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)

Jiapeng Lu, Yuan Lu*, Xiaochen Wang, Xinyue Li, George C Linderman, Chaoqun Wu, Xiuyuan Cheng, Lin Mu, Haibo Zhang, Jiamin Liu, Meng Su, Hongyu Zhao, Erica S Spatz, John A Spertus, Frederick A Masoudi, Harlan M Krumholz†, Lixin Jiang†*

Summary

Background Hypertension is common in China and its prevalence is rising, yet it remains inadequately controlled. Few studies have the capacity to characterise the epidemiology and management of hypertension across many heterogeneous subgroups. We did a study of the prevalence, awareness, treatment, and control of hypertension in China and assessed their variations across many subpopulations.

Methods We made use of data generated in the China Patient-Centered Evaluative Assessment of Cardiac Events (PEACE) Million Persons Project from Sept 15, 2014, to June 20, 2017, a population-based screening project that enrolled around 1·7 million community-dwelling adults aged 35–75 years from all 31 provinces in mainland China. In this population, we defined hypertension as systolic blood pressure of at least 140 mm Hg, or diastolic blood pressure of at least 90 mm Hg, or self-reported antihypertensive medication use in the previous 2 weeks. Hypertension awareness, treatment, and control were defined, respectively, among hypertensive adults as a self-reported diagnosis of hypertension, current use of antihypertensive medication, and blood pressure of less than 140/90 mm Hg. We assessed awareness, treatment, and control in 264 475 population subgroups—defined a priori by all possible combinations of 11 demographic and clinical factors (age [35–44, 45–54, 55–64, and 65–75 years], sex [men and women], geographical region [western, central, and eastern China], urbanity [urban *vs* rural], ethnic origin [Han and non-Han], occupation [farmer and non-farmer], annual household income [< ¥10 000, ¥10 000–50 000, and ≥¥50 000], education [primary school and below, middle school, high school, and college and above], previous cardiovascular events [yes or no], current smoker [yes or no], and diabetes [yes or no]), and their associations with individual and primary health-care site characteristics, using mixed models.

Findings The sample contained 1738 886 participants with a mean age of 55·6 years (SD 9·7), 59·5% of whom were women. 44·7% (95% CI 44·6–44·8) of the sample had hypertension, of whom 44·7% (44·6–44·8) were aware of their diagnosis, 30·1% (30·0–30·2) were taking prescribed antihypertensive medications, and 7·2% (7·1–7·2) had achieved control. The age-standardised and sex-standardised rates of hypertension prevalence, awareness, treatment, and control were 37·2% (37·1–37·3), 36·0% (35·8–36·2), 22·9% (22·7–23·0), and 5·7% (5·6–5·7), respectively. The most commonly used medication class was calcium-channel blockers (55·2%, 55·0–55·4). Among individuals whose hypertension was treated but not controlled, 81·5% (81·3–81·6) were using only one medication. The proportion of participants who were aware of their hypertension and were receiving treatment varied significantly across subpopulations; lower likelihoods of awareness and treatment were associated with male sex, younger age, lower income, and an absence of previous cardiovascular events, diabetes, obesity, or alcohol use (all p<0·01). By contrast, control rate was universally low across all subgroups (<30·0%).

Interpretation Among Chinese adults aged 35–75 years, nearly half have hypertension, fewer than a third are being treated, and fewer than one in twelve are in control of their blood pressure. The low number of people in control is ubiquitous in all subgroups of the Chinese population and warrants broad-based, global strategy, such as greater efforts in prevention, as well as better screening and more effective and affordable treatment.

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*Joint first authors listed alphabetically

†Joint senior authors

National Clinical Research Center of Cardiovascular Diseases, State Key Laboratory of Cardiovascular Disease, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, China (J Lu PhD, C Wu MS, H Zhang MD, J Liu MD, M Su PhD, Prof L Jiang MD); **Center for Outcomes Research and Evaluation, Yale University/Yale-New Haven Hospital, New Haven, CT, USA** (Y Lu ScD, G C Linderman BS, L Mu BS, E S Spatz MD, Prof H M Krumholz MD); **Department of Mathematics** (X Cheng PhD) **and Department of Biostatistics** (X Wang BS, X Li MS, Prof H Zhao PhD), **New Haven, CT, USA; Health Outcomes Research, Saint Luke's Mid America Heart Institute/University of Missouri-Kansas City, Kansas City, MS, USA** (Prof J A Spertus MD); **and Division of Cardiology, University of Colorado Anschutz Medical Campus, Aurora, CO, USA** (Prof F A Masoudi MD).

Introduction

Blood pressure control is a national public health priority in China.[1] Surveys in China show that high blood pressure is common, but hypertension treatment and control rates are less than 50% and 20%, respectively, across different studies.[2–9] Findings from previous studies have estimated China's average burden of hypertension,[2–9] but national data on hypertension treatment are scarce, and how hypertension awareness, treatment, and control rates vary geographically and across population subgroups is uncertain. Because of their small sample sizes, previous studies examined hypertension measures in only a few subgroups, and to our knowledge none had the capacity to create a wide variety of discrete subgroups to investigate

Correspondence to:
Prof Lixin Jiang, National Clinical Research Center of Cardiovascular Diseases, State Key Laboratory of Cardiovascular Disease, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, 100037, China.
jiangl@fwoxford.org

Research in context

Evidence before this study

We searched PubMed and the China National Knowledge Infrastructure databases for articles about the burden of hypertension in China published before July 1, 2017, without language restrictions. Our search terms were "burden", "awareness", "treatment", "control", "hypertension", and "China". We excluded studies that were hospital-based or done in one province. We identified 30 articles (published from 1989 to 2014) that showed a high prevalence of hypertension in the Chinese population, but with low awareness, treatment, and control. Of these 30 studies, two reported geographical variations in prevalence, awareness, treatment, and control, two compared these indicators between China and other countries, and only one reported the number of medications used by treated hypertensive patients but did not include detail about treatment patterns. No previous study enrolled patients from every province, investigated variations in treatment and control according to both geographical and individual characteristics, or assessed use of antihypertensive medications.

Added value of this study

Our study was the most recent nationwide report of the burden of hypertension across all 31 provinces in mainland China and in 264 475 population subgroups that were based on all possible combinations of 11 demographic and clinical variables and included more than 500 people. The study assessed geographical and individual variations in hypertension treatment and control, and antihypertensive medication use among treated patients. We showed that, despite the high prevalence of hypertension, awareness, treatment, and control were low across all population subgroups. People who were male, younger, with lower incomes, without previous cardiovascular events, and without coexisting conditions (diabetes, obesity, or alcohol use) were less likely to be aware of, or treated and controlled for, hypertension. Most people with hypertension were either not treated or treated inadequately.

Implications of all the available evidence

Our study identified the need for broad-based reform and interventions to mitigate the burden of hypertension in China, and a strategy to prevent and control hypertension that includes all provinces and subpopulations. Future research should focus on assessing the causes of low awareness, treatment, and control of hypertension from the perspectives of patients, doctors, and the health system, and on assessments of interventions and treatment strategies to control blood pressure at the population level. Nationally integrated strategies such as health education, free blood-pressure screening, and improved access to affordable medications are urgently needed to improve the prevention and control of hypertension in China.

variations in hypertension measures. Additionally, most previous studies did not link blood pressure control with diverse individual and primary health-care sites,[10–13] and did not present data on the intensity and classes of medications used by patients, who often require several drugs to control blood pressure.

See Online for appendix

Accordingly, we report here the results from 1·7 million participants in our China Patient-Centered Evaluative Assessment of Cardiac Events (PEACE) Million Persons Project, a government-funded, large-scale population-based screening project in China. We assessed the prevalence, awareness, treatment, and control of hypertension by geography and subpopulations; the number and classes of medications used by treated patients; and the association of hypertension awareness, treatment, and control with both individual and primary health-care site characteristics.

Methods

Study design and participants

The China PEACE Million Persons Project has been described previously.[14] Briefly, the pilot phase was successfully done between Oct 1, 2014, and June 30, 2015, to screen 0·4 million community-dwelling residents in four Chinese provinces (Jilin, Liaoning, Zhejiang, and Guangxi).[14] Data were missing for less than 5% of participants, and audit results showed that the overall quality of the data was high. From Sept 15, 2014, to June 20, 2017, we used a convenience sampling strategy to select 141 sites (88 rural counties and 53 urban districts) from all 31 provinces in mainland China (see appendix for more detail). At each site, we selected about five towns or subdistricts according to their size and population stability, in which potential participants were invited to the trial by local staff via extensive publicity campaigns on television and in newspapers.[14] Participants were enrolled if they were aged 35–75 years and registered in the selected region's Hukou (a record officially identifying area residents). During 2015–17, residents aged 35–75 years who had lived in the selected regions for at least 6 of the previous 12 months were enrolled. Of 1765 425 enrolled participants, 26 539 (1·5%) were excluded because of missing data for blood pressure and covariates (appendix). The central ethics committee at the China National Center for Cardiovascular Disease approved this project. All enrolled participants provided written informed consent.

Data collection and variables

For each participant, we measured blood pressure two times on their right upper arm after 5 min of rest in a seated position using an electronic blood pressure monitor (Omron HEM-7430; Omron Corporation, Kyoto, Japan) and a standard protocol (appendix). During a

standardised in-person interview done by trained personnel (appendix), participants were asked if they had used or taken a prescription drug for antiplatelet, blood pressure, lipid, or glucose control in the past 2 weeks. Those who answered "yes" and knew the drug names were asked to report the name, dose, and frequency of each drug. Those who did not remember the exact dose stated the number of tablets or pills taken (appendix).

Consistent with the US Joint National Committee and Chinese definitions,[15–17] hypertension was defined as an average systolic blood pressure (SBP) of at least 140 mm Hg or an average diastolic blood pressure (DBP) of at least 90 mm Hg, or self-reported use of an antihypertensive drug in the past 2 weeks. Stage 2 and above hypertension was defined as an average SBP of at least 160 mm Hg or an average DBP of at least 100 mm Hg.[17] Participants were deemed to be aware of hypertension if they responded "yes" when asked "have you ever been diagnosed with hypertension?" Treatment of hypertension was defined as current use of antihypertensive medication. Hypertension control was defined as an average SBP of less than 140 mm Hg and an average DBP of less than 90 mm Hg over two readings in people with hypertension; patients not meeting these criteria were considered uncontrolled.

We also collected information on participants' socio-demographic characteristics, health behaviours, and medical history during the in-person interviews (appendix). We took physical measurements, including height and weight, following standard protocols. Body-mass index (BMI) was defined as weight (kg) divided by height² (m²); obesity was defined as a BMI of at least 28 kg/m², based on the recommendations of the Working Group on Obesity in China.[18]

Statistical analysis

We estimated the prevalence of hypertension among all participants, as well as awareness, treatment, and control of hypertension among hypertensive participants. To systematically examine how hypertension awareness, treatment, and control varied by subpopulations, we did a comprehensive analysis of population subgroups. These were defined a priori by all possible combinations of 11 selected characteristics: age (35–44, 45–54, 55–64, and 65–75 years), sex (men and women), geographical region (western, central, and eastern China), urbanity (urban *vs* rural), ethnic origin (Han and non-Han), occupation (farmer and non-farmer), annual household income (<¥10 000 [equivalent to US$1452], ¥10 000–50 000 [$1452–7259], and ≥¥50 000 [$7259]), education (primary school and below, middle school, high school, and college and above), previous cardiovascular events (yes or no), current smoker (yes or no), and diabetes (yes or no). We retained 264 475 subgroups of more than 500 people, calculated the prevalence of hypertension, and the proportions of those who were aware of their condition, receiving treatment, and had achieved control. We used histograms to show the distributions (appendix), and repeated the analysis by restricting the subgroups to 130 085 that included at least 3000 participants each.

To characterise the pattern of antihypertensive medication use, we assessed the number and classes of medications used by treated patients. Medication classes were the six defined by the 2010 Chinese guidelines for the management of hypertension,[16] including angiotensin-converting-enzyme (ACE) inhibitors or angiotensin-receptor blockers (ARBs), β-blockers, calcium-channel blockers, diuretics, α-blockers, and fixed-dose combination drugs. We also collected information on traditional Chinese medicines used for hypertension (appendix).

Finally, we developed multivariable mixed models with a logit link function and township-specific random intercepts, taking into account spatial autocorrelation, to identify both individual and primary health-care site characteristics independently associated with hypertension awareness, treatment, and control. We calculated two sets of models: the first, using 1·7 million participants in the Million Persons Project, assessed individual characteristics associated with hypertension awareness, treatment, and control. The explanatory variables included participants' age, sex, geographic regions, education, annual household income, health insurance status, smoking, drinking, obesity, physician-diagnosed diabetes mellitus, and previous cardiovascular events (myocardial infarction or stroke). In a sensitivity analysis, we tested all 146 two-way interaction terms between covariates and used p=0·0003 as the Bonferroni corrected threshold for significance. In the second set of models, we linked the Million Persons Project with another study, the Primary Health Care Survey (done in a subset of Million Persons Project sites) of 1·03 million participants at 113 sites (appendix).

In the sensitivity analyses, we calculated age-standardised and sex-standardised rates of hypertension prevalence, awareness, treatment, and control at the national and regional levels, using data from all 31 provinces in the 2010 Chinese census.[19] We assigned individuals different weights so that the age and sex distributions matched the census data. All analyses were done with SAS 9.3 and R 3.02.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Our sample contained 1 738 886 people with a mean age of 55·6 years (SD 9·7), and 1 035 026 (59·5%, 95% CI 59·4–59·6) were women. Compared with the population aged 35–75 years in the 2010 Chinese census (46·6%), our sample contained more people aged 50 years and older (70·1%; table 1).

Overall, 44·7% (777 637, 95% CI 44·6–44·8) of the study population had hypertension, including 15·2% (264 822, 15·2–15·3) with stage 2 and above hypertension (table 1). Hypertension prevalence increased with age in both men and women (figure 1). People with higher blood pressure were more likely to have lower annual household income, lower educational status, currently smoke, currently drink, have diabetes, obesity, and previous cardiovascular events than those with lower blood pressure (table 1).

Fewer than half (347 755, 44·7% [95% CI 44·6–44·8]) of the people with hypertension and just over half (147 887, 55·8% [55·7–56·0]) of those with stage 2 and above hypertension were aware of their diagnosis. Among the people with hypertension, 233 933 (30·1% [30·0–30·2]) were taking prescribed medications to lower blood pressure, and 55 876 (7·2% [7·1–7·2]) had achieved control (figure 1). Among the 15·2% of people with stage 2 and above hypertension, more than 60% were not treated and only a third took allopathic drugs for hypertension.

The 264 475 population subgroups varied with respect to hypertension prevalence (range 11·4–88·3%),

	Overall (n=1 738 886)	No hypertension (n=961 249)	All hypertension (n=777 637)	Stage 2 and above hypertension (n=264 822)
Prevalence	100·0% (100·0–100·0)	55·3% (55·2–55·4)	44·7% (44·6–44·8)	15·2% (15·2–15·3)
Age (years)				
35–39	77 668 (4·5%)	64 096 (6·7%)	13 572 (1·7%)	4391 (1·7%)
40–44	184 594 (10·6%)	140 398 (14·6%)	44 196 (5·7%)	13 625 (5·1%)
45–49	256 922 (14·8%)	174 123 (18·1%)	82 799 (10·6%)	26 397 (10·0%)
50–54	304 060 (17·5%)	177 001 (18·4%)	127 059 (16·3%)	41 005 (15·5%)
55–59	248 157 (14·3%)	127 944 (13·3%)	120 213 (15·5%)	39 336 (14·9%)
60–64	299 540 (17·2%)	136 111 (14·2%)	163 429 (21·0%)	56 108 (21·2%)
65–69	224 432 (12·9%)	89 541 (9·3%)	134 891 (17·3%)	48 699 (18·4%)
70–75	143 513 (8·3%)	52 035 (5·4%)	91 478 (11·8%)	35 261 (13·3%)
Sex				
Men	703 860 (40·5%)	373 961 (38·9%)	329 899 (42·4%)	111 004 (41·9%)
Women	1 035 026 (59·5%)	587 288 (61·1%)	447 738 (57·6%)	153 818 (58·1%)
Urbanity				
Urban	675 339 (38·8%)	388 598 (40·4%)	286 741 (36·9%)	92 866 (35·1%)
Rural	1 063 547 (61·2%)	572 651 (59·6%)	490 896 (63·1%)	171 956 (64·9%)
Geographical region of China				
Eastern	576 110 (33·1%)	293 056 (30·5%)	283 054 (36·4%)	93 725 (35·4%)
Western	675 880 (38·9%)	401 480 (41·8%)	274 400 (35·3%)	98 380 (37·1%)
Central	486 896 (28·0%)	266 713 (27·7%)	220 183 (28·3%)	72 717 (27·5%)
Ethnic group				
Han	1 529 611 (88·0%)	833 104 (86·7%)	696 507 (89·6%)	233 173 (88·0%)
Non-Han	207 376 (11·9%)	127 268 (13·2%)	80 108 (10·3%)	31 255 (11·8%)
Unknown*	1899 (0·1%)	877 (0·1%)	1022 (0·1%)	394 (0·1%)
Education				
Primary school or lower	769 511 (44·3%)	387 976 (40·4%)	381 535 (49·1%)	135 535 (51·2%)
Middle school	558 880 (32·1%)	322 264 (33·5%)	236 616 (30·4%)	77 708 (29·3%)
High school	258 905 (14·9%)	154 575 (16·1%)	104 330 (13·4%)	33 203 (12·5%)
College or above	125 113 (7·2%)	81 215 (8·4%)	43 898 (5·6%)	14 430 (5·4%)
Unknown*	26 477 (1·5%)	15 219 (1·6%)	11 258 (1·4%)	3946 (1·5%)
Household income (¥/year)				
<10 000	390 948 (22·5%)	208 204 (21·7%)	182 744 (23·5%)	67 295 (25·4%)
10 000–50 000	958 190 (55·1%)	530 784 (55·2%)	427 406 (55·0%)	143 234 (54·1%)
>50 000	229 483 (13·2%)	131 188 (13·6%)	98 295 (12·6%)	30 146 (11·4%)
Unknown*	160 265 (9·2%)	91 073 (9·5%)	69 192 (8·9%)	24 147 (9·1%)
Marital status				
Married	1 615 561 (92·9%)	902 844 (93·9%)	712 717 (91·7%)	241 472 (91·2%)
Widowed, separated, divorced, or single	100 412 (5·8%)	45 531 (4·7%)	54 881 (7·1%)	19 595 (7·4%)
Unknown*	22 913 (1·3%)	12 874 (1·3%)	10 039 (1·3%)	3755 (1·4%)

(Table 1 continues on next page)

	Overall (n=1 738 886)	No hypertension (n=961 249)	All hypertension (n=777 637)	Stage 2 and above hypertension (n=264 822)
(Continued from previous page)				
Health insurance status				
Insured	1 701 087 (97·8%)	939 638 (97·8%)	761 449 (97·9%)	259 234 (97·9%)
Uninsured	10 083 (0·6%)	6099 (0·6%)	3984 (0·5%)	1306 (0·5%)
Unknown*	27 716 (1·6%)	15 512 (1·6%)	12 204 (1·6%)	4282 (1·6%)
Medical history				
Myocardial infarction	12 649 (0·7%)	4560 (0·5%)	8089 (1·0%)	2611 (1·0%)
Stroke	40 555 (2·3%)	10 879 (1·1%)	29 676 (3·8%)	11 568 (4·4%)
Cardiovascular disease risk factors				
Diabetes mellitus	105 379 (6·1%)	35 377 (3·7%)	70 002 (9·0%)	24 989 (9·4%)
Current smoker	340 219 (19·6%)	185 504 (19·3%)	154 715 (19·9%)	52 340 (19·8%)
Current drinker	418 818 (24·1%)	217 158 (22·6%)	201 660 (25·9%)	69 463 (26·2%)
Obesity (body-mass index ≥28 kg/m²)	272 796 (15·7%)	98 203 (10·2%)	174 593 (22·5%)	66 675 (25·2%)

Data are % (95% CI) or n (%). No hypertension: systolic blood pressure <140 mm Hg, diastolic blood pressure <90 mm Hg, and not taking antihypertensive medication. All hypertension: systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg, or taking antihypertensive medication. Stage 2 and above hypertension: systolic blood pressure ≥160 mm Hg or diastolic blood pressure ≥100 mm Hg. *Participants either refused to answer the question or did not know the answer.

***Table 1*: Characteristics of the study population by blood pressure levels**

awareness (3·8–90·9%), and treatment (2·2–76·2%), but hypertension control was poor (<30%) in all subgroups (appendix). Subgroups with at least 3000 participants had similar results (appendix). Compared with people of younger age, with no previous cardiovascular events, and non-Han ethnicity, older people, with previous cardiovascular events, and Han ethnicity had higher awareness, treatment, and control rates for their hypertension (figure 2). Additionally, regional variations occurred for hypertension prevalence, awareness, treatment, and control; prevalence was highest in the eastern region, but awareness, treatment, and control were highest in the central region, followed by the eastern and western regions (appendix). Compared with urban areas, rural areas had slightly higher hypertension prevalence (rural 46·1% [95% CI 46·1–46·3] *vs* urban 42·5% [42·3–42·6]) but lower awareness, treatment, and control (urban 46·3% [46·1–46·5], 33·4% [33·2–33·5], and 9·1% [9·0–9·2] *vs* rural 43·8% [43·7–43·9], 28·2% [28·0–28·3], and 6·1% [6·0–6·2], respectively). In all different age groups, rural areas had higher prevalence, but lower awareness, treatment, and control rates of hypertension compared with urban areas (appendix).

In sensitivity analyses, we standardised our national census-based estimates and noted lower prevalence, awareness, treatment, and control: 37·2% (95% CI 37·1–37·3), 36·0% (35·8–36·2), 22·9% (22·7–23·0), and 5·7% (5·6–5·7), respectively.

Among patients treated for hypertension, 189 740 (81·1% [95% CI 81·0–81·3]) reported using one medication, 39 832 (17·0% [16·9–17·2) reported two, and 4361 (1·9% [1·8–1·9]) reported three or more (appendix). Among patients treated with one, two, and three or more medications, respectively, 44 694 (23·6% [23·4–23·7]), 9979 (25·1% [24·6–25·5]), and 1203 (27·6% [26·3–28·9]) achieved control. Of the treated patients, 178 057 (76·1% [75·9–76·3]) did not have their blood pressure under control. Among

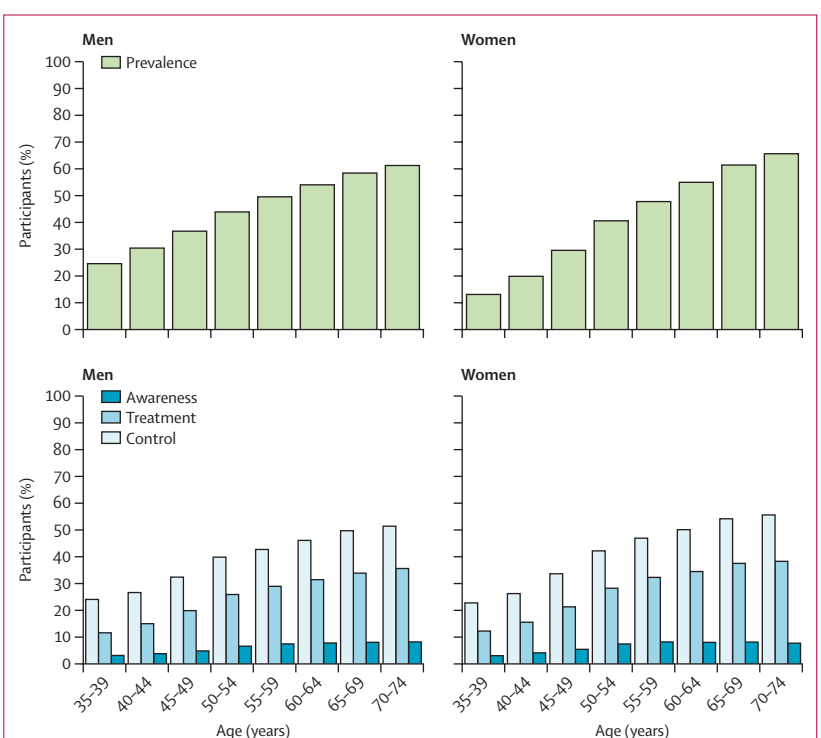

***Figure 1*: Prevalence, awareness, treatment, and control of hypertension among study participants**
Data are shown stratified by age and sex.

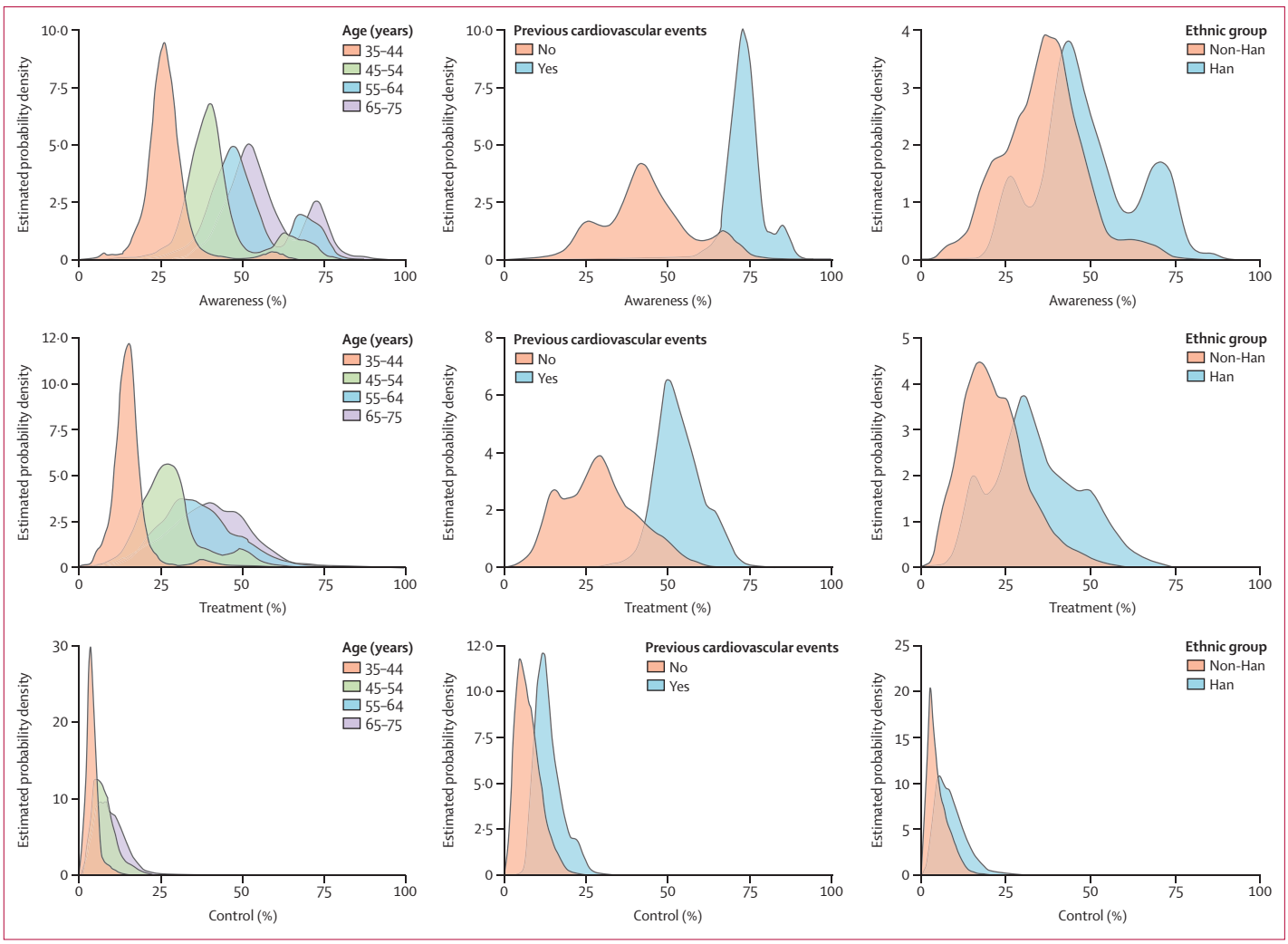

***Figure 2*: Density plots of awareness, treatment, and control of hypertension in 264 475 subgroups**
Data are shown stratified by age, previous cardiovascular disease, and ethnic origin. The density means estimated probability of the corresponding awareness, treatment, and control rate. The area under the curve is 1.

patients who were treated but not controlled, 145 046 (81·5% [81·3–81·6]) used one medication, 29 853 (16·8% (16·6–16·9]) used two, and 3158 (1·8% [1·6–1·9]) used three or more.

Overall, calcium-channel blockers were the most commonly used medication class (116 806, 55·2% [95% CI 55·0–55·4]), followed by ACE inhibitors or ARBs (60 361, 28·5% [28·3–28·7]) and diuretics (19 851, 9·4% [9·3–9·5]; appendix), and 19 180 (8·2% [8·1–8·3]) used traditional Chinese medicines. Among patients using only one medication, nifedipine was the most common agent, followed by amlodipine and indapamide (table 2). Calcium-channel blockers plus ACE inhibitors or ARBs was the most common combination therapy (13 812, 6·5% [6·4–6·6]), followed by ACE inhibitors or ARBs plus a diuretic (5745, 2·7% [2·6–2·8]) and calcium-channel blockers plus a β-blocker (4582, 2·2% [2·1–2·3]). Among patients using two separate medications, nifedipine plus metoprolol was the most frequent combination with 897 (6·7% [6·3–7·1]) using this in urban areas and 787 (4·8% [4·5–5·1]) in rural areas.

Multivariable mixed models identified several characteristics associated with hypertension prevalence, awareness, treatment, and control (table 3). People who were older, men, those with lower education, non-farmers, current smokers, with previous cardiovascular events, and coexisting conditions (diabetes or obesity) were more likely to have a higher risk of hypertension. Among people with hypertension, those who were older, women, those with higher education, higher annual household income, with prior cardiovascular events, and coexisting conditions (diabetes or obesity) were more likely to be aware of, treated for, and controlled for hypertension. Those without health insurance, farmers, and current drinkers were less aware of, treated for, or controlled for hypertension. Sex, age, previous

	Overall	35–44 years	45–54 years	55–64 years	65–75 years
Among adults using one medication					
Nifedipine	49 034 (26·2%)	1398 (22·1%)	9926 (24·2%)	19 516 (26·5%)	18 194 (27·5%)
Amlodipine	14 390 (7·7%)	476 (7·5%)	3240 (7·9%)	5594 (7·6%)	5080 (7·7%)
Indapamide	11 598 (6·2%)	349 (5·5%)	2712 (6·6%)	4664 (6·3%)	3873 (5·9%)
Compound reserpine*	9944 (5·3%)	227 (3·6%)	2036 (5·0%)	3922 (5·3%)	3759 (5·7%)
Nitrendipine	9107 (4·9%)	193 (3·0%)	1565 (3·8%)	3490 (4·7%)	3859 (5·8%)
Total	187 320 (100%)	6335 (100%)	40 995 (100%)	73 749 (100%)	66 241 (100%)
Among adults using two medications					
Nifedipine and metoprolol	1684 (5·7%)	48 (4·2%)	369 (5·3%)	621 (5·5%)	646 (6·2%)
Captopril and nifedipine	1441 (4·8%)	52 (4·5%)	279 (4·0%)	582 (5·2%)	528 (5·0%)
Nifedipine and irbesartan	911 (3·1%)	42 (3·7%)	217 (3·1%)	342 (3·0%)	310 (3·0%)
Amlodipine besylate and irbesartan	893 (3·0%)	32 (2·8%)	235 (3·4%)	330 (2·9%)	296 (2·8%)
Nifedipine and telmisartan	711 (2·4%)	38 (3·3%)	183 (2·6%)	265 (2·4%)	225 (2·1%)
Total	29 792 (100%)	1143 (100%)	6913 (100%)	11 263 (100%)	10 473 (100%)
Among adults using three medications					
Nifedipine, metoprolol, and irbesartan	61 (2·5%)	3 (3·0%)	6 (1·1%)	23 (2·6%)	29 (3·1%)
Amlodipine, metoprolol, and irbesartan	54 (2·2%)	4 (4·0%)	9 (1·6%)	18 (2·1%)	23 (2·5%)
Nifedipine, telmisartan, and metoprolol	41 (1·7%)	0	13 (2·4%)	12 (1·4%)	16 (1·7%)
Total	2453 (100%)	99 (100%)	549 (100%)	876 (100%)	929 (100%)

Data are n (%) stratified by age and number of medications. *A fixed-dose combination drug consisting of reserpine (0·032 mg), hydrochlorothiazide (3·1 mg), potassium chloride (30 mg), dihydralazine sulfate (2·1 mg), and promethazine (2·1 mg).

***Table 2*: The most commonly used medications among treated adults with hypertension**

cardiovascular events, diabetes, and obesity were stronger predictors for hypertension awareness than for treatment and control, whereas education, annual household income, farming occupation, smoking, and drinking were stronger predictors for control than for treatment and awareness.

In a sensitivity analysis, 21 interaction terms were significant for hypertension awareness, 24 significant for hypertension treatment, and 20 significant for hypertension control (appendix). Among these, for more than 90% of the interaction terms (20, 23, and 18 for awareness, treatment, and control, respectively), their odds ratios (ORs) fell between 0·75 and 1·25. Except for geographical regions, the only primary health-care site characteristic associated with higher hypertension awareness, treatment, and control rate was having more primary health-care physicians with at least a bachelor's degree, but the absolute association was not strong (OR 1·00, 95% CI 1·00–1·01 for awareness; OR 1·01, 95% CI 1·00–1·01 for treatment; OR 1·01, 95% CI 1·00–1·02 for control). Compared with the western region, the central and eastern regions were associated with a higher proportion of people who had hypertension awareness, treatment, and control rates (appendix).

Discussion

In this study, hypertension was highly prevalent in China but remained undertreated and uncontrolled. Although 45% of middle-aged adults had hypertension (15% with stage 2 and above hypertension), most were untreated; even among people with stage 2 and above hypertension, only a third were treated. People who were male, younger, lower income, without prior cardiovascular events, and without coexisting conditions were less likely to be aware of, treated for, and controlled for hypertension. However, variation in awareness and treatment did not reflect a similar pattern in control. We showed remarkably low control rates (<30%) that were consistent across more than 200 000 subgroups, highlighting China's need for a national hypertension strategy.

We have added to the scientific literature in several ways with this study, although our findings of poor management of hypertension are consistent with previous studies in China.[3,4,6–9] First, the size of our study, the largest on hypertension in China, allowed us to study a wide variety of subgroups with a substantial number of people. We analysed 264 475 subgroups defined by all possible combinations of 11 selected characteristics to systematically examine how hypertension awareness, treatment, and control rates vary within the Chinese population. Our results reveal that hypertension control in community-dwelling residents in China is poor overall and across diverse population subgroups. The most direct implication is that China needs a universal, rather than a targeted, approach to hypertension and that the impediments to control must be illuminated.

Second, we provide new information about individual and primary health-care site characteristics associated

	Prevalence	Awareness	Treatment	Control
Age (per 5 years)	1·35 (1·35–1·35)	1·20 (1·20–1·20)	1·19 (1·19–1·20)	1·07 (1·07–1·08)
Sex				
Men	1 (ref)	1 (ref)	1 (ref)	1 (ref)
Women	0·97 (0·96–0·98)	1·18 (1·16–1·19)	1·16 (1·14–1·18)	1·11 (1·09–1·14)
Ethnic origin				
Non–Han	1 (ref)	1 (ref)	1 (ref)	1 (ref)
Han	1·00 (0·98–1·01)	1·00 (0·97–1·02)	1·03 (1·01–1·06)	1·06 (1·01–1·12)
Marital status				
Not married	1 (ref)	1 (ref)	1 (ref)	1 (ref)
Married	0·93 (0·92–0·94)	0·97 (0·95–0·99)	1·01 (0·99–1·03)	1·08 (1·05–1·12)
Annual household income (¥)				
<10 000	1 (ref)	1 (ref)	1 (ref)	1 (ref)
10 000–50 000	1·00 (0·98–1·01)	1·02 (1·01–1·04)	1·04 (1·02–1·06)	1·09 (1·06–1·12)
>50 000	1·00 (0·99–1·02)	1·09 (1·07–1·12)	1·10 (1·08–1·13)	1·22 (1·18–1·27)
Education level				
Lower than college	1 (ref)	1 (ref)	1 (ref)	1 (ref)
College or above	0·93 (0·91–0·96)	1·16 (1·12–1·21)	1·14 (1·10–1·19)	1·22 (1·15–1·30)
Occupation				
Not a farmer	1 (ref)	1 (ref)	1 (ref)	1 (ref)
Farmer	0·96 (0·95–0·97)	0·90 (0·89–0·92)	0·83 (0·82–0·85)	0·80 (0·77–0·82)
Health insurance status				
Insured	1 (ref)	1 (ref)	1 (ref)	1 (ref)
Uninsured	0·99 (0·93–1·05)	0·78 (0·70–0·85)	0·76 (0·69–0·85)	0·75 (0·62–0·91)
Cardiovascular disease risk factors				
Current smoker	1·03 (1·02–1·04)	1·03 (1·02–1·05)	0·99 (0·98–1·01)	1·13 (1·10–1·16)
Current drinker	1·50 (1·48–1·52)	0·94 (0·93–0·96)	0·87 (0·85–0·88)	0·74 (0·72–0·77)
Diabetes mellitus	2·59 (2·57–2·62)	2·25 (2·21–2·29)	1·79 (1·76–1·83)	1·37 (1·34–1·41)
Obesity (body–mass index ≥28 kg/m^2)	1·80 (1·77–1·82)	1·66 (1·64–1·68)	1·55 (1·53–1·57)	1·02 (0·99–1·04)
Previous cardiovascular diseases	2·20 (2·15–2·24)	3·20 (3·12–3·29)	2·60 (2·54–2·67)	2·07 (2·00–2·13)
Geographical region of China				
Western	1 (ref)	1 (ref)	1 (ref)	1 (ref)
Central	1·52 (1·44–1·60)	1·02 (0·93–1·11)	0·87 (0·77–0·98)	0·93 (0·80–1·08)
Eastern	1·34 (1·26–1·42)	1·10 (0·91–1·19)	1·08 (0·94–1·23)	1·06 (0·90–1·25)

Data are odds ratios (95% CI).

***Table 3*: Individual characteristics associated with prevalence, awareness, treatment, and control of hypertension**

with hypertension awareness, treatment, and control, and formally test interactions between covariates. Lower awareness, treatment, and control rates are associated with younger men and people with less education, lower income, and no cardiovascular risk factors—people who might have little contact with the health-care system. However, our analysis revealed that no group had substantially better control, even though awareness and treatment did vary. We have also assessed primary health-care site characteristics by linking the current study with the Primary Health Care Survey, but we could not identify strong explanations for the low control. Ultimately, differences in awareness and treatment are not translating into control, and thus improving both are necessary, but not sufficient, to achieve better control. There is no evidence of any population subgroup excelling in hypertension control and no evidence that a particular biological or societal factor is associated with achieving high control. This suggests a fundamental structural change is needed to address hypertension in China, and education and screening will not be sufficient without parallel efforts to improve treatments. The issues might include the need for screening and education, supplemented by protocols and policies that ensure provision of adequate treatment and access to affordable medications.

Third, our assessment of antihypertensive medications highlights substantial opportunities to intensify treatment among the few patients whose hypertension was treated but not controlled. Taking advantage of the medication data, our study showed that only a quarter of treated patients had their hypertension under control and most used only one antihypertensive drug. Because hypertension control often requires multiple medications, our finding that use of multiple medications is rare in China might help to partly explain the few people with optimal control.

Compared with national data from high-income countries such as the USA,[20–22] our data showed a four-times higher prevalence of stage 2 and above hypertension but substantially fewer people with hypertension awareness, treatment, or control in China. Using data from the 2013–14 US National Health and Nutrition Examination Survey, we estimated that 87% of adults aged 40–75 years with hypertension were diagnosed, 73% were treated, and 61% achieved blood pressure goals. By contrast, the corresponding percentages are only 44·7%, 30·1%, and 7·2% in China. Moreover, the classes of medications used differed greatly between the two countries. ACE inhibitors or ARBs, β-blockers, and diuretics are commonly used in the USA but less so in China despite guideline recommendations.[15,16] China's lower use of diuretics might reflect that new guidelines recommend other medication classes (calcium-channel blockers, ACE inhibitors, and ARBs) as initial therapy and that insurance coverage for these drugs has been expanded.[15,16,23] Moreover, China is commonly using a diuretic (indapamide) that is different from those used in the USA and Europe. Additionally, combination therapy is used much more frequently in the USA than in China.[21] Many factors contribute to these differences, including primary care physicians' prescription habits, physicians' knowledge of and willingness to adhere to new hypertension treatment guidelines, and affordability of newer drugs. Finally, traditional Chinese medicines are still widely used, but these might not be effective for treating hypertension.

Our study has several policy implications. Unlike many other countries, stroke is the leading cause of death in China, causing 20% of deaths annually.[24]

Because high blood pressure is a major attributable risk factor of stroke,[5] uncontrolled hypertension could largely contribute to the high stroke mortality in China. This fact is even more relevant because blood pressure levels in China are increasing, a trend presumably related to increases in population ageing, urbanisation, dietary changes, and obesity.[25] Therefore, an important step to mitigate the burden of cardiovascular diseases in China is to continue previous efforts to reduce blood pressure at the population level. A few key actions might be effective, as highlighted in the 2016 *Lancet* Commission report on hypertension.[26] These include promoting free blood pressure screening and public awareness programmes, strengthening health systems, integrating hypertension management into routine primary care practice, promoting structured physician-education programmes to reduce clinical inertia and improve guideline adherence,[27–29] removing financial barriers to health care, and improving access to affordable drugs.[30] Additionally, given the high prevalence of hypertension, China must respond with high-quality individual clinical care as the basis for public health interventions, including diet and physical activity, to prevent the development of hypertension in unaffected individuals.

Our study had several potential limitations. First, our study did not use representative sampling because it was not possible with such rapid, large-scale recruitment. We corrected for the characteristics of the underlying population at the national and regional levels using the 2010 Chinese census data and found that the corrected estimates were lower for awareness, treatment, and control. Moreover, we would expect that our sampling biases would result in overestimates of awareness, treatment, and control as study participants by virtue of responding to this screening project would be more likely connected with the health system. Second, we did not obtain information about patients' adherence to medication, access to regular physicians, or physicians' knowledge of antihypertensive medication use, which reduced our ability to investigate some potential reasons for suboptimal treatment. Third, we did not capture or classify non-pharmacological treatment strategies, such as dietary modification, which might yield an underestimation of hypertension treatment but would not affect our assessments of awareness and control. Fourth, people who used an antihypertensive medication might not have reported that use, possibly yielding an underestimation of the hypertension treatment rate. Finally, the blood pressure levels used to define hypertension control in this paper are largely consistent with European, Canadian, and British guidelines[1–3] but might underestimate control if higher goal blood-pressure levels are used as in the eighth Joint National Committee.[4]

We conclude that hypertension is a major public health challenge in China. Despite its high prevalence, hypertension control in community-dwelling residents is poor, both overall and in diverse population subgroups. Our findings support broad-based opportunities to mitigate the burden of hypertension and suggest the need for a national strategy on hypertension prevention and control.

Contributors

LJ and HMK conceived the China PEACE Million Persons Project and take responsibility for its all aspects. JLu led the data collection. HMK, LJ, and JLu designed the study. HMK, LJ, YL, and JLu conceived this article. HMK, LJ, YL, and JLu wrote the manuscript, with further contributions from HZhang, JLiu, MS, ESS, JAS, and FAM. XW and XL completed all the statistical analysis supported by CW, XC, LM, GCL, and HZhao. All authors interpreted data, contributed to critical revisions, and approved the final version of the Article.

Declaration of interests

HMK is a recipient of research agreements from Medtronic, and Johnson & Johnson (Janssen) through Yale, to develop methods of clinical trial data sharing; received a grant from the US Food and Drug Administration and Medtronic, through Yale, to develop methods for post-market surveillance of medical devices; works under contract with the US Centers for Medicare & Medicaid Services to develop and maintain performance measures; chairs a cardiac scientific advisory board for United Health; is a participant or participant representative of the IBM Watson Health Life Sciences Board; is a member of the Advisory Board for Element Science and the Physician Advisory Board for Aetna; and is the founder of Hugo, a personal health information platform. All other authors declare no competing interests.

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References

1 Chen Z. Launch of the health-care reform plan in China. *Lancet* 2009; **373:** 1322–24.

2 Yang ZJ, Liu J, Ge JP, et al. Prevalence of cardiovascular disease risk factor in the Chinese population: the 2007–2008 China National Diabetes and Metabolic Disorders Study. *Eur Heart J* 2012; **33:** 213–20.

3 Li D, Lv J, Liu F, et al. Hypertension burden and control in mainland China: analysis of nationwide data 2003–2012. *Int J Cardiol* 2015; **184:** 637–44.

4 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.

5 He J, Gu D, Chen J, et al. Premature deaths attributable to blood pressure in China: a prospective cohort study. *Lancet* 2009; **374:** 1765–72.

6 Yang G, Wang Y, Zeng Y, et al. Rapid health transition in China, 1990–2010: findings from the Global Burden of Disease Study 2010. *Lancet* 2013; **381:** 1987–2015.

7 Wang J, Zhang L, Wang F, Liu L, Wang H, China National Survey of Chronic Kidney Disease Working Group. Prevalence, awareness, treatment, and control of hypertension in China: results from a national survey. *Am J Hypertens* 2014; **27:** 1355–61.

8 Li W, Gu H, Teo KK, et al. Hypertension prevalence, awareness, treatment, and control in 115 rural and urban communities involving 47 000 people from China. *J Hypertens* 2016; **34:** 39–46.

9 Lewington S, Lacey B, Clarke R, et al. The burden of hypertension and associated risk for cardiovascular mortality in China. *JAMA Intern Med* 2016; **176:** 524–32.

10 Wang Z, Wang X, Chen Z, et al. Hypertension control in community health centers across China: analysis of antihypertensive drug treatment patterns. *Am J Hypertens* 2014; **27:** 252–59.

11 Yang L, Yan J, Tang X, Xu X, Yu W, Wu H. Prevalence, awareness, treatment, control and risk factors associated with hypertension among adults in southern China, 2013. *PLoS One* 2016; **11:** e0146181.

12 Gao Y, Chen G, Tian H, et al. Prevalence of hypertension in china: a cross-sectional study. *PLoS One* 2013; **8:** e65938.

13 Meng XJ, Dong GH, Wang D, et al. Prevalence, awareness, treatment, control, and risk factors associated with hypertension in urban adults from 33 communities of China: the CHPSNE study. *Journal Hypertens* 2011; **29:** 1303–10.

14 Lu J, Xuan S, Downing NS, et al. Protocol for the China PEACE (Patient-centered Evaluative Assessment of Cardiac Events) Million Persons Project pilot. *BMJ Open* 2016; **6:** e010200.

15 James PA, Oparil S, Carter BL, et al. 2014 evidence-based guideline for the management of high blood pressure in adults: report from the panel members appointed to the Eighth Joint National Committee (JNC 8). *JAMA* 2014; **311:** 507–20.

16 Liu LS, Writing Group of Chinese Guidelines for the Management of H. 2010 Chinese guidelines for the management of hypertension. *Chin J Cardiol* 2011; **39:** 579–615.

17 Chobanian AV, Bakris GL, Black HR, et al. The seventh report of the joint national committee on prevention, detection, evaluation, and treatment of high blood pressure: the JNC 7 report. *JAMA* 2003; **289:** 2560–72.

18 Zhou BF. Predictive values of body mass index and waist circumference for risk factors of certain related diseases in Chinese adults—study on optimal cut-off points of body mass index and waist circumference in Chinese adults. *BES* 2002; **15:** 83–96.

19 National Bureau of Statistics of China. 2010 Population Census of People's Republic of China. http://www.stats.gov.cn/english/Statisticaldata/CensusData/rkpc2010/indexch.htm (accessed April 17, 2017).

20 Egan BM, Zhao Y, Axon RN. US trends in prevalence, awareness, treatment, and control of hypertension, 1988–2008. *JAMA* 2010; **303:** 2043–50.

21 Gu Q, Burt VL, Dillon CF, Yoon S. Trends in antihypertensive medication use and blood pressure control among United States adults with hypertension: the National Health And Nutrition Examination Survey, 2001 to 2010. *Circulation* 2012; **126:** 2105–14.

22 Yoon SS, Gu Q, Nwankwo T, Wright JD, Hong Y, Burt V. Trends in blood pressure among adults with hypertension: United States, 2003 to 2012. *Hypertension* 2015; **65:** 54–61.

23 Taylor J. 2013 ESH/ESC guidelines for the management of arterial hypertension. *Eur Heart J* 2013; **34:** 2108–09.

24 GBD Mortality Causes of Death Collaborators. Global, regional, and national age-sex specific all-cause and cause-specific mortality for 240 causes of death, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2015; **385:** 117–71.

25 Danaei G, Finucane MM, Lu Y, et al. National, regional, and global trends in fasting plasma glucose and diabetes prevalence since 1980: systematic analysis of health examination surveys and epidemiological studies with 370 country-years and 2·7 million participants. *Lancet* 2011; **378:** 31–40.

26 Olsen MH, Angell SY, Asma S, et al. A call to action and a lifecourse strategy to address the global burden of raised blood pressure on current and future generations: the *Lancet* Commission on hypertension. *Lancet* 2016; **388:** 2665–712.

27 Luders S, Schrader J, Schmieder RE, Smolka W, Wegscheider K, Bestehorn K. Improvement of hypertension management by structured physician education and feedback system: cluster randomized trial. *Eur J Cardiovasc Prev Rehabil* 2010; **17:** 271–79.

28 Onysko J, Maxwell C, Eliasziw M, et al. Large increases in hypertension diagnosis and treatment in Canada after a healthcare professional education program. *Hypertension* 2006; **48:** 853–60.

29 Johnson W, Shaya FT, Khanna N, et al. The Baltimore Partnership to Educate and Achieve Control of Hypertension (The BPTEACH Trial): a randomized trial of the effect of education on improving blood pressure control in a largely African American population. *J Clin Hypertens* 2011; **13:** 563–70.

30 Su M, Zhang Q, Bai X, et al. Availability, cost, and prescription patterns of antihypertensive medications in primary health care in China: a nationwide cross-sectional survey. *Lancet* 2017; published online Oct 25. http://dx.doi.org/10.1016/S0140-6736(17)32476-5.