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U-shaped association between dietary calcium density intake during adolescence and hypertension in adulthood: a 20-year longitudinal nationwide study in China

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Abstract

We assessed longitudinal association between calcium intake during adolescence and hypertension in adulthood. Longitudinal study data of 1611 participants from the China Health and Nutrition Survey during 1991–2011 were used. On average they were followed for 11·4 years. Dietary calcium intake during adolescence was assessed based on three 24-hour dietary recalls collected in each visit/survey between 1991 and 2009 (seven waves). The intake was recoded into quartiles. Cumulative mean±SD calcium intake was 199·9±144·8 mg/1000 kcal/day during adolescence. In total 102 participants had hypertension in adulthood (97 men and 5 women). There was a clear U-shaped association between adolescence calcium intake quartiles and adulthood hypertension: across the quartiles, hypertension prevalence was 6·7%, 4·0%, 5·2% and 9·5%, respectively. After adjustment for potential confounders including weight status and dietary pattern, odds ratios (OR, 95% CI) for hypertension were 2·32 (95% CI 1·07–5·00) for lowest quartile, 1·00 (reference), 1·34 (95% CI 0·61–2·97), and 3·10 (95% CI 1·49–6·46) across the quartiles. Lower or higher calcium intake during adolescence was associated with hypertension in adulthood independent of weight status and dietary pattern.

Key words: Calcium intake: Blood pressure: Chinese: Adolescence: Adults

With rapid social and economic developments during the past three decades, China is facing a growing threat from non-communicable chronic diseases (NCD), while hypertension significantly increases the risk of NCD in China and many countries[1]. Hypertension is known to be a leading contributor to CVD and continues to be a major concern despite recent developments in treatment and prevention[2]. Hypertension prevalence in Chinese adults increased substantially from 14·4 % in 1991 to 18·8 % in 2002 and 25·2 % in 2012, while the prevalence of obesity and overweight has increased rapidly as well[3–5]. During this period, there are many shifts in people's dietary intakes in China.

Dietary habits were associated with hypertension risk[6]. Of the dietary habits, Ca intake has drawn a lot attention. Ca intake is known to regulate blood pressure (BP) by modifying Ca influx in vascular smooth muscle cells[7]. Two previous meta-analyses reported significant negative correlations between Ca intake and BP levels[8,9]. However, most of the existing studies were cross-sectional studies or had focused on single time points in childhood or adulthood.

Abbreviations: BP, blood pressure; CHNS, China Health and Nutrition Survey; DBP, diastolic blood pressure; NCD, non-communicable chronic diseases; SBP, systolic blood pressure.

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Dietary patterns in China have significantly changed in the past three decades, and efforts were made to increase people's dairy consumption aiming to increase Ca intake[10]. However, overall dietary Ca intake in China is still very low and is less than half of the 2013 Chinese Dietary Reference Intakes in both adolescents and adults[11–13]. At least, this is partially due to low dairy consumption, especially in rural areas in China, which have low access to and low acceptance to consume dairy products. However, it is unknown how dietary Ca intake during adolescence may affect hypertension in adulthood.

Evidence is accumulating for a role of early-life exposures in chronic disease aetiology[14], including childhood and adolescence diet, which may make a significant contribution to primary disease prevention. Previous studies have indicated that low birth weight or overweight/obese, which may represent nutrition status during childhood and adolescence, has been associated with higher risk of hypertension[14–16]. The present study aimed to assess the longitudinal association between Ca intake during adolescence and hypertension during adulthood. We used the data collected over a 20-year period from the China Health and Nutrition Survey (CHNS).

Methods and materials

Study design and study sample

This was a longitudinal study based on repeated measurements of dietary intake and hypertension over 20 years from the CHNS. The CHNS is an ongoing, open, prospective, household-based cohort study conducted in nine provinces in China[17]. The CHNS uses a multistage random-cluster sampling process to select samples in both urban and rural areas. Ten waves of data collection (i.e. 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011 and 2015) have been conducted. As the 1989 survey did not collect dietary information among adolescents and the 2015 survey data are not released, we used data from surveys between 1991 and 2011.

Between 1991 and 2009, there were 7295 adolescents aged 12–18 years in the study. Of them, 5359 had information on Ca intake. In total, 1611 adults (1016 men and 595 women) with needed complete information were included in our longitudinal data analysis. They had 24-h dietary recall during adolescence (aged 12–18 years) between 1991 and 2009 and BP measures during adults (age ≥ 20 years) between 1993 and 2011.

The surveys were approved by the institutional review committees of the University of North Carolina and the National Institute of Nutrition and Food Safety (China). Informed consent was obtained from all participants.

Outcome variable: hypertension

Systolic and diastolic blood pressures (SBP and DBP) were measured on the right arm in triplicate at each survey by experience physicians using sphygmomanometers (measuring range: 0–300 mmHg) in the sitting position after 5 min of rest according to standardised protocol[18]. Three measurements were obtained with a 30-s interval between cuff inflation. Otherwise, participants were asked to take a 10–30 min rest before the next measurement was taken. The average of the three BP measurements at each wave was used in the analysis.

Hypertension was defined if a subject had one of the following SBP ≥ 140 mmHg, DBP ≥ 90 mmHg, self-reported hypertension or current use of antihypertensive medications[19]. Participants who completed ≥ 1 BP test during adulthood were included in the analysis.

Exposure variables: cumulative mean calcium intake

At each wave, individual dietary intake was assessed by trained investigators conducting a 24-h dietary recall for three consecutive days. In addition, foods and condiments in the home inventory, foods purchased from markets or harvested from gardens were weighed and recorded by interviewers at the beginning and end of the 3-d survey period. A detailed description of dietary measurements has been published previously[20]. Food consumption data were converted to nutrient intakes using the Chinese food composition table[21]. The dietary assessment method has been validated[22].

We calculated a cumulative average intake of Ca per 1000 kcal (mg/1000 kcal/d) for each individual at each wave during adolescence to reduce variation within individuals and to represent long-term habitual intake[23]. For example, if a participant attended the survey in 1991, 1993 and 1997 at the age of 12, 14 and 18 years with an intake of x, y and z, the cumulative mean intake was calculated as $(x + y + z)/3$. In total, 853, 748 and 10 participants had one, two and three dietary measures during adolescence (12–18 years old), respectively.

Covariates

Sociodemographics and lifestyle factors were collected in each wave using a structured questionnaire. Some of them were adjusted for in our models. The following constructed variables were included to reflect socio-economic status: education (low: illiterate/primary school; medium: junior middle school and high: high middle school or higher), per capita annual family income (recoded into tertiles as low, medium and high) and urbanisation levels (recoded into tertiles as low, medium and high)[20].

In addition, the following factors were considered as potential confounders in our analysis. Smoking status was categorised into non-smokers, ex-smokers and current smokers. Alcohol drinking was categorised as yes or no. Physical activity level (metabolic equivalents of task) was estimated on the basis of self-reported activities (including occupational, domestic, transportation and leisure-time physical activity) and duration using a Compendium of Physical Activities[24].

BMI was calculated as weight (kg) divided by height square (m^2). According to Guidelines for the Prevention and Control of Overweight and Obesity in Chinese Adults, overweight/obesity was defined as ≥ 24·0 kg/m^2[25].

Statistical analysis

Cumulative average Ca intake during adolescence was recoded into quartiles (Q1, 93·4 (SD 16·9) mg/1000 kcal/d; Q2, 132·8 (SD 10·0) mg/1000 kcal/d; Q3, 182·3 (SD 20·9) mg/1000 kcal/d; Q4, 391·8 (SD 173·6) mg/1000 kcal/d). The

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χ^2 test was used to compare differences between groups for categorical variables, and ANOVA was used for continuous variables.

Mixed effects logistic model using melogit command in Stata was used to assess the association between Ca intake and hypertension. A set of models were used: model 1 adjusted for age and sex; model 2 further adjusted for energy intake, education, income, urbanisation, smoking, alcohol drinking, physical activity, overweight/obesity; and model 3 further adjusted for dietary patterns derived by factor analysis[26]. All the variables treated as time-varying covariates except sex and Ca intake. To assess the non-linear association between Ca intake and hypertension, we used restricted cubic spline method with four knots (at 5, 35, 65 and 95 percentile) in a fully adjusted mixed effect logistic regression. The results were visually presented. In sensitivity analysis, we adjusted for intake of fat, Na, fruit and vegetable instead of overall dietary patterns.

To test the multiplicative interaction between Ca intake with weight status, education, income and urbanisation, the interaction terms among them were added in the multivariable mixed effects logistics model.

To assess the association between Ca intake and BP during adulthood at the last survey, simultaneous-quantile regression using 'sqreg' command in Stata was used with the focus on the 0·7, 0·8 and 0·9 quantiles of SBP and DBP. We did not conduct sex-specific quantile regression, as there was no significant sex and Ca intake interaction.

All analyses were performed using STATA 16.1 (StataCorp). Significance was considered when $P < 0·05$ (two-sided).

Results

Descriptive results

The mean age was 23·0 (SD 2·8) years at the first survey in adulthood. The cumulative mean Ca intake was 199·9 (SD 144·8) mg/1000 kcal/d or 452·9 (SD 322·3) mg/d during adolescence and 391·8 (SD 173·6) mg/1000 kcal/d or 853·3 (SD 393·5) mg/d in the high quartile (Q4). Figure 1 shows the distribution of Ca intake. Ca intake level was low in the study population. The majority of the sample had a Ca intake during adolescence below 1000 mg/d, recommended by the 2013 Chinese Dietary Reference Intakes for young adolescence (14–17 years old); only 7·3 % (8·2 % in men and 5·7 % in women) had Ca intake ≥ 1000 mg/d.

Table 1 shows sample characteristics at the first survey in adulthood in all and according to quartiles of cumulative Ca intake during adolescence (Q1–4). Across Q1–4, the intakes of fat and fruit increased from 69·0 (SD 38·7) to 71·7 (SD 39·1) g/d and 33·2 (SD 102·2) to 41·1 (SD 114·5) g/d, while carbohydrate intake decreased from 347·7 (SD 116·3) to 327·9 (SD 113·8) g/d.

In total, 102 adults had hypertension in adulthood (ninety-seven men and five women). The prevalence of hypertension in adulthood during follow-up varied by Q1–4 with the lowest risk in Q2 and then increased from 4·0 % to 9·5 % in Q4 (Fig. 2). Mean BP at the last survey between 1993 and 2011 by Q1–4 were 74·2 mmHg, 74·4 mmHg, 74·6 mmHg and 75·0 mmHg for DBP, and 112·2 mmHg, 113·5 mmHg, 113·7 mmHg and 113·7 mmHg for SBP.

Association between calcium intake and hypertension

Mixed effects models revealed a U-shaped association between Ca intake and hypertension, using Q2 as a reference (lowest incidence of hypertension) (Table 2). After adjustment for potential confounders including weight status and dietary patterns, individuals who had lower and higher adolescent Ca intake had increased risks of hypertension (Q1, OR = 2·22, 95 % CI 1·01, 4·88; Q4, OR = 2·96, 95 % CI 1·40, 6·26) and high DBP (Q1, OR = 3·08, 95 % CI 1·13, 8·37; Q4, OR = 4·50, 95 % CI 1·75, 11·58). In sensitivity analysis, adjusting for intake of fat, Na, fruit and vegetable instead of overall dietary patterns, the above

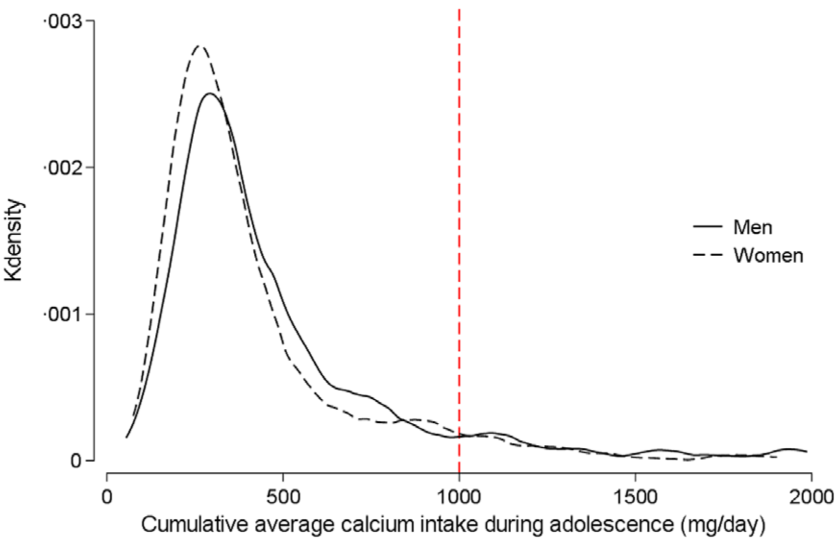

Fig. 1. Distribution of cumulative mean calcium intake during adolescence in nationwide study in China: The 1991–2011 China Health Nutrition Survey data (n = 1611)[a]. [a]The red dotted line represents the recommended daily calcium intake for young adolescence (14–17 years old) issued by the Chinese Nutrition Society.

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Table 1. Study sample characteristics at first survey during adulthood by quartiles of cumulative calcium intake during adolescence in nationwide study in China: The 1991-2011 China Health Nutrition Survey data ($n = 1611$)

	Quartiles					
	Total	Q1	Q2	Q3	Q4	*P*-value test trend
	$n = 1611$	$n = 403$	$n = 403$	$n = 403$	$n = 402$	
Age (years)	23·0 (2·8)	23·3 (3·1)	22·7 (2·5)	23·0 (2·8)	23·1 (2·8)	0·010
Sex (n, %)						0·670
Men	1,016 (63·1%)	258 (64·0%)	248 (61·5%)	262 (65·0%)	248 (61·7%)	
Women	595 (36·9%)	145 (36·0%)	155 (38·5%)	141 (35·0%)	154 (38·3%)	
Socioeconomic status						
Education (n, %)						<0·001
Low	141 (8·9%)	31 (7·9%)	58 (14·5%)	33 (8·3%)	19 (4·8%)	
Medium	756 (47·6%)	229 (58·1%)	174 (43·5%)	173 (43·5%)	180 (45·5%)	
High	691 (43·5%)	134 (34·0%)	168 (42·0%)	192 (48·2%)	197 (49·7%)	
Income (n, %)						0·005
Low	465 (29·1%)	126 (31·4%)	131 (32·9%)	97 (24·2%)	111 (27·9%)	
Medium	551 (34·5%)	147 (36·7%)	143 (35·9%)	136 (33·9%)	125 (31·4%)	
High	582 (36·4%)	128 (31·9%)	124 (31·2%)	168 (41·9%)	162 (40·7%)	
Urbanization (n, %)						<0·001
Low	379 (23·6%)	113 (28·2%)	115 (28·5%)	77 (19·2%)	74 (18·4%)	
Medium	590 (36·7%)	157 (39·2%)	149 (37·0%)	147 (36·6%)	137 (34·1%)	
High	639 (39·7%)	131 (32·7%)	139 (34·5%)	178 (44·3%)	191 (47·5%)	
Lifestyle behaviors						
Smoking (n, %)						0·150
Non smoker	1,101 (68·7%)	254 (63·0%)	277 (69·6%)	284 (70·8%)	286 (71·5%)	
Ex-smokers	21 (1·3%)	7 (1·7%)	5 (1·3%)	6 (1·5%)	3 (0·8%)	
Current smokers	480 (30·0%)	142 (35·2%)	116 (29·1%)	111 (27·7%)	111 (27·8%)	
Alcohol drinking (Yes, n, %)	532 (33·8%)	139 (35·1%)	126 (32·7%)	146 (36·8%)	121 (30·7%)	0·290
Physical activity (MET)	137·1 (110·8)	136·7 (110·9)	149·4 (120·7)	133·2 (105·9)	129·2 (104·7)	0·077
BMI (kg/m^2)	21·2 (2·9)	21·2 (3·0)	21·4 (2·8)	21·2 (2·9)	21·2 (2·9)	0·860
Overweight/obesity (BMI> = 24; n, %)	245 (15·4%)	60 (14·9%)	59 (14·8%)	66 (16·7%)	60 (15·1%)	0·870
Dietary intakes						
Energy intake (kcal/d)	2270·1 (679·4)	2292·6 (660·0)	2254·6 (696·8)	2290·9 (691·8)	2243·2 (669·2)	0·660
Fat intake (g/d)	69·5 (38·3)	69·0 (38·7)	64·1 (37·0)	73·4 (37·9)	71·7 (39·1)	0·005
Protein intake (g/d)	69·9 (23·5)	69·5 (22·5)	68·8 (23·0)	71·4 (24·3)	70·0 (24·2)	0·450
Carbohydrate intake (g/d)	339·8 (120·0)	347·7 (116·3)	348·8 (128·9)	334·6 (119·3)	327·9 (113·8)	0·039
Intake of fruit (g/d)	41·8 (114·3)	33·2 (102·2)	37·2 (115·3)	56·0 (123·3)	41·1 (114·5)	0·034
Intake of fresh vegetable (g/d)	284·7 (162·4)	282·0 (172·1)	294·0 (167·8)	281·9 (154·1)	280·8 (155·1)	0·630
Calcium intake						
Most recent calcium intake (mg/d)	369·0 (216·6)	343·2 (221·8)	360·8 (209·1)	387·4 (200·4)	385·0 (231·4)	0·013
Cumulative adolescent calcium intake (mg/d)	452·9 (322·3)	227·3 (74·8)	307·4 (84·3)	424·8 (124·9)	853·3 (393·5)	<0·001
Cumulative adolescent calcium intake (mg/1000 kcal/d)	199·9 (144·8)	93·4 (16·9)	132·8 (10·0)	182·3 (20·9)	391·8 (173·6)	<0·001
Adulthood hypertension						
Hypertension in adulthood during follow-up (n, %)	102 (6·3%)	27 (6·7%)	16 (4·0%)	21 (5·2%)	38 (9·5%)	0·010

Data are presented as mean (SD) for continuous measures, and n (%) for categorical measures. The dietary intakes were estimated based a 24-h dietary recall on each of 3 consecutive days collected between 1991 and 2009, which cover week days and weekend. Cumulative mean calcium intake (mg/1000 kcal/day) during adolescence was recoded into quartiles. Cumulative mean calcium intake was recoded into quartiles (Q1, 93·4 ±16·9 mg/1000kcal/day; Q2, 132·8 ±10·0 mg/1000kcal/day; Q3, 182·3 ± 20·9 mg/1000kcal/day; Q4, 391·8 ±173·6 mg/1000kcal/day).

association did not change (data not shown). Figure 3 shows the non-linear association between Ca intake and hypertension.

Table 3 shows the results of quantile regression between Q1–4 and adulthood BP at the last survey between 1993 and 2011. There was a positive association between Q1–4 and SBP during adulthood at quantiles of 0·7, 0·8 and 0·9. Across Q1–4, the regression coefficients for SBP at 0·9 quantile were 0·00, 0·57, 2·35 and 2·81 (95 % CI 0·00, 5·61) ($P_{trend} = 0·023$), respectively. There was a borderline significant trend of positive association between Ca intake and DBP at 0·7 quantile ($P_{trend} = 0·056$).

No interaction was observed among adolescent Ca intake and weight status, education, income and urbanisation on the risk of hypertension (data not shown).

Discussion

This 20-year longitudinal study in China identified a U-shaped association between cumulative Ca intake during adolescence and hypertension in adulthood. To our knowledge, this is the first such longitudinal study that reported such an association in a population with low level of Ca intake in Asia.

Accumulating evidence from others' research also indicated that lower Ca intake was associated with elevated BP and hypertension risk in adults or adolescents[8,9]. The US National Health and Nutrition Examination data found that lower intake of Ca was associated with higher mean SBP and hypertension prevalence in American adults[27], which was consistent with

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Table 2. Associations (OR (95 % CI)) between hypertension adulthood and quartiles of cumulative calcium intake during adolescence in nationwide study in China: The 1991–2011 China Health Nutrition Survey data (*n* = 1611)

	Q1		Q2 (reference group)		Q3		Q4		
	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	*P* for quadratic term
1. Hypertension*									
n		27		16		21		38	
%		6·7		4·0		5·2		9·5	
Model 1	1·67	0·84, 3·34	1·00		1·07	0·52, 2·23	2·11	1·08, 4·11	0·011
Model 2	2·22	1·01, 4·88	1·00		1·54	0·70, 3·42	2·96	1·40, 6·26	0·006
Model 3	2·32	1·07, 5·00	1·00		1·34	0·61, 2·97	3·10	1·49, 6·46	0·001
2. High diastolic blood pressure									
n		22		10		17		30	
%		5·5		2·5		4·2		7·5	
Model 1	2·02	0·92, 4·44	1·00		1·35	0·59, 3·08	2·54	1·20, 5·41	0·011
Model 2	3·08	1·13, 8·37	1·00		2·45	0·91, 6·56	4·50	1·75, 11·58	0·010
Model 3	3·33	1·23, 9·07	1·00		2·31	0·85, 6·28	5·05	1·96, 13·03	0·003
3. High systolic blood pressure									
n		10		9		9		13	
%		2·5		2·2		2·2		3·2	
Model 1	0·91	0·33, 2·54	1·00		0·83	0·30, 2·33	1·12	0·42, 2·94	0·760
Model 2	0·98	0·31, 3·10	1·00		0·97	0·32, 2·98	1·21	0·41, 3·53	0·792
Model 3	0·96	0·33, 2·80	1·00		0·61	0·20, 1·87	1·06	0·38, 2·91	0·493

* Hypertension (any wave) during adulthood.
Mixed effects logistic models were fit using the longitudinal data collected during 1991–2011. Model 1 adjusted for age and sex; model 2 further adjusted for energy intake, education, income, urbanisation, smoking, alcohol drinking, physical activity, overweight/obesity and model 3 further adjusted for dietary patterns. All the covariates were treated as time-varying covariates except sex and Ca intake. Cumulative mean Ca intake was recoded into quartiles (Q1, 93·4 (SD 16·9) mg/1000 kcal/d; Q2, 132·8 (SD 10·0) mg/1000 kcal/d; Q3, 182·3 (SD 20·9) mg/1000 kcal/d; Q4, 391·8 (SD 173·6) mg/1000 kcal/d).

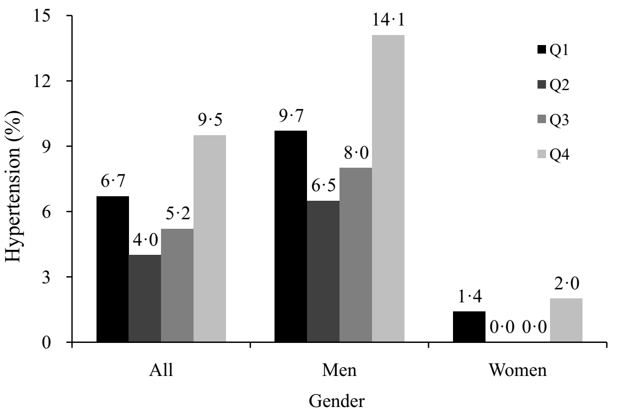

Fig. 2. Prevalence of hypertension (%) among adults by quartiles of calcium intake during adolescence: The 1991–2011 China Health Nutrition Survey data (***n*** **= 1611**)[a]. [a]Hypertension was defined as if a subject had one of the following SBP ≥ 140 mmHg, DBP ≥ 90 mmHg, self-reported hypertension or current use of antihypertensive medications. Cumulative mean calcium intake was recoded into quartiles (Q1, 93·4 (SD 16·9) mg/1000 kcal/d; Q2, 132·8 (SD 10·0) mg/1000 kcal/d; Q3, 182·3 (SD 20·9) mg/1000 kcal/d; Q4, 391·8 (SD 173·6) mg/1000 kcal/d).

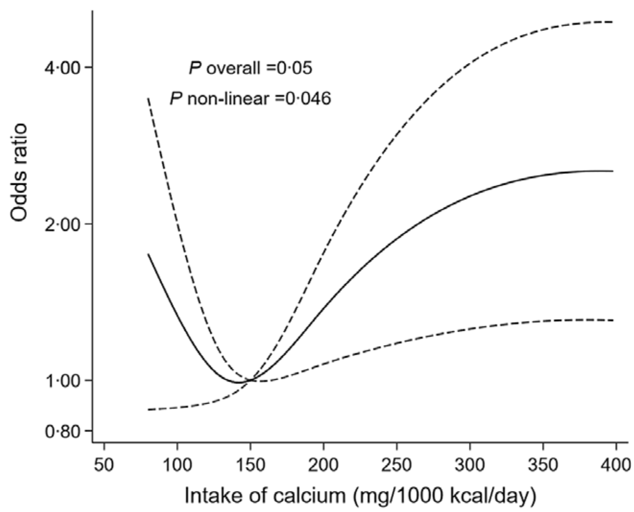

Fig. 3. Non-linear association between calcium intake during adolescence and hypertension of adults attending the China Health and Nutrition Survey 1991–2011. Mixed effects logistic regression model was adjusted for age, sex, energy intake, education, income, urbanisation, smoking, alcohol drinking, physical activity, overweight/obesity and dietary patterns.

other studies conducted in European and Asian adults[28–32]. Similar results were also observed in Brazilian and American children[22,33]. Prior findings indicated that early-life exposure, including childhood and adolescent diet, can affect the risk of hypertension and is able to protect from hypertension[14–16]. To our knowledge, no other study has evaluated dietary Ca intake in adolescents in relation to the risk of hypertension in adulthood.

Our study observed a U-shaped association between adolescent Ca intake and hypertension risk in adulthood in China, where most people have a plant-based diet and low Ca intake. Those who had Ca intake at 132·8 mg/1000 kcal/d or 307·4 mg/d during adolescence had the lowest risk of hypertension and high DBP compared with the lowest and highest groups. No interaction was observed among Ca intake and

Table 3. Quantile regression results (regression coefficients and 95 % CI) on the association between quartiles of calcium intake during adolescence (exposure variable) and blood pressure (BP) (outcome variable) of adults at the last survey between 1991 and 2011

	Q1	Q2		Q3		Q4		
		Regression coefficients	95 % CI	Regression coefficients	95 % CI	Regression coefficients	95 % CI	*P* for trend
1) Systolic BP								
0·7 quantile	0 (ref)	0·97	–0·93, 2·87	1·09	–1·13, 3·31	2·38	0·39, 4·36	0·079
0·8 quantile	0 (ref)	1·03	–1·28, 3·35	1·71	–1·04, 4·46	3·04	0·88, 5·20	0·005
0·9 quantile	0 (ref)	0·57	–1·96, 3·09	2·35	–0·30, 5·00	2·81	0·00, 5·61	0·023
2) Diastolic BP								
0·7 quantile	0 (ref)	0·66	–0·9, 2·22	0·89	–0·7, 2·48	1·89	0·51, 3·27	0·056
0·8 quantile	0 (ref)	0·17	–1·62, 1·95	0·13	–1·49, 1·76	0·98	–0·53, 2·49	0·150
0·9 quantile	0 (ref)	0·41	–1·63, 2·46	0·94	–0·89, 2·77	1·19	–0·79, 3·18	0·179

Values were the regression coefficients (95 % CI) from simultaneous-quantile regression using 'sqreg' command in Stata with the focus on the 0·7, 0·8 and 0·9 quantiles of systolic BP and diastolic BP. Models adjusted for age, sex, energy intake, education, income, urbanisation, smoking, alcohol drinking, physical activity, overweight/obesity and dietary patterns.

weight status, education, income and urbanisation. Higher DBP and SBP are important risk factors for cardiovascular events in different ages; the superiority of SBP with advancing age, while DBP plays a key role during young and mid-life stage. The age range of our study was about 20–37 years (interquartile range of 21–24 years), which may explain the difference association among Ca intake, high DBP and SPB.

The present study suggested that optimal dietary Ca intake during adolescence against hypertension in adulthood was about 132·8 mg/1000 kcal/d or 307·4 mg/d. However, this optimal dose we found was only 1/3 of the 2013 Chinese Dietary Reference Intakes for adolescents issued by the Chinese Nutrition Society[13], and much less than that in Brazilian (458·4 mg/d) and American children (female, 509·0 mg/d; male, 671·8 mg/d)[34,35]. The disparity may be due to different dairy consumption across countries. Compared with more than 80 % of dietary Ca in westerners[36,37], and nearly one-third in Japanese[38] and Koreans[39] were derived from dairy and meat products, only less than 5 % was from eggs and milk for Chinese[40,41]. In our sample, the mean dairy consumption was very low, although it had increased rapidly over time (ranged from 1·9 g/d in 1991 to 28·2 g/d in 2009). Another complex issue is that the bioavailability of Ca intake varies from different food sources and thus may affect health outcomes differently. It is worth mentioning that based on data from CHNS, more than 70 % of the Ca intake were from plant-based food (e.g. vegetables, legumes, cereals) and milk products[42].

BP is regulated by circulating Ca concentration, which varies within a relatively small range, despite a wide range of dietary Ca intakes among individuals[43,44]. Fang and colleagues[43] recently summarised that Chinese could maintain a positive Ca balance at Ca intake at lower dose (about 300 mg/d) than westerners. Although Ca supplementation is encouraged to improve Ca intake status in China and some people do take such and other multivitamin supplements, high Ca intake could be an indicator for heavy metal contamination in plant-based food population[45,46] and thus increases health risks. Our study found that there was a higher burden of hypertension among young adults with high Ca intake during adolescence. It urges more studies to elucidate the appropriate adolescent Ca intake levels for health outcomes including to lower hypertension risks.

China is facing a rising epidemic of NCD, and it shows no sign of abating. Prevention of NCD including hypertension through promoting healthy eating and lifestyle has been elevated to a national public policy priority. In October 2016, the State issued the 'Healthy China 2030', bringing the NCD issue into sharper and more concrete focus[47]. It also exerts an important guiding and cohesive effect on the prevention and treatment of NCD over the next 10 years. Our study findings added another complex factor for related researches, policymakers and public health professionals to consider in their NCD prevention efforts. Our findings on the relationship between Ca intake during adolescence and hypertension in adulthood do not support the recommended intake of Ca for adolescents recommended by the Chinese Nutrition Society.

The strengths of our study include the longitudinal study design, multiple measurements of dietary intake and the relatively large sample size. The repeated measures of 3-d dietary intake in combination with household food inventory provide a robust estimate of long-term Ca intake. The large variation in Ca intake makes it possible to assess the association between Ca intake and hypertension. However, we were not able to explore the potential mechanisms due to a lack of related biomarkers. Second, the information of Ca supplement use was not available, and the data up to 2011 were analysed due to data availability. However, the use of dietary supplement was not common among adolescents in China. Third, among the 5359 participants with information on Ca intake, 685 did not reach the age of 20 years in the last survey wave in 2011. Thus, the rate of lost to follow-up was high (57·2 %), and there were some difference in age but no difference in BMI and SBP between the included participants and those who were lost to follow-up. Furthermore, because most of the individuals included were men and relatively younger, analytic sample bias may exist. Finally, compared with those excluded in the analysis, the 1611 participants included in the analysis had slightly older age (13·9 (SD 1·3) *v.* 13·7 (SD 1·3) years), lower DBP (65·5 (SD 8·9) *v.* 66·4 (SD 8·8) mmHg) and more likely lived in low urbanisation area (46·6 % *v.* 40·0 %) when they first entered the survey as adolescents. However, there was no difference in SBP (100·7 (SD 11·8) *v.* 101·0 (SD 11·8) mmHg). In the analyses, we have adjusted for potential confounders including weight status and dietary pattern and residual confounding is possible.

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In conclusion, our study found a U-shaped association between Ca intake during adolescence and hypertension in adulthood independent of weight status and dietary pattern in China. Our results support the importance of appropriate amount of Ca intake during childhood for hypertension prevention.

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Supplementary material

For supplementary material referred to in this article, please visit https://doi.org/10.1017/S0007114521002701

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