



BMJ Open Long-term trends and regional variations of hypertension incidence in China: a prospective cohort study from the China Health and Nutrition Survey, 1991–2015

Yunmei Luo ^{1,2} Fan Xia,³ Xuexin Yu,⁴ Peiyi Li,¹ Wenzhi Huang ⁵, Wei Zhang ⁴

To cite: Luo Y, Xia F, Yu X, *et al.* Long-term trends and regional variations of hypertension incidence in China: a prospective cohort study from the China Health and Nutrition Survey, 1991–2015. *BMJ Open* 2021;**11**:e042053. doi:10.1136/bmjopen-2020-042053

► Prepublication history for this paper is available online. To view these files, please visit the journal online (<http://dx.doi.org/10.1136/bmjopen-2020-042053>).

Received 29 June 2020

Revised 23 November 2020

Accepted 10 December 2020

ABSTRACT

Objective The aim is to explore the trends of hypertension incidence and regional variations in China from 1991 to 2015.

Design A dynamic prospective cohort study.

Setting China Health and Nutrition Survey 1991–2015.

Participants 12 952 Chinese adults aged 18+ years.

Primary outcome measures Incident hypertension from 1993 to 2015.

Results Age-standardised hypertension incidence increased from 40.8 per 1000 person-years (95% CI 38.3 to 43.4) between 1993 and 1997 to 48.6 (95% CI 46.1 to 51.0) between 2011 and 2015. The increasing trends were further supported by results from subsequent extended Cox proportional hazard model. In addition, results from the modelling analysis showed that individuals in eastern, central and northeastern China had greater risks of hypertension occurrence in comparison with their counterparts in western China.

Conclusion Hypertension incidence increased during the study period. The growth called for more attention on the health education and health promotion of individuals with great risks.

INTRODUCTION

Along with ageing population, non-communicable chronic diseases, particularly stroke and ischaemic heart disease, have led to great burden of disease, deaths and years of life lost in both developed and developing countries.^{1 2} Connected closely with various cardiovascular diseases,^{3 4} high systolic blood pressure (SBP) was ranked as the leading risk factor of risk-attributable disability-adjusted life-years (DALYs) among selected 195 countries and territories.⁵ For instance, high SBP accounted for 2.54 million deaths and more than 5% of DALYs in China in 2017.⁶

Existing evidence has confirmed a worldwide high prevalence of hypertension.^{4–6} Countries, such as Singapore⁶ and Korea,⁷

Strengths and limitations of this study

- The dynamic cohort study design employed individuals from diverse social and geographic contexts, which enabled us to depict the long-term trends of hypertension incidence and regional disparities in the context of China's rapid social development and population ageing.
- We adopted both self-reported health outcomes and objective outcomes from physical tests, which to some extent minimised the recall bias and underestimation in underserved areas.
- We did not employ a national representative sample and did not include individuals from all provinces in China, which undermined the representation of our findings.
- Guidelines recommend to identify hypertension cases by using blood pressure values that are measured in different days, while individuals' blood pressure data in the China Health and Nutrition Survey were collected on the same day, which may lead to unavoidable bias.
- We did not distinguish the grade of hypertension, and future research is necessary.

had a significant proportion of individuals with hypertension. Likewise, with the extended life expectancy,⁸ changes in lifestyle behaviours,⁹ and rapid urbanisation,¹⁰ developing countries, such as China, experienced a substantial increase in the prevalence of hypertension, ranging from 13.6% in 1991 to 27.9% in 2015.¹¹

Although the increasing prevalence of hypertension provided critical information for public health practice and disease control programmes, it could not accurately depict the epidemiological transition as the incidence measure.¹² Prior studies have indicated that the increasing prevalence could coexist with the decreasing incidence in the context



© Author(s) (or their employer(s)) 2021. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

For numbered affiliations see end of article.

Correspondence to

Professor Wei Zhang;
weizhanghx@163.com

of healthy ageing.¹³ For evidence-based health-promoting initiatives, empirical research on hypertension incidence is warranted.

However, research on the long-term trends of the incidence of hypertension from China is scarce and relatively outdated.^{14 15} This is an important knowledge gap because developing countries are experiencing unprecedented social development. Up-to-date information among developing countries could greatly contribute to depict global epidemiological transitions. Moreover, regional disparities are a major health concern in China as a result of inequitable socioeconomic development and healthcare resource distribution,^{16–18} while the existing research provides insufficient information regarding the regional disparities in the hypertension incidence.^{19–21}

Hence, this study aims to explore the long-term trends of hypertension incidence among Chinese from diverse social and geographic contexts. In addition, we are particularly interested in regional variations while taking the individual-level risk factors into account.

METHODS

Data source

The present study derived data from the China Health and Nutrition Survey (CHNS). CHNS has been collaboratively conducted by Carolina Population Center at the University of North Carolina at Chapel Hill and the National Institute for Nutrition and Health (former National Institute of Nutrition and Food Safety) at the Chinese Center for Disease Control and Prevention. Initiated in 1989, CHNS consisted of 10-wave data in 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011 and 2015, respectively. Overall, CHNS employed a multistage random cluster method to draw the study sample, which included over 30 000 individuals from three provincial-level cities and 12 provinces. Individuals in the survey came from diverse social, geographic and cultural contexts. CHNS employed face-to-face questionnaire interviews to collect data, and the physical health examinations were conducted by well-trained investigators. Information regarding survey design, data collection, and quality control could be retrieved from the cohort profile.²²

Study design and exclusion criteria

The present study employed a dynamic cohort study design as not all individuals entered the cohort at the same time. To evaluate the long-term trends of hypertension incidence, we excluded individuals (a) without individual ID and community ID; (b) aged under 18 years because of the low incidence of hypertension among children and teenagers; (c) with hypertension in his/her first investigation; (d) with only one observation or only one record of hypertension status and (e) who were pregnant during the study period to exclude gestational hypertension. Furthermore, we excluded observations after the

diagnosis of hypertension (figure 1). As death data were not available in CHNS, censoring could be for death or lost to follow-up.

Exposures

The primary exposure variable of this study were the timing of entering the cohort and geographic regions. For modelling analyses, it was not feasible to treat the waves as continuous variables, and therefore, we respectively grouped the individuals entering the cohort from (a) 1991, 1993 and 1997; (b) 2000, 2004, 2006 and 2009 and (c) 2011 and 2015. In this case, two dummies were introduced in the model with individuals from 1991 to 1997 as the reference group.

Geographic regions were defined according to the bulletin of the National Bureau of Statistics of China. Specifically, we grouped individuals from (a) Beijing, Shanghai, Jiangsu Province, Zhejiang Province and Shandong Province as eastern China; (b) Henan Province, Hubei Province and Hunan Province as central China; (c) Liaoning Province and Heilongjiang Province as north-eastern China and (d) Yunnan Province, Guangxi Zhuang Autonomous Region, Guizhou Province, Chongqing and Shanxi Province as western China.

Outcomes

We included incidence of hypertension as the primary outcome. First, we adopted self-reported hypertension, which was derived from the answer to the question, 'Has a doctor ever told you that you had high blood pressure?'. If individuals self-reported no hypertension history, the outcomes would be further supplemented by the blood pressure tests to avoid the recall bias and underestimation from self-reported measures. According to the criteria of the 2018 Clinical Guideline in China and the 2018 ESC/ESH HTN Guideline,²³ hypertension was confirmed with the SBP ≥ 140 mm Hg or with the diastolic blood pressure ≥ 90 mm Hg. To guarantee the accuracy of the tests, the blood pressure was detected in triplicate by professional health workers on the same day.

Covariates

To adjust for variations in baseline characteristics, we introduced several confounding factors that may influence the occurrence of hypertension. These factors included urban versus rural settings, sociodemographic characteristics (age, sex, race, marital status, educational attainment and employment status) and lifestyle attributes (body mass index (BMI), smoking behaviours, alcohol consumption and physical activity).^{15 24}

Statistical analysis

First, we performed χ^2 tests and Kruskal-Wallis rank-sum tests to evaluate variations in baseline characteristics over time. Second, we calculated the crude incidence of hypertension as below²⁵:

$$\text{Incidence} = \frac{\text{number of new hypertension cases}}{\text{total person-years at risk}}$$

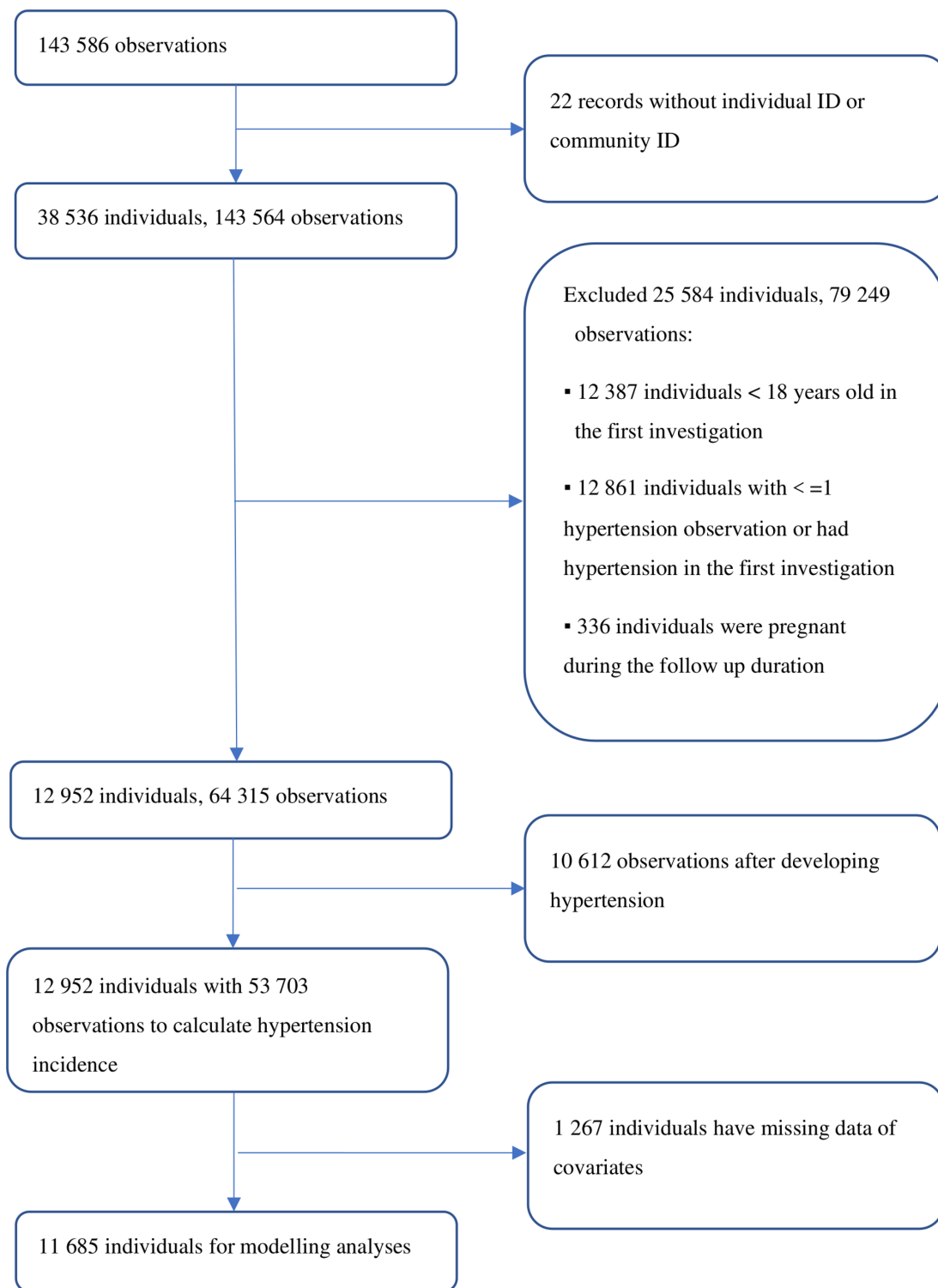


Figure 1 Flowchart showing the selection of the subjects who were included in the final analysis of hypertension incidence in China, with covariate information missing rate of 9.78%.

The ‘person-years at risk’ is the period from the first hypertension-free year to the year when the subsequent hypertension is confirmed. In addition, we conducted direct standardisation to calculate the age-standardised incidence of hypertension by using the study sample from wave 2011 to wave 2015 as the standard population. Subgroup analyses were conducted by sex.

To further evaluate the long-term trends and geographic variations of incident hypertension, we performed an extended Cox proportional hazard model while including all covariates to control for baseline variations. Because the effect of age did not conform to the proportional hazard assumption, we performed a time-dependent Cox regression model with age as a time-dependent variable.

Table 1 Observation distribution of study sample from 1991 to 2015

Wave	1991	1993	1997	2000	2004	2006	2009	2011	2015
1989									
1991	5938								
1993	5166	677							
1997	3313	485	1691						
2000	2658	335	1451	1009					
2004	2050	234	1037	813	837				
2006	1722	188	865	642	684	376			
2009	1378	142	385	398	413	302	692		
2011	1200	114	329	335	359	216	630	1732	
2015	912	86	250	236	231	152	353	1732	0

As for sensitivity analyses, we construct the multi-level Poisson regression indicating similar findings.

Data analyses were performed with Stata V.15.0 (StataCorp, Texas, USA). A two-tailed *p* value of less than 0.05 was considered statistical significance.

Patient and public involvement

Patients and the public were not involved in the research.

RESULTS

Study population

The CHNS consisted of data of 38 558 individuals with 143 586 observations from 1989 to 2015, and the present study only included 12 952 individuals from 1991 to 2015 after sample selection (figure 1). Table 1 presents the distribution of observations from included individuals during the study period. For example, 5938 individuals entered the cohort in 1991, with only 912 followed-up in 2015 (table 1). Among the 12 952 participants, 5119 of them developed hypertension during the follow-up period.

Table 2 presents the baseline characteristics of the study sample. Overall, variations existed in all baseline characteristics. Newly recruited individuals were older ($p<0.001$) and well educated ($p<0.001$). They were more likely to be obese ($p<0.001$), Han ($p<0.001$) and men ($p<0.001$), and they were less likely to be smokers ($p<0.001$), employed ($p<0.001$) and physically active ($p<0.001$).

Crude and age-standardised incidence

Table 3 presents the crude and age-standardised hypertension incidence during the study period. For the calculation of hypertension incidence, we employed the full sample of 12 952 individuals with 53 703 observations. The age-standardised incidence of hypertension witnessed a significant increase, ranging from 40.8 per 1000 person-years (95% CI 38.3 to 43.4) between 1993 and 1997 to 48.6 per 1000 person-years (95% CI 46.1 to 51.0) between 2011 and 2015. The increasing pattern was also exhibited among men (1993–1997: 46.2, 95% CI 42.1 to 50.4; 2011–2015: 55.7, 95% CI 51.7 to 59.7) and women

(1993–1997: 36.5, 95% CI 33.2 to 39.7; 2011–2015: 43.3, 95% CI 40.2 to 46.3).

Extended COX proportional hazard analysis

For the modelling analysis, we included 11 685 individuals without missing data (missing rate, 9.78%). Among the identified cases, the duration from free of hypertension to incident hypertension ranged from 2 to 24 years, with a median of 9 years.

Table 4 presents results from extended Cox proportional hazard analysis while taking variations in baseline characteristics into account. First, the increasing trends of hypertension incidence were robust, as suggested by the modelling results. Specifically, individuals entering the cohort from 2000 to 2009 (adjusted Hazard Ratio (aHR)=1.10, 95% CI 1.01 to 1.21) and those from 2011 to 2015 (aHR=1.19, 95% CI 1.04 to 1.37) had a higher risk of hypertension in comparison with individuals entering the cohort from 1991 to 1997. With reference to regional variations, individuals in central (aHR=1.26, 95% CI 1.16 to 1.37), northeastern (aHR=1.56, 95% CI 1.41 to 1.72) and eastern China (aHR=1.48, 95% CI 1.36 to 1.63), respectively, had a higher risk of hypertension occurrence relative to their counterparts in western China.

In addition, there existed no urban–rural differences in developing hypertension (table 4). Risks of incident hypertension increased with age, BMI and alcohol consumption, while it was negatively associated with educational attainment. Women had a lower risk of incident hypertension compared with men (aHR=0.81, 95% CI 0.74 to 0.88). Relative to those without a job, employees had a lower risk of developing hypertension (aHR=0.90, 95% CI 0.82 to 0.99). Han individuals were significantly associated with a higher risk (aHR=1.11, 95% CI 1.01 to 1.23) relative to the minority.

DISCUSSION

By employing a study sample of 12 925 individuals from diverse social and geographic contexts, we found the age-standardised incidence of hypertension increased during

Table 2 Baseline characteristics of study individuals, n (%)*

Characteristic	Time entering the cohort			P value
	1991–1997	2000–2009	2011–2015	
Region				
Western	2256 (27.16)	611 (20.97)	523 (30.20)	<0.001
Central	2817 (33.92)	800 (27.45)	85 (4.91)	
Northeastern	1288 (15.51)	794 (27.25)	83 (4.79)	
Eastern	1945 (23.42)	709 (24.33)	1041 (60.10)	
Urban–rural				
Rural	5616 (67.61)	1717 (58.92)	777 (44.86)	<0.001
Urban	2690 (32.39)	1197 (41.08)	955 (55.14)	
Age (years)				
18–29	2374 (28.58)	695 (23.85)	221 (12.76)	<0.001
30–39	2382 (28.68)	854 (29.31)	345 (19.92)	
40–49	1752 (21.09)	621 (21.31)	424 (24.48)	
50–59	1004 (12.09)	405 (13.90)	456 (26.33)	
≥60	794 (9.56)	339 (11.63)	286 (16.51)	
Sex				
Male	3986 (47.99)	1168 (40.08)	736 (42.49)	<0.001
Female	4320 (52.01)	1746 (59.92)	996 (57.51)	
BMI (kg/m²)				
<18.5	763 (9.27)	191 (6.60)	60 (3.46)	<0.001
18.5–23.9	6012 (73.07)	1776 (61.35)	955 (55.14)	
24.0–27.9	1238 (15.05)	760 (26.25)	545 (31.47)	
≥28	215 (2.61)	168 (5.80)	172 (9.93)	
Race				
Other	1038 (12.59)	340 (11.69)	72 (4.17)	<0.001
Han	7204 (87.41)	2568 (88.31)	1656 (95.83)	
Marital status				
Other	1183 (14.29)	341 (11.82)	192 (11.14)	<0.001
Married	7098 (85.71)	2545 (88.18)	1531 (88.86)	
Education attainment				
Primary school and below	4416 (53.81)	741 (26.43)	410 (23.73)	<0.001
Middle school	2377 (28.97)	1103 (39.34)	457 (26.45)	
High school or equivalent	1240 (15.11)	742 (26.46)	472 (27.31)	
College and above	173 (2.11)	218 (7.77)	389 (22.51)	
Employed				
No	1145 (13.85)	1044 (35.95)	716 (41.34)	<0.001
Yes	7121 (86.15)	1860 (64.05)	1016 (58.66)	
Smoking history				
Never or smoking cessation	5300 (64.72)	2163 (74.97)	1326 (77.18)	<0.001
Current smoker, cigarettes < 20/day	1481 (18.09)	370 (12.82)	205 (11.93)	
Current smoker, cigarettes ≥20/day	1408 (17.19)	352 (12.20)	187 (10.88)	
Alcohol consumption				
Never	5042 (61.82)	2037 (70.93)	1116 (65.03)	<0.001
Not more than once per month	469 (5.75)	102 (3.55)	144 (8.39)	
1–3 times per month	661 (8.10)	173 (6.02)	127 (7.40)	

Continued

Table 2 Continued

Characteristic	Time entering the cohort			P value
	1991–1997	2000–2009	2011–2015	
1–2 times per week	781 (9.58)	227 (7.90)	127 (7.40)	
3–4 times per week	450 (5.52)	126 (4.39)	64 (3.73)	
On a daily basis	753 (9.23)	207 (7.21)	138 (8.04)	
Physical activity				
Very light	997 (12.56)	780 (27.73)	823 (49.46)	<0.001
Light	1307 (16.46)	799 (28.40)	453 (27.22)	
Moderate	1291 (16.26)	461 (16.39)	209 (12.56)	
Heavy or very heavy	4344 (54.71)	773 (27.48)	179 (10.76)	

*Overall, we included 11 685 individuals in the modelling analyses after excluding 97 individuals without body mass index, 74 without race, 62 without marital status, 214 without educational attainment, 50 without employment status, 160 without smoking history, 208 without alcohol consumption and 449 without physical activity. (Missing rate 9.78%.)

the study period. The increasing pattern remained even after controlling for variations in baseline characteristics. Furthermore, we found that individuals in economically developed eastern, central and northeastern China had greater risks of incident hypertension in comparison with those in western China.

Instead of focusing on the incidence measure, the vast majority of prior studies focused on the prevalence measure. For example, one of the previous studies in China indicated that the prevalence of hypertension rose substantially from 13.6% in 1991 to 27.9% in 2015.¹¹ The findings were further supplemented by results from Lu *et al*, which suggested a higher prevalence of hypertension among those aged between 35 and 75 years (44.7%).²⁶ Compared with these earlier studies, our focus on the incidence measure provided a more accurate reflection of the epidemiologic transition of hypertension in China.¹² Our findings updated the trends of hypertension incidence in comparison with that from Liang *et al*, which indicated a

similar pattern from 1991 to 2009.¹⁵ Even though hypertension incidence appeared to vary across countries,^{27–29} the comparison is untenable because we adopted different standard populations. Further empirical research across countries is warranted.

With the rapid economic development, people often change their dietary patterns from light diet to high salt and fat diet along with a secondary lifestyle.³⁰ These changes would significantly impact the prevalence and control of hypertension in China.³⁰ In addition, due to data limitation, we were unable to introduce several potential risks factors, such as sodium intake or dietary pattern, parental history, psychological status, ambient air pollutants, working hours and household income.^{31–34} These factors may explain the residual time effects in the model.

Although existing evidence on the regional disparities of hypertension incidence is scant, prior research indicates that central, northeastern and eastern China had a higher prevalence of hypertension compared

Table 3 Crude and age-standardised incidence over time per 1000 person-years

Incidence	1991	1993–1997	2000–2009	2011–2015
Total				
Case (person-year)	–	1114 (35 486)	2571 (70 575)	1434 (29 492)
Crude incidence (95% CI)	–	31.3 (29.6 to 33.2)	36.4 (35.0 to 37.8)	48.6 (46.1 to 51.2)
Age-standardised incidence (95% CI)*	–	40.8 (38.3 to 43.4)	41.5 (39.9 to 43.2)	48.6 (46.1 to 51.0)
Male				
Case (person-year)	–	594 (17 530)	1292 (32 524)	699 (12 532)
Crude incidence (95% CI)	–	33.8 (31.2 to 36.7)	39.7 (37.6 to 41.9)	55.7 (51.7 to 60.0)
Age-standardised incidence (95% CI)*	–	46.2 (42.1 to 50.4)	45.7 (43.0 to 48.3)	55.7 (51.7 to 59.7)
Female				
Case (person-year)	–	520 (17 956)	1279 (38 051)	735 (16 960)
Crude incidence (95% CI)	–	28.9 (26.5 to 31.5)	33.6 (31.8 to 35.5)	43.3 (40.3 to 46.5)
Age-standardised incidence (95% CI)*	–	36.5 (33.2 to 39.7)	38.0 (35.9 to 40.1)	43.3 (40.2 to 46.3)

*Age-standardised incidence was calculated using the study sample in 2011–2015 as the standard population.

Table 4 Extended Cox proportional hazard analysis of hypertension incidence

Characteristic	aHR (95% CI)	P value
Timing of entering the cohort		
1991–1997	Ref.	
2000–2009	1.10 (1.01 to 1.21)	0.025
2011–2015	1.19 (1.04 to 1.37)	0.010
Geographic region		
Western	Ref.	
Central	1.26 (1.16 to 1.37)	<0.001
Northeastern	1.56 (1.41 to 1.72)	<0.001
Eastern	1.48 (1.36 to 1.63)	<0.001
Urban (vs rural)	0.94 (0.88 to 1.01)	0.109
Age*		
18–29	Ref.	
30–39	1.93 (1.41 to 2.65)	<0.001
40–49	3.99 (2.93 to 5.43)	<0.001
50–59	5.16 (3.74 to 7.12)	<0.001
≥60	9.11 (6.50 to 12.77)	<0.001
Female (vs male)	0.81 (0.74 to 0.88)	<0.001
Body mass index (kg/m²)		
<18.5	Ref.	
18.5–23.9	1.31 (1.16 to 1.48)	<0.001
24.0–27.9	2.07 (1.81 to 2.36)	<0.001
≥28	2.82 (2.37 to 3.34)	<0.001
Race (Han vs others)	1.11 (1.01 to 1.23)	0.032
Married (vs others)	0.92 (0.83 to 1.02)	0.149
Educational attainment		
Primary school and below	Ref.	
Middle school	0.91 (0.84 to 0.99)	0.020
High school or equivalent	0.86 (0.77 to 0.95)	0.002
College and above	0.82 (0.68 to 0.98)	0.033
Employed (yes vs no)	0.90 (0.82 to 0.99)	0.036
Smoking		
Never or smoking cessation	Ref.	
Current smoker, cigarettes <20/day	0.98 (0.89 to 1.07)	0.752
Current smoker, cigarettes ≥20/day	1.05 (0.96 to 1.16)	0.237
Alcohol consumption		
Never	Ref.	
Not more than once per month	0.89 (0.78 to 1.03)	0.125
1–3 times per month	1.17 (1.04 to 1.32)	0.006
1–2 times per week	1.00 (0.89 to 1.12)	0.963
3–4 times per week	1.05 (0.92 to 1.21)	0.412
On a daily basis	1.18 (1.06 to 1.31)	0.002
Physical activity		

Continued

Table 4 Continued

Characteristic	aHR (95% CI)	P value
Very light	Ref.	
Light	0.92 (0.83 to 1.02)	0.154
Moderate	0.99 (0.88 to 1.11)	0.930
Heavy and very heavy	0.91 (0.82 to 1.02)	0.118

 *Estimated time effect of age, $p < 0.001$.

with western China,³⁵ which is in line with our findings. In sharp contrast, prior investigators have noted that northeastern and central China had lower all-cause mortality rates relative to western China.³⁶ These findings appear to suggest that individuals in China's economically developed regions are experiencing extended life expectancy with relatively unhealthy ageing.¹² However, one should be aware of the possibility that although individuals in western China had lower risks of hypertension compared with the other three regions, local public awareness and timely treatment could be a challenging issue.

Differed from previous studies,^{15 37} no urban–rural disparities were observed in the present study. This may be a result of the narrowing gap of lifestyle between rural and urban residents. With the rapid economic development and urbanisation in the past few decades, the lifestyle and dietary pattern of rural residents are approaching to those of their counterparts in urban China.^{9 10} This possibility has been further supported by the fact that the prevalence of hypertension in rural China exceeded that of urban China in 2015.²⁶ Taking into account the lower treatment rate and insufficient awareness among rural residents,³⁸ one should direct more attention to rural China.

Moreover, we found that smoking history was not associated with incident hypertension. The effect of smoking on the development of the chronic disease is unclear and appears to differ across life courses.^{39–41} Prior research based on Korean has found a J-shaped association between physical activity and incident hypertension,⁴² while the present study on Chinese did not observe a similar association, which is in line with findings based on Japanese.⁴³ The effect of physical activity on the development of hypertension seems to be controversial and varies across countries. Further analyses are warranted.

Consistent with the previous studies,^{44–47} several risk factors, including age, gender, educational attainment, race, alcohol consumption and BMI, were confirmed by our analyses. The growing incidence of hypertension emphasises the early prevention, education, detection and management for hypertension.⁴⁸ Mentoring aforementioned lifestyle behaviours, such as alcohol consumption, may be helpful to constrain the hypertension incidence.⁴⁹ Public health and lifestyle interventions targeting high-risk individuals, such as older adults, men and obese population, hold promise.



Conclusion

Hypertension incidence increased during the study period. Individuals in eastern, central and northeastern China had greater risks of hypertension in comparison with their counterparts in western China. Risks of incident hypertension increased with age, BMI and alcohol consumption but negatively associated with educational attainment. The growth of hypertension incidence calls for more attention on the health education and health promotion of individuals with great risks.

Strengths and limitations of this study

The present study has two major strengths. First, the dynamic cohort study design employed individuals from diverse social and geographic contexts, which enabled us to depict the long-term trends of hypertension incidence and regional disparities in the context of China's rapid social development and population ageing. In addition, we adopted both self-reported health outcomes and objective outcomes from physical tests, which avoided the recall bias and underestimation in underserved areas.

Nevertheless, this study is subject to several limitations. First, we did not employ a national representative sample and did not include individuals from all provinces in China, which undermined the representation of our findings. As a community-based survey, the CHNS excluded institutionalised individuals, which further diminished the representation of our findings among Chinese. Third, 2018 Clinical Guideline in China recommend to identify hypertension cases by using blood pressure values that are measured in different days,²³ while individuals' blood pressure data in the CHNS were collected on the same day in the CHNS, leading to unavoidable bias. Last, we did not distinguish the grade of hypertension, and future research is necessary.

Author affiliations

¹Institute of Hospital Management, West China Hospital, Sichuan University, Chengdu, Sichuan, China

²West China Medical Publishers, West China Hospital, Sichuan University, Chengdu, Sichuan, China

³Department of Neurosurgery, West China Hospital, Sichuan University, Chengdu, Sichuan, China

⁴West China Biomedical Big Data Center, West China Hospital, Sichuan University, Chengdu, Sichuan, China

⁵Department of Infection Control, West China Hospital, Sichuan University, Chengdu, Sichuan, China

Correction notice This article has been corrected since it first published. The provenance and peer review statement has been included.

Acknowledgements We thank the National Institute for Nutrition and Health, China Center for Disease Control and Prevention, Carolina Population Center (P2C HD050924, T32 HD007168), the University of North Carolina at Chapel Hill, the NIH (R01-HD30880, DK056350, R24 HD050924 and R01-HD38700) and the NIH Fogarty International Center (D43 TW009077 and D43 TW007709) for financial support for the CHNS data collection and analysis files from 1989 to 2015 and future surveys, and the China-Japan Friendship Hospital, Ministry of Health for support for CHNS 2009, Chinese National Human Genome Center at Shanghai since 2009 and Beijing Municipal Center for Disease Prevention and Control since 2011.

Contributors WZ designed this study and revised the manuscript. YL, FX and XY performed data clean, statistical analysis and wrote the first draft of the manuscript,

which PL and WH subsequently revised. All authors read the article and approve it for publication.

Funding This study was supported by China's National Development and Reform Commission Grant (No. 2018GFGW001) to WZ.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval China Health and Nutrition Survey (CHNS) was approved by the ethics committee of Carolina Population Center at the University of North Carolina at Chapel Hill and the NINH at the CCDC. Informed consent was obtained from all subjects before the investigation.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. Data are available from China Health and Nutrition Survey (<https://www.cpc.unc.edu/projects/china/data/>).

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iDs

Yunmei Luo <http://orcid.org/0000-0002-2661-3214>

Wenzhi Huang <http://orcid.org/0000-0002-4074-8422>

Wei Zhang <http://orcid.org/0000-0003-3113-9577>

REFERENCES

- 1 GBD 2017 Causes of Death Collaborators. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980-2017: a systematic analysis for the global burden of disease study 2017. *Lancet* 2018;392:1736-88.
- 2 GBD 2017 Risk Factor Collaborators. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990-2017: a systematic analysis for the global burden of disease study 2017. *Lancet* 2018;392:1923-94.
- 3 Lloyd-Jones DM, Larson MG, Leip EP, et al. Lifetime risk for developing congestive heart failure: the Framingham Heart Study. *Circulation* 2002;106:3068-72.
- 4 Lewington S, Clarke R, Qizilbash N, et al. Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. *Lancet* 2002;360:1903-13.
- 5 GBD 2017 DALYs and HALE Collaborators. Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018;392:1859-922.
- 6 Liew SJ, Lee JT, Tan CS, et al. Sociodemographic factors in relation to hypertension prevalence, awareness, treatment and control in a multi-ethnic Asian population: a cross-sectional study. *BMJ Open* 2019;9:e025869.
- 7 Cho SMJ, Lee H, Kim HC. Differences in prevalence of hypertension subtypes according to the 2018 Korean Society of hypertension and 2017 American College of Cardiology/American heart association guidelines: the Korean National health and nutrition examination survey, 2007-2017 (KNHANES IV-VII). *Clin Hypertens* 2019;25:26.
- 8 GBD 2017 Mortality Collaborators. Global, regional, and national age-sex-specific mortality and life expectancy, 1950-2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018;392:1684-735.
- 9 Gong P, Liang S, Carlton EJ, et al. Urbanisation and health in China. *Lancet* 2012;379:843-52.
- 10 LeBlanc AG, Chaput J-P. Urbanisation and fitness: worrying trends from China. *Lancet Child Adolesc Health* 2019;3:837-9.
- 11 Wang Z, Chen Z, Zhang L, et al. Status of hypertension in China: results from the China hypertension survey, 2012-2015. *Circulation* 2018;137:2344-56.
- 12 Omran AR. The epidemiologic transition: a theory of the epidemiology of population change. 1971. *Milbank Q* 2005;83:731-57.

- 13 Geiss LS, Wang J, Cheng YJ, *et al.* Prevalence and incidence trends for diagnosed diabetes among adults aged 20 to 79 years, United States, 1980-2012. *JAMA* 2014;312:1218-26.
- 14 Chen Z, Li SN, Wang X, *et al.* [The incidence of hypertension, overweight, and obesity and relationship with cardiovascular events among middle-aged Chinese: 6 years follow-up results]. *Zhonghua Xin Xue Guan Bing Za Zhi* 2020;48:47-53.
- 15 Liang Y, Liu R, Du S, *et al.* Trends in incidence of hypertension in Chinese adults, 1991-2009: the China Health and Nutrition Survey. *Int J Cardiol* 2014;175:96-101.
- 16 Yu X, Xia F, Zhang W. Trends and geographic variations in self-reported diabetes incidence: a prospective open cohort study of Chinese men and women, 1997-2015. *Diabet Med* 2020:e14447.
- 17 Zhou M, Wang H, Zeng X, *et al.* Mortality, morbidity, and risk factors in China and its provinces, 1990-2017: a systematic analysis for the global burden of disease study 2017. *Lancet* 2019;394:1145-58.
- 18 Xia F, Yu X, Li Y, *et al.* Geographic variations of stroke incidence in Chinese communities: an 18-year prospective cohort study from 1997 to 2015. *J Stroke* 2020;22:345-56.
- 19 Chen Y, Liang X, Zheng S, *et al.* Association of body fat mass and fat distribution with the incidence of hypertension in a population-based Chinese cohort: a 22-year follow-up. *J Am Heart Assoc* 2018;7:e007153.
- 20 Sun Z, Zheng L, Zhang X, *et al.* Ethnic differences in the incidence of hypertension among rural Chinese adults: results from Liaoning Province. *PLoS One* 2014;9:e86867.
- 21 Chen X, Liu Y, Sun X, *et al.* Comparison of body mass index, waist circumference, conicity index, and waist-to-height ratio for predicting incidence of hypertension: the rural Chinese cohort study. *J Hum Hypertens* 2018;32:228-35.
- 22 Popkin BM, Du S, Zhai F, *et al.* Cohort Profile: The China Health and Nutrition Survey--monitoring and understanding socio-economic and health change in China, 1989-2011. *Int J Epidemiol* 2010;39:1435-40.
- 23 Williams B, Mancia G. Ten Commandments of the 2018 ESC/ESH HTN Guidelines on hypertension in adults. *Eur Heart J* 2018;39:3007-8.
- 24 Qi S-F, Zhang B, Wang H-J, *et al.* Joint effects of age and body mass index on the incidence of hypertension subtypes in the China Health and Nutrition Survey: a cohort study over 22years. *Prev Med* 2016;89:23-30.
- 25 Gao M, Kuang W, Qiu P, *et al.* The time trends of cognitive impairment incidence among older Chinese people in the community: based on the CLHLS cohorts from 1998 to 2014. *Age Ageing* 2017;46:787-93.
- 26 Lu J, Lu Y, Wang X, *et al.* Prevalence, awareness, treatment, and control of hypertension in China: data from 1.7 million adults in a population-based screening study (China PEACE Million Persons Project). *Lancet* 2017;390:2549-58.
- 27 Mendonça RdeD, Lopes ACS, Pimenta AM, *et al.* Ultra-processed food consumption and the incidence of hypertension in a Mediterranean cohort: the Seguimiento Universidad de Navarra Project. *Am J Hypertens* 2017;30:358-66.
- 28 Li M, McDermott R. Obesity, albuminuria, and gamma-glutamyl transferase predict incidence of hypertension in Indigenous Australians in rural and remote communities in northern Australia. *J Hypertens* 2015;33:704-10.
- 29 Bernabe-Ortiz A, Sanchez JF, Carrillo-Larco RM, *et al.* Rural-To-urban migration and risk of hypertension: longitudinal results of the PERU MIGRANT study. *J Hum Hypertens* 2017;31:22-8.
- 30 Fan W-G, Xie F, Wan Y-R, *et al.* The impact of changes in population blood pressure on hypertension prevalence and control in China. *J Clin Hypertens* 2020;22:150-6.
- 31 He FJ, Li J, Macgregor GA. Effect of longer term modest salt reduction on blood pressure: cochrane systematic review and meta-analysis of randomised trials. *BMJ* 2013;346:f1325.
- 32 Gando Y, Sawada SS, Kawakami R, *et al.* Combined association of cardiorespiratory fitness and family history of hypertension on the incidence of hypertension: a long-term cohort study of Japanese males. *Hypertens Res* 2018;41:1063-9.
- 33 Bo Y, Guo C, Lin C, *et al.* Dynamic changes in long-term exposure to ambient particulate matter and incidence of hypertension in adults. *Hypertension* 2019;74:669-77.
- 34 Trudel X, Brisson C, Gilbert-Ouimet M, *et al.* Long working hours and the prevalence of masked and sustained hypertension. *Hypertension* 2020;75:532-8.
- 35 Li J, Shi L, Li S, *et al.* Urban-rural disparities in hypertension prevalence, detection, and medication use among Chinese adults from 1993 to 2011. *Int J Equity Health* 2017;16:50.
- 36 Yu X, Zhang W. All-cause mortality rate in China: do residents in economically developed regions have better health? *Int J Equity Health* 2020;19:12.
- 37 Arici M, Turgan C, Altun B, *et al.* Hypertension incidence in Turkey (HinT): a population-based study. *J Hypertens* 2010;28:240-4.
- 38 Feng XL, Pang M, Beard J. Health system strengthening and hypertension awareness, treatment and control: data from the China Health and Retirement Longitudinal Study. *Bull World Health Organ* 2014;92:29-41.
- 39 Kim BJ, Seo DC, Kim BS, *et al.* Relationship between cotinine-verified smoking status and incidence of hypertension in 74,743 Korean adults. *Circ J* 2018;82:1659-65.
- 40 Gao K, Shi X, Wang W. The life-course impact of smoking on hypertension, myocardial infarction and respiratory diseases. *Sci Rep* 2017;7:4330.
- 41 Li G, Wang H, Wang K, *et al.* The association between smoking and blood pressure in men: a cross-sectional study. *BMC Public Health* 2017;17:797.
- 42 Kim Y, Sharp S, Hwang S, *et al.* Exercise and incidence of myocardial infarction, stroke, hypertension, type 2 diabetes and site-specific cancers: prospective cohort study of 257 854 adults in South Korea. *BMJ Open* 2019;9:e025590.
- 43 Lu Y, Lu M, Dai H, *et al.* Lifestyle and risk of hypertension: follow-up of a young pre-hypertensive cohort. *Int J Med Sci* 2015;12:605-12.
- 44 Jayawardana NWIA, Jayalath WATA, Madhujith WMT, *et al.* Aging and obesity are associated with undiagnosed hypertension in a cohort of males in the Central Province of Sri Lanka: a cross-sectional descriptive study. *BMC Cardiovasc Disord* 2017;17:165.
- 45 Sinnott S-J, Smeeth L, Williamson E, *et al.* Trends for prevalence and incidence of resistant hypertension: population based cohort study in the UK 1995-2015. *BMJ* 2017;358:j3984.
- 46 Zhou W, Shi Y, Li Y-Q, *et al.* Body mass index, abdominal fatness, and hypertension incidence: a dose-response meta-analysis of prospective studies. *J Hum Hypertens* 2018;32:321-33.
- 47 Roerecke M, Kaczorowski J, Tobe SW, *et al.* The effect of a reduction in alcohol consumption on blood pressure: a systematic review and meta-analysis. *Lancet Public Health* 2017;2:S2468-2667(17)30003-8:e108-20.
- 48 Whelton PK, Carey RM, Aronow WS, *et al.* 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: Executive summary: a report of the American College of Cardiology/American heart association Task force on clinical practice guidelines. *Circulation* 2018;138:CIR.000000000000597:e426-83.
- 49 Holmes MV, Dale CE, Zuccollo L, *et al.* Association between alcohol and cardiovascular disease: Mendelian randomisation analysis based on individual participant data. *BMJ* 2014;349:g4164.