57–0.98), 0.66 (0.50–0.87), 0.70 (0.54–0.92), and 0.73 (0.56–0.97) (*P*, trend: 0.035) comparing each quintile of FVI with the lowest quintile. The magnitude of

Table 1 Baseline characteristics of 5659 respondents according to fruit and vegetable intake

Characteristics	Quintiles of fruit and vegetable intake					
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*P* trend[a]
N	1126	1128	1123	1148	1134	
Mean fruit and vegetable intake (g/day)	179.5	286.7	364.4	456.5	671.9	
Age (year)	40.87 ± 12.6	42.60 ± 12.3	43.08 ± 11.2	42.65 ± 11.7	41.71 ± 11.8	0.221
Male (%)	47.0	44.0	50.8	47.7	51.8	0.001
Urban residence (%)	26.8	27.2	30.0	26.9	33.2	0.002
Energy intake (kcal/day)	1967.2 ± 610.7	2121.7 ± 577.7	2226.9 ± 597.6	2305.4 ± 630.3	2377.2 ± 623.8	< 0.001
Body mass index (kg/m^2)	22.9 ± 3.2	22.7 ± 3.1	22.7 ± 3.0	22.9 ± 2.9	22.8 ± 4.7	0.663
Never smoke (%)	72.9	72.4	66.1	69.5	67.7	0.003
No alcohol intake (%)	71.5	71.4	66.7	68.2	68.6	0.077
No sugar-sweetened beverage intake (%)	74.9	76.8	77.4	73.2	71.4	0.175
Leisure physical activity (MET-h/week)	23.9 ± 28.7	20.9 ± 24.2	22.5 ± 22.6	24.0 ± 27.9	27.8 ± 37.3	< 0.001
Red meat (g/day)	73.1 ± 57.8	81.0 ± 57.7	90.7 ± 63.7	93.4 ± 66.5	105.9 ± 84.0	< 0.001
Whole grains (g/day)	387.1 ± 170.7	402.2 ± 164.7	429.7 ± 184.4	442.8 ± 202.6	477.9 ± 237.0	< 0.001
Systolic BP (mmHg)	114.6 ± 11.2	114.3 ± 11.3	114.2 ± 11.1	113.8 ± 11.5	113.9 ± 11.0	0.153
Diastolic BP (mmHg)	75.0 ± 7.4	75.0 ± 7.6	75.2 ± 7.4	74.5 ± 7.9	74.7 ± 7.6	0.217

Values are mean ± SD for continuous variables and % for categorical variables

[a]Linear trends across increasing fruit and vegetable intake were tested using Jonckheere–Terpstra test for continuous variables, Chi-square test for binary categorical variables, and linear by linear association test for ordinal variables

Table 2 Relative risks of hypertension according to fruit and vegetable intake in all respondents and subgroups ($n = 5659$)

	Quintiles of fruit and vegetable intake					
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*P* trend[a]
All respondents						
Range (g/day)	< 243.33	243.33 to < 326.67	326.67 to < 405.00	405.00 to < 520.83	≥ 520.83	
N, cases/total	186/1126	176/1128	163/1123	174/1148	167/1134	
Basic model[b]	1.00 (reference)	0.76 (0.58–0.98)*	0.67 (0.51–0.87)**	0.72 (0.55–0.93)*	0.73 (0.55–0.95)*	0.030
Multivariable model 1[c]	1.00 (reference)	0.75 (0.57–0.98)*	0.66 (0.50–0.87)**	0.70 (0.54–0.92)*	0.73 (0.56–0.97)*	0.035
Multivariable model 2[d]	1.00 (reference)	0.74 (0.55–0.99)*	0.65 (0.48–0.88)**	0.68 (0.50–0.92)*	0.73 (0.53–0.99)*	0.055
Multivariable model 2 + BMI	1.00 (reference)	0.79 (0.58–1.07)	0.72 (0.53–0.99)*	0.71 (0.52–0.97)*	0.78 (0.57–1.08)	0.119
Baseline age						
18 to < 45 years						
N, cases/total	62/671	48/630	60/645	56/650	49/680	
Multivariable model 2[d]	1.00 (reference)	0.69 (0.41–1.18)	0.56 (0.32–0.95)*	0.56 (0.33–0.97)*	0.54 (0.31–0.95)*	0.033
45 to < 65 years						
N, cases/total	124/455	128/498	103/478	118/498	118/454	
Multivariable model 2[d]	1.00 (reference)	0.77 (0.54–1.11)	0.70 (0.48–1.01)	0.71 (0.49–1.03)	0.83 (0.56–1.22)	0.312
Gender						
Male						
N, cases/total	94/529	74/496	94/571	104/548	96/587	
Multivariable model 2[d]	1.00 (reference)	0.54 (0.34–0.86)**	0.66 (0.43–1.02)	0.82 (0.53–1.27)	0.81 (0.52–1.26)	0.905
Female						
N, cases/total	92/597	102/632	69/552	70/600	71/547	
Multivariable model 2[d]	1.00 (reference)	0.95 (0.64–1.42)	0.64 (0.41–0.98)*	0.55 (0.35–0.86)**	0.73 (0.47–1.15)	0.018
Body mass index						
< 25 kg/m^2						
N, cases/total	86/804	96/851	113/864	115/885	89/843	
Multivariable model 2[d]	1.00 (reference)	0.77 (0.51–1.16)	0.89 (0.60–1.32)	0.90 (0.60–1.34)	0.80 (0.52–1.23)	0.612
≥ 25 kg/m^2						
N, cases/total	100/322	80/277	50/259	59/263	78/291	
Multivariable model 2[d]	1.00 (reference)	0.79 (0.49–1.27)	0.47 (0.28–0.80)**	0.52 (0.31–0.87)*	0.72 (0.43–1.20)	0.073
Baseline smoking status						
Never						
N, cases/total	99/689	111/735	88/672	93/720	93/663	
Multivariable model 2[d]	1.00 (reference)	0.87 (0.60–1.26)	0.72 (0.49–1.05)	0.70 (0.48–1.04)	0.85 (0.57–1.27)	0.246
Former or current						
N, cases/total	61/256	45/280	60/344	65/316	49/317	
Multivariable model 2[d]	1.00 (reference)	0.53 (0.31–0.90)*	0.57 (0.34–0.94)*	0.62 (0.37–1.04)	0.58 (0.34–0.98)*	0.148
Baseline alcohol intake						
Never						
N, cases/total	99/670	110/720	93/669	92/700	100/662	
Multivariable model 2[d]	1.00 (reference)	0.88 (0.61–1.28)	0.78 (0.53–1.15)	0.67 (0.46–0.99)*	0.94 (0.64–1.39)	0.404
Former or current						
N, cases/total	61/275	46/295	55/348	66/337	42/317	
Multivariable model 2[d]	1.00 (reference)	0.52 (0.31–0.89)*	0.49 (0.29–0.81)**	0.65 (0.39–1.08)	0.48 (0.28–0.82)**	0.054
Baseline systolic/diastolic BP						
< 120/80 mmHg						
N, cases/total	39/445	38/479	37/469	42/517	44/476	
Multivariable model 2[d]	1.00 (reference)	0.73 (0.41–1.33)	0.91 (0.52–1.62)	0.74 (0.41–1.32)	0.97 (0.54–1.75)	0.986
≥ 120/80 mmHg						
N, cases/total	111/461	102/492	99/501	109/480	93/480	

Table 2 (continued)

	Quintiles of fruit and vegetable intake					
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*P* trend[a]
Multivariable model 2[d]	1.00 (reference)	0.73 (0.50–1.06)	0.60 (0.41–0.88)**	0.74 (0.51–1.09)	0.72 (0.48–1.06)	0.166

*$P<0.05$, **$P<0.01$, ***$P<0.001$

[a]Linear trend was tested using the continuous variable of fruit and vegetable intake

[b]Basic model adjusted for age (continuous), gender (male, female), residence (urban, rural), baseline energy intake (continuous)

[c]Multivariable model 1 additionally adjusted for smoking status (never, former or current), alcohol intake (6 ordinal frequencies from 1: never to 6: almost every day), sugar-sweetened beverage intake (6 ordinal frequencies from 1: never to 6: almost every day), leisure physical activity (continuous)

[d]Multivariable model 2 adjusted for all covariates in multivariable model 1 plus intake of red meat (continuous) and whole grains (continuous)

association appeared stronger after additional adjustment for lifestyle factors: the RRs and 95% CIs of hypertension were 0.74 (0.55–0.99), 0.65 (0.48–0.88), 0.68 (0.50–0.92), and 0.73 (0.53–0.99) (*P*, trend: 0.055) comparing each quintile group of FVI with the lowest quintile group. This association was slightly attenuated after adjustment for other dietary risk factors and further attenuated after adjustment for BMI. When we stratified analyses by participant characteristics, the magnitude of association was stronger among those who were former or current alcohol smokers and who had prehypertension (≥ 120/80 mmHg) at baseline. There was a significant inverse association between FVI and the risk of hypertension among those who were youths (18 to < 45 years) (*P*, trend: 0.033), female (*P*, trend: 0.018), overweight (≥ 25 kg/m^2) (*P*, trend: 0.073), and former or current alcohol drinkers (*P*, trend: 0.054).

For the change of FVI, the magnitude of association with hypertension attenuated but remained significant (see Table 3). In the multivariable model 2, increasing FVI by 65.00 to < 215.00 g/day in 5 years was associated with a lower risk of hypertension with an RR of 0.65 (0.47–0.89), and this association remained significant after additionally adjusting BMI. Likewise, when we stratified analyses by participant characteristics, the magnitude of association was stronger among those who were youths, female, who never smoked, who never consumed alcohol, and those who had prehypertension.

Continuous variables of change of FVI were used in multiple linear regression models, respectively (see Table 4). In the fully adjusted models, each SD increment in FVI was associated with a 0.323 (0.001–0.646) mmHg decrease in systolic BP and a 0.353 (0.134–0.572) mmHg decrease in diastolic BP measurement. Each SD increment in fruit intake was associated with a 0.273 (0.058–0.487) mmHg decrease in diastolic BP, with no systolic BP marginally significant. Each SD increment in vegetable intake was associated with a 0.276 (0.038–0.514) mmHg decrease in diastolic BP, with no significant difference with systolic BP. The magnitude of association was stronger for total fruits than for total vegetables and stronger for diastolic BP than for systolic BP.

Discussion

In this national cohort of Chinese adults, long-term higher FVI, as well as a longitudinal increase in FVI, was independently associated with a decreased risk of developing hypertension. The magnitude of association was stronger among certain populations, including those who were younger, female, overweight, and who had prehypertension. When examined separately, fruit intake was more significantly associated with lower BP than vegetable intake. All associations attenuated after adding BMI into the model. To our knowledge, our study is the first to prospectively analyze the association between FVI and subsequent risk of hypertension in China.

Our results strengthen evidence of the long-term benefit of FVI in the prevention of hypertension among Chinese adults and are consistent with previous studies in Western countries [8–11, 25, 26], but the magnitude of association was stronger in the present study. In particular, a recent meta-analysis, which clustered nine cohorts with 185,676 participants from six Western countries found similar results as those presented in the current study. The highest FVI was shown to be inversely associated with the risk of incident hypertension as compared with the lowest intake, and the pooled RR and 95% CI was 0.90 (0.84–0.98) [11].

There are likely multiple reasons for the reverse association between FVI and the risk of hypertension. For example, clinical and biological studies [27] have reported certain micro- and macro-nutrients, which are rich in fruits and vegetables, were effective in lowering BP, including potassium [28], magnesium [29], vitamin C [30], folic acid [31], flavonoids [32], and carotenoids. The mechanisms were postulated as lowering BP through improving endothelial function, modulating baroreflex sensitivity, causing vasodilation, and increasing antioxidant activity [10]. The attenuation of

Table 3 Relative risks of hypertension according to change of fruit and vegetable intake in all respondents and subgroups ($n = 3789$)

	Quintiles of change of fruit and vegetable intake					
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*P* trend[a]
All respondents						
Range (g/day)	<−209.33	−209.33 to <−53.67	−53.67 to < 65.00	65.00 to < 215.00	≥215.00	
N, cases/total	167/757	133/758	140/754	125/760	123/760	
Basic model[b]	1.00 (reference)	0.71 (0.55–0.93)*	0.78 (0.60–1.01)	0.67 (0.51–0.88)**	0.72 (0.55–0.94)*	0.016
Multivariable model 1[c]	1.00 (reference)	0.70 (0.53–0.92)*	0.75 (0.57–0.99)*	0.59 (0.45–0.79)**	0.65 (0.49–0.87)**	0.001
Multivariable model 2[d]	1.00 (reference)	0.74 (0.54–1.00)	0.76 (0.56–1.04)	0.65 (0.47–0.89)**	0.76 (0.55–1.05)	0.051
Multivariable model 2 + BMI	1.00 (reference)	0.80 (0.59–1.10)	0.77 (0.56–1.05)	0.69 (0.50–0.95)*	0.79 (0.57–1.11)	0.083
Baseline age						
18 to <45 years						
N, cases/total	46/345	33/347	39/366	42/394	35/413	
Multivariable model 2[d]	1.00 (reference)	0.61 (0.35–1.07)	0.49 (0.27–0.88)*	0.54 (0.31–0.94)*	0.43 (0.23–0.78)**	0.006
45 to <65 years						
N, cases/total	121/412	100/411	101/388	83/366	88/347	
Multivariable model 2[d]	1.00 (reference)	0.80 (0.55–1.16)	0.93 (0.64–1.35)	0.72 (0.49–1.06)	1.04 (0.70–1.55)	0.846
Gender						
Male						
N, cases/total	83/336	64/335	69/327	69/332	58/327	
Multivariable model 2[d]	1.00 (reference)	0.73 (0.47–1.15)	0.74 (0.47–1.17)	0.80 (0.52–1.25)	0.85 (0.53–1.35)	0.578
Female						
N, cases/total	84/421	69/423	71/427	56/428	65/433	
Multivariable model 2[d]	1.00 (reference)	0.69 (0.44–1.06)	0.74 (0.48–1.14)	0.48 (0.30–0.77)**	0.64 (0.40–1.02)	0.017
Body mass index						
<25 kg/m^2						
N, cases/total	88/525	79/588	92/545	72/568	69 / 571	
Multivariable model 2[d]	1.00 (reference)	0.71 (0.47–1.06)	0.96 (0.64–1.43)	0.64 (0.42–0.97)*	0.75 (0.49–1.15)	0.156
≥25 kg/m^2						
N, cases/total	79/232	54/170	48/209	53/192	54/189	
Multivariable model 2[d]	1.00 (reference)	0.99 (0.59–1.66)	0.54 (0.32–0.92)*	0.76 (0.45–1.27)	0.95 (0.56–1.63)	0.431
Baseline smoking status						
Never						
N, cases/total	107/507	87/536	90/526	77/545	80/545	
Multivariable model 2[d]	1.00 (reference)	0.58 (0.39–0.86)**	0.70 (0.48–1.03)	0.50 (0.33–0.74)***	0.62 (0.41–0.94)*	0.014
Former or current						
N, cases/total	60/249	46/222	50/228	48/215	43/215	
Multivariable model 2[d]	1.00 (reference)	1.06 (0.64–1.77)	0.90 (0.52–1.55)	1.00 (0.58–1.71)	1.07 (0.61–1.88)	0.917
Baseline alcohol intake						
Never						
N, cases/total	108/499	89/522	89/512	74/522	86/526	
Multivariable model 2[d]	1.00 (reference)	0.69 (0.47–1.00)	0.77 (0.53–1.14)	0.52 (0.35–0.79)**	0.80 (0.54–1.20)	0.114
Former or current						
N, cases/total	59/258	44/235	51/242	51/238	37/234	
Multivariable model 2[d]	1.00 (reference)	0.81 (0.47–1.38)	0.78 (0.46–1.33)	0.91 (0.54–1.52)	0.67 (0.38–1.18)	0.289
Baseline systolic/diastolic BP						
<120/80 mmHg						
N, cases/total	48/352	40/378	35/377	38/359	30/362	
Multivariable model 2[d]	1.00 (reference)	0.71 (0.41–1.22)	0.73 (0.41–1.27)	0.92 (0.54–1.57)	0.60 (0.32–1.12)	0.324
≥120/80 mmHg						
N, cases/total	119/405	93/380	105/377	87/401	93/398	

Table 3 (continued)

	Quintiles of change of fruit and vegetable intake					
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*P* trend[a]
Multivariable model 2[d]	1.00 (reference)	0.76 (0.52–1.11)	0.80 (0.55–1.17)	0.53 (0.35–0.79)**	0.85 (0.58–1.26)	0.116

$^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$

[a]Linear trend was tested using the continuous variable of fruit and vegetable intake

[b]Basic model adjusted for age (continuous), gender (male, female), residence (urban, rural), baseline energy intake (continuous)

[c]Multivariable model 1 additionally adjusted for smoking status (never, former or current), alcohol intake (6 ordinal frequencies from 1: never to 6: almost every day), sugar-sweetened beverage intake (6 ordinal frequencies from 1: never to 6: almost every day), leisure physical activity (continuous)

[d]Multivariable model 2 adjusted for all covariates in multivariable model 1 plus intake of red meat (continuous) and whole grains (continuous)

Table 4 Linear relation between change of fruit and vegetable intake (1 SD) and change of blood pressure (mmHg) ($n=3789$)

	Change of systolic blood pressure		Change of diastolic blood pressure	
	β (95% CI)	*P*	β (95% CI)	*P*
Change of total fruits and vegetables (1 SD)				
Basic model[a]	−0.397 (−0.674, −0.120)	0.005	−0.387 (−0.575, −0.198)	<0.001
Multivariable model 1[b]	−0.463 (−0.753, −0.172)	0.002	−0.443 (−0.640, −0.245)	<0.001
Multivariable model 2[c]	−0.351 (−0.674, −0.028)	0.033	−0.380 (−0.600, −0.160)	0.001
Multivariable model 2+BMI	−0.323 (−0.646, −0.001)	0.049	−0.353 (−0.572, −0.134)	0.002
Change of total fruits (1 SD)				
Basic model[a]	−0.322 (−0.607, −0.038)	0.027	−0.319 (−0.513, −0.125)	0.001
Multivariable model 1[b]	−0.359 (−0.654, −0.063)	0.017	−0.332 (−0.533, −0.132)	0.001
Multivariable model 2[c]	−0.295 (−0.609, 0.018)	0.065	−0.303 (−0.518, −0.088)	0.006
Multivariable model 2+BMI	−0.264 (−0.578, 0.049)	0.098	−0.273 (−0.487, −0.058)	0.013
Change of total vegetables (1 SD)				
Basic model[a]	−0.301 (−0.590, −0.011)	0.042	−0.289 (−0.485, −0.092)	0.004
Multivariable model 1[b]	−0.373 (−0.683, −0.063)	0.019	−0.368 (−0.578, −0.157)	0.001
Multivariable model 2[c]	−0.248 (−0.599, 0.104)	0.167	−0.287 (−0.526, −0.047)	0.019
Multivariable model 2+BMI	−0.237 (−0.587, 0.114)	0.185	−0.276 (−0.514, −0.038)	0.023

Values for 1 SD were 179.1 g/day for fruits and vegetables, 114.9 g/day for fruits and 130.5 g/day for vegetables

[a]Basic model adjusted for age (continuous), gender (male, female), residence (urban, rural), baseline energy intake (continuous)

[b]Multivariable model 1 additionally adjusted for smoking status (never, former or current), alcohol intake (6 ordinal frequencies from 1: never to 6: almost every day), sugar-sweetened beverage intake (6 ordinal frequencies from 1: never to 6: almost every day), leisure physical activity (continuous)

[c]Multivariable model 2 adjusted for all covariates in multivariable model 1 plus intake of red meat (continuous) and whole grains (continuous)

the associations after adjusting for red meat, whole grains and BMI confirmed dietary risk factors and supported the concept that maintaining normal body weight could be one important pathway through which FVI may contribute to BP regulation [27].

In the present study, an inverse association with hypertension risk appeared to be stronger for the change of intake of fruits than for vegetables. A linear tendency towards decreased systolic BP with increased vegetable intake was not significant. The similar weaker associations with vegetable intake were commonly noted in previous studies. In the Health Professionals Follow-up Study (HPFS) [25], the Coronary Artery Risk Development in Young Adults (CARDIA) Study [33] and the OHASAMA study [34], the hypertensive HRs (95% CI) were 0.93 (0.78–1.12), 0.94 (0.75–1.18), and 0.75 (0.40–1.39) for vegetable intake, while 0.88 (0.80–0.97), 0.75 (0.60–0.94), and 0.40 (0.21–0.75) for fruit intake, comparing the highest with the lowest intake, respectively. According to previous studies analyzing individual fruit and vegetables [13, 25], certain vegetables (i.e., broccoli, carrots, tofu) were associated with a lower risk of hypertension, whereas some vegetables (i.e., string beans, Brussels sprouts) were associated with an increased risk of hypertension. A possible explanation for the difference is the cooking methods of vegetables and different nutritional compositions of fruits and vegetables possibly leading to the deviation of effect.

Interestingly, there were clear differences among certain characteristics for the relationship between FVI and the risk of hypertension in this study. The stronger magnitude of association for women may result from the complex influence of genetic differences, hormonal differences, health behaviors, and responses to social and environmental factors [35].

Strengths and limitations

Our study has several strengths, including the prospective study design, standardized approach in BP measurement, and the comprehensive assessment of covariates. However, there are several limitations in our study. First, dietary intake was self-reported and therefore subject to differential misclassification, and was limited by the accuracy of recalls. Second, despite comprehensive adjustment for multiple demographic, lifestyle and dietary factors, residual confounding by unmeasured or imprecisely measured hypertension risk factors may persist. Finally, participants resided in China which may limit the generalizability of the findings. As such, this study should be replicated in other populations outside of China.

Conclusions

The findings of the current study suggest that FVI may reduce the risk of hypertension among Chinese adults. Furthermore, dietary FVI recommendations (e.g., provided by public health awareness campaigns, physicians in clinical settings) for hypertension should consider age, gender, and BMI-specific differences and prehypertension status.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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