Area-level socioeconomic inequalities in hypertension care cascade in China: a nationwide population-based study based on the ChinaHEART project

Wenyao Peng,[a] Siqi Lin,[a] Xuan Liu,[a] Bowang Chen,[a] Xueke Bai,[a] Chaoqun Wu,[a] Xiaoyan Zhang,[a] Yang Yang,[a] Jianlan Cui,[a] Wei Xu,[a] Lijuan Song,[a] Hao Yang,[a] Wenyan He,[a] Yan Zhang,[a] Xi Li,[a,b,c,**] and Jiapeng Lu[a,*]

[a]National Clinical Research Center for 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
[b]Fuwai Hospital Chinese Academy of Medical Sciences, Shenzhen, Shenzhen, China
[c]Central China Sub-center of the National Center for Cardiovascular Diseases, Zhengzhou, China

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Summary

Background Socioeconomic status (SES) is one of key social determinants of health. Compared to individual-level SES, the association between area-level SES and hypertension management has been understudied and under-recognised. In this study, we aimed to assess the association between area-level SES and hypertension awareness, treatment, combination therapy and control, and the modification effect of individual characteristics on the associations.

Methods During Dec 2015 and Dec 2022, 1,559,748 residents with hypertension aged 35–75 years from 31 provinces in the China Health Evaluation And risk Reduction through nationwide Teamwork (ChinaHEART) were included. The composite value of area-level SES was generated from national census data and categorized into tertiles. Multivariable mixed models with random effects to account for county-level administrative area were fitted to compute odds ratios (OR) and 95% confidence intervals (CIs) for the independent and interactive associations of both area- and individual-level SES with hypertension management (awareness, treatment, combination therapy and control) and their disparities across different population subgroups.

Findings Among the included participants with hypertension aged 59·1 ± 9·1 years, 794,675 (50·95%), 650,485 (41·70%) and 206,103 (13·21%) were aware, treated, and controlled, respectively. Compared with the high area-level SES group, the low group was significantly associated with a lower odds of hypertension awareness (OR: 0·75, 95% CI: 0·65–0·86), treatment (0·69, 0·59–0·81), combination therapy (0·65, 0·51–0·84), and control (0·62, 0·51–0·75). Participants with low SES at both individual and area level had the lowest odds of hypertension management. Area-level SES had stronger influences on hypertension awareness, treatment and control, but a weaker influence on combination therapy, in the young and those with high individual-level SES.

Interpretation Area-level SES on plays a key role in the awareness, treatment, combination therapy and control of hypertension, with different magnitude of associations. Integrated action to improve area-level circumstances and promote targeted interventions to hypertension care cascade are needed to reduce health inequalities in China.

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Keywords: Hypertension; Hypertension care; Socioeconomic status; Health equity

*Corresponding author. National Clinical Research Center for Cardiovascular Diseases, Fuwai Hospital, 167 Beilishi Road, Beijing, 100037, China.
**Corresponding author. National Clinical Research Center for Cardiovascular Diseases, Fuwai Hospital, 167 Beilishi Road, Beijing, 100037, China.
E-mail addresses: lujiapeng@fuwaihospital.org (J. Lu), xi.li@nccd.org.cn (X. Li).

Research in context

Evidence before this study

We searched PubMed for articles that were published from database inception to Oct 10, 2024, using the search terms ("socioeconomic status (SES)" OR "social determinants of health") AND ("area-level" OR "neighborhood") AND ("hypertension" OR "blood pressure") AND ("awareness" OR "treatment" OR "control"), and only 49 articles published in English were considered. Among them, 16 studies focused on hypertension and nine studies involved in area-level or individual-level SES, which underscored the importance of addressing social determinants of health to reduce hypertension disparities. Eight studies have shown lower area-level or individual-level SES were associated with poorer hypertension control. One study conducted in China has showed that increased relative deprivation on individual-level was likely to have higher odds of uncontrolled blood pressure. However, there were only three studies on association between individual- or area-level SES and hypertension awareness, and none of them focused on combination therapy. Both the interaction and combination effect between area- and individual-level SES on hypertension awareness, treatment, combination therapy and control, as well as the modification effect of individual characteristics have not been studied yet in China.

Added value of this study

Based on a nationwide cohort in China, we found that both area- and individual-level SES play a key role in the awareness, treatment, combination therapy and control of hypertension. Participants with low SES at both area- and individual-level had the lowest odds of being well managed. The stronger associations between area-level SES and hypertension awareness, treatment and control were observed in the young, those with high individual-level SES, and rural areas, while associations between area-level SES and combination therapy were more pronounced in elder people, females, and those with low individual-level SES.

Implications of all the available evidence

Socioeconomic status is one of the most important factors in health inequality. Area-socioeconomic inequalities in hypertension management exist in China. Targeted interventions are needed for different population at each stage of hypertension care cascade. Multisectoral collaborations between health and non-health sectors are required to reduce health inequalities in China.

Introduction

Hypertension remains the most important risk factor contributing to the global burden of disease, leading to 10·8 million deaths every year,[1] which highlights the importance of hypertension management. Socioeconomic status (SES) is one of the most important social determinants that cause health inequality, which has been associated with disparities in hypertension care globally.[2] In addition to individual-level SES, area-level SES representing the living environment of residence, may influence individuals' overall health by affecting access to healthcare services.[3] Thus, more evidences on area-level influencing hypertension management and their interplay are needed to support the efforts of clinicians and policymakers to reduce the disease burden.

Compared to research on individual-level socioeconomic status (SES) as a factor influencing hypertension management,[4] the association between area-level SES and hypertension management has been understudied and under-recognised. First, some study examining area-level SES have considered only the wealth aspect of the region,[5] which was not a comprehensive indicator to reflect the local economic level and societal landscape. Second, most studies have focused solely on the treatment or control of hypertension,[6–11] yet awareness as the first step in the cascade of hypertension care is critical to enable individuals to seek timely intervention and comply with management programs. In addition, the association between SES and combination therapy remains to be investigated. Third, there is a knowledge gap in exploring the complex interactions between individual and area-level SES in shaping hypertension outcomes.[12] Thus, the relationship between area-level SES and hypertension cascade care, as well as interactions between area- and individual characteristics, are critical to enhancing targeted strategies for mitigating the global impact of cardiovascular disease.

Accordingly, using data from ChinaHEART (China Health Evaluation And Risk Reduction through Nationwide Teamwork), a national prospective population-based cohort, we aimed to assess the independent association between area-level SES and hypertension awareness, treatment, combination therapy and control, as well as the modification effect of individual characteristics on the association between area-level SES and hypertension management.

Methods

Study design and population

The ChinaHEART project is a government-funded public health project designed for screening and management of cardiovascular disease (CVD) risk throughout China. The design of the project has been described previously.[13] In brief, from December 2015 to

December 2022, 363 sites (including 523 county-level areas) in 31 provinces in mainland China were selected, to provide diversity in geographic distribution, development levels and population structure. The selection of the study site also considered population size, population stability, and the local capacity to support the project. Residents aged 35–75 years, who had lived in the community for at least six months in the previous year, from these sites were invited to participate in the project and provide their baseline information. The overall response rate was 38·52%.

Among the 4·3 million screened participants, 1,990,707 participants with hypertension were included. Participants with medical history of CVD or cancer (115,614), those who refused to answer or responded "unknown" to the questions about individual-level SES (280,730), and those whose information on area-level SES was lacking (34,615) were excluded from this study. Eventually, a total of 1,559,748 participants from 472 county-level areas with hypertension were included in the study (Appendix Figure S1).

The project protocol was approved by the central ethics committee at Fuwai Hospital (Beijing, China; approval number 2014-574). Written informed consent was obtained from all enrolled participants.

Data collection and variable definition

For each participant, a face-to-face interview using electronic questionnaires was conducted by trained personnel to collect information on demographic factors (i.e., age, sex, and marital status), individual-level SES factors, lifestyle factors, medical history, and medication use at baseline. For tobacco smoking, participants were asked about their current smoking status ('yes' or 'no') and how often they currently smoked ('never', 'occasionally', 'most days' or 'every day'). Participants who smoke at present, occasionally, most days and every day were defined as current smokers, and the others were categorized into non-current smokers.[14] For alcohol drinking, we asked about drinking frequency ('never', 'once or less per month', '2–4 times per month', '2–3 times per week', 'more than 4 times per week'). Participants who drank two or three times a week or more in the past year were defined as current drinkers, and the others were categorised into non-current drinkers.[15] For blood pressure, weight, and height at baseline were measured using the standardised protocols and unified devices. Body mass index (BMI) was defined as weight in kilograms divided by the square of height in metres. Participants were categorized into four categories according to Chinese obesity guideline[16]: low weight (BMI <18·5 kg/m^2), normal weight (18·5 $kg/m^2 \leq$ BMI <24 kg/m^2), overweight (24 $kg/m^2 \leq$ BMI< 28 kg/m^2), and obese (BMI $\geq$28 kg/m^2).

For each participant, we measured blood pressure twice on their right upper arm after 5 min of rest in a seated position (Omron HEM-7430) and a mean blood pressure was calculated. If the differences between the first two blood pressure was large than 10 mmHg, a third measurement was conducted, and a mean blood pressure was calculated using the last two measurements. Hypertension was defined as meeting at least one of the following criteria according to the US and Chinese definitions[17,18]: 1) self-reported hypertension (aware); 2) clearly report the name of the drug or self-reported taking antihypertensive drugs (treated); 3) systolic blood pressure (SBP) $\geq$140 mmHg or diastolic blood pressure (DBP) $\geq$90 mmHg. Hypertension control was defined as having a mean SBP <140 mmHg and DBP <90 mmHg among individuals who had hypertension. Combination therapy referred to those who took two or more types of antihypertensive drugs.

The overall individual-level SES was generated from three factors including education, household income, and employment, using latent class analysis (Appendix Methods), as they have been widely used in previous studies.[19] Education level was categorized as primary school or below, middle school, high school, and college or above.[20] Household income was categorized into three groups: less than 10,000 (about 1379 in US dollars based on the exchange rate on 2025.02.22), 10,000–50000, and over 50,000 Chinese Yuan/year (about 6895 in US dollars). Employment was classified as unemployed and employed. Considering the substantial income difference between the retired and the unemployed in China, the retired was categorized as employed group.

A composite value of overall area-level SES was calculated, including 11 factors pertaining to fields in education, income, living condition and rural-urban difference, for each county in China based on 2010 national census data. The coefficients of 11 factors were loadings from a principal component analysis by Wang et al. (Appendix Methods).[21] The area-level SES data were linked with individual data based on the participants' county-level administrative area code. Participants were categorized according to the tertile of the composite value, with the highest tertile indicating the lowest area-level SES.

Statistical analysis

We described participant characteristics by area-level SES using percentages for categorical variables and mean ± standard deviation as appropriate for continuous variables. To compare characteristics among different categories of area-level SES, analysis of variance tests for continuous variables and χ^2 test for categorical variables were conducted.

To quantify the independent association of both individual-level and area-level SES with hypertension awareness, treatment, combination therapy and control, multivariable mixed models with random effects to account for county-level administrative area were fitted to compute odds ratios (OR) and 95% confidence intervals

(CI) with adjustment for age, sex (female or male), marital status (married, unmarried, or unknown), urbanity (rural or urban), region (central, eastern or western), smoking (current smoker or non-current smoker), drinking (current drinker or non-current drinker), and BMI category (low weight, normal, overweight, obese, or unknown).

To assess the combined associations of area- and individual-level SES with hypertension awareness, treatment, combination therapy and control, participants were categorized into nine groups based on SES on two levels. Multivariable mixed models were used to estimated ORs and 95% CIs, with participants having high SES on both area and individual levels as the reference group. In these models, age, sex, marital status, urbanity, region, smoking, drinking, and BMI category were adjusted as covariates.

Subgroup analyses stratified by age (<60 and ≥ 60), sex (male and female), individual-level SES (low, middle, and high), and urbanity (rural and urban) were used to evaluate the disparities in the association between area-level SES and hypertension management. In these analyses, the reference group was those with high area-level SES, with adjustment for age, sex, marital status, individual-level SES, urbanity, region, smoking, drinking, and BMI category when appropriate. A product term of area-level SES and stratified variable was additionally included in the models and P for interaction <0.05 indicated statistically significant.

To examine the robustness of our analyses, we did two sensitivity analyses. First, considering that area-level SES has changed with the development of urbanization over the past decade, we repeated main analyses using area-level SES from 2020 national census data. Second, we repeated main analyses using subset of our study population who provided information on other lifestyle factors (diet and leisure-time physical activity) to examine robustness of our analyses when considering additional potential confounders (Appendix Methods).

All analyses were conducted using SAS version 9·4 (SAS Institute, Cary, North Carolina, USA). Two tailed tests were used and the P-value <0·05 was considered to be statistically significant.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or the decision to submit the manuscript for publication.

Results

Among all included participants, the average age was 59·1 ± 9·1 years, 910,203 (58·36%) were female, and 991,441 (63·56%) were living in rural areas (Table 1). Overall, 884,307 (56·70%), 438,596 (28·12%), and 236,845 (15·18%) participants had low, middle and high individual-level SES, respectively. Participants with low area-level SES were more likely to live in rural or western areas and have low education and annual household income. Additionally, they tended to be current smokers and had low or normal weight.

Among the included participants with hypertension, 794,675 (50·95%, CI% 50·87–51·03%) were aware of their condition; 650,485 (41·70%, 41·63–41·78%) and 206,103 (13·21%, 13·16–13·27%) were treated and controlled, respectively. Among individuals who were treated, 60,585 (9·31%, 9·24–9·38%) had combination therapy. After adjusting for potential confounders, both area-level and individual-level SES were positively associated with the hypertension awareness, treatment and control (Table 2). Low area-level SES was associated with lower odds of hypertension awareness (OR: 0·75, 95% CI: 0·65–0·86), treatment (0·69, 0·59–0·81), and control (0·62, 0·51–0·75). Individuals with low individual-level SES also had lower odds of hypertension awareness (OR: 0·82, 95% CI: 0·81–0·83), treatment (0·80, 0·79–0·81), and control (0·74, 0·73–0·75). Among the treated individuals, low SES at area-level (0·65, 0·51–0·84) and individual-level (0·63, 0·61–0·64) were associated with lower odds of combination therapy, respectively. In the sensitivity analyses, the results were unchanged when using area-level SES from 2020 census data (Appendix Table S1) or considering other potential confounders (Appendix Table S2).

Combined association analyses showed that participants with low SES at both area- and individual-level had the lowest odds of hypertension awareness, treatment, combination therapy, and control (Fig. 1). Compared to participants with high SES at both levels, the ORs (95% CIs) for those with low SES at both levels were 0·60 (0·52–0·69) for hypertension awareness, 0·55 (0·47–0·64) for treatment, 0·46 (0·38–0·56) for combination therapy, and 0·41 (0·32–0·53) for control.

Significant associations of area-level SES with hypertension management were observed across most subgroups, with significant effect modification by individual factors such as age, sex, individual-level SES, and urbanity (P for interaction <0·01 for all). For hypertension awareness (Table 3), the association appeared stronger in participants aged <60 years (OR for low SES: 0·71, 95% CI: 0·61–0·82), in males (0·74, 0·64–0·86), in groups of high individual-level SES (0·61, 0·52–0·71), and in rural areas (0·69, 0·53–0·90). Similar results were found for hypertension treatment and control. Compared with their counterparts, being aged <60 years (OR for low SES: 0·67, 0·57–0·79), with high individual-level SES (0·57, 0·49–0·67), and in rural areas (0·58, 0·42–0·79) had lower treatment rates (Table 4) (P for interaction <0·01 for all). For hypertension control (Table 5), the association appeared stronger in participants aged <60 years (OR for low SES: 0·59, 0·48–0·72), in males (0·56, 0·46–0·69), in groups of high individual-level SES (0·51, 0·41–0·63), and in rural areas (0·45, 0·31–0·67) (P for interaction <0·01 for all). Paradoxically,

	Overall	Area-level socioeconomic status			P value
		High	Middle	Low	
N	1,559,748	507,603	530,564	521,581	
Age, mean (SD), year	59·1 (9·10)	59·3 (9·0)	59·3 (9·0)	58·6 (9·3)	<0·0001
Female	910,203 (58·36)	292,842 (57·69)	312,222 (58·85)	305,139 (58·5)	<0·0001
Rural area	991,441 (63·56)	121,297 (23·9)	393,980 (74·26)	476,164 (91·29)	<0·0001
Region					<0·0001
Eastern	565,875 (36·28)	286,045 (56·35)	186,901 (35·23)	92,929 (17·82)	
Central	472,169 (30·27)	96,946 (19·10)	186,226 (35·10)	188,997 (36·24)	
Western	521,704 (33·45)	124,612 (24·55)	157,437 (29·67)	239,655 (45·95)	
Married	1,440,612 (92·36)	469,860 (92·56)	490,246 (92·4)	480,506 (92·12)	<0·0001
Education level					<0·0001
Primary school or below	795,117 (50·98)	155,382 (30·61)	297,169 (56·01)	342,566 (65·68)	
Middle school	512,914 (32·88)	207,494 (40·88)	172,852 (32·58)	132,568 (25·42)	
High school	157,689 (10·11)	94,224 (18·56)	38,130 (7·19)	25,335 (4·86)	
College or above	94,082 (6·03)	50,503 (9·95)	22,413 (4·22)	21,112 (4·05)	
Household income (Chinese Yuan/year)					<0·0001
<10,000	329,178 (21·10)	48,111 (9·48)	120,045 (22·63)	161,022 (30·87)	
10,000–50,000	942,250 (60·41)	295,831 (58·28)	334,654 (63·08)	311,765 (59·77)	
>50,000	288,320 (18·49)	163,661 (32·24)	75,865 (14·30)	48,794 (9·36)	
Employment					<0·0001
Employed	1,412,420 (90·55)	452,138 (89·07)	471,883 (88·94)	488,399 (93·64)	
Unemployed	147,328 (9·45)	55,465 (10·93)	58,681 (11·06)	33,182 (6·36)	
Individual-level SES					<0·0001
Low	884,307 (56·70)	177,407 (34·95)	330,898 (62·37)	376,002 (72·09)	
Middle	438,596 (28·12)	185,653 (36·57)	145,172 (27·36)	107,771 (20·66)	
High	236,845 (15·18)	144,543 (28·48)	54,494 (10·27)	37,808 (7·25)	
Lifestyles					
Current smoker	319,772 (20·50)	99,508 (19·6)	109,394 (20·62)	110,820 (21·25)	<0·0001
Current drinker	191,915 (12·30)	63,224 (12·46)	69,127 (13·03)	59,564 (11·42)	<0·0001
Body mass index					<0·0001
Low weight	19,083 (1·22)	3904 (0·77)	6683 (1·26)	8496 (1·63)	
Normal weight	506,701 (32·49)	147,203 (29·00)	178,189 (33·58)	181,309 (34·76)	
Overweight	674,043 (43·21)	230,346 (45·38)	228,607 (43·09)	215,090 (41·24)	
Obese	356,197 (22·84)	125,142 (35·13)	115,884 (21·84)	115,171 (22·08)	
Unknown	3724 (0·24)	1008 (0·20)	1201 (0·23)	1515 (0·29)	

Categorical variables were summarized as frequencies and percentages, and continuous variables as means and standard deviations. SES, socioeconomic status.

Table 1: **Baseline characteristics of participants according to area-level socioeconomic status.**

the association between combination therapy (Appendix Table S3) with low area-level SES was found to be more pronounced among younger individuals (OR for low SES: 0·60, 0·46–0·79), females (0·62, 0·48–0·81), and those with low individual-level SES (0·57, 0·43–0·77). Stronger associations were observed between area-level SES (OR for low SES: 0·64, 0·51–0·81) and hypertension control among untreated participants, and between area-level SES (0·64, 0·53–0·78) and hypertension control among participants with combination therapy (Appendix Table S4).

Discussion

Main findings

Based on a population cohort of over 1·5 million residents with hypertension from 31 provinces in China, we found that low area- and individual-level SES were independently associated with lower rate of hypertension awareness, treatment, control and combination therapy, with different magnitude of associations. The combination of low SES at both levels showed the poorest hypertension management. Stronger associations between area-level SES and hypertension awareness, treatment and control were found in younger people, those with high individual-level SES and those living in rural area, while associations between area-level SES and combination therapy were more pronounced in elder people, females, and those with low individual-level SES.

Comparison with other studies

Our study adds to the existing literatures in several ways. First, we provided more comprehensive

Hypertension management	Events	Prevalence rate % (95% CI)	High: Events	High: Prevalence rate % (95% CI)	High: OR (95% CI)	Middle: Events	Middle: Prevalence rate % (95% CI)	Middle: OR (95% CI)	Low: Events	Low: Prevalence rate % (95% CI)	Low: OR (95% CI)
Area-level SES											
Aware	794,675	50·95 (50·87, 51·03)	284,887	56·12 (55·99, 56·26)	1 (reference)	263,891	49·74 (49·60, 49·87)	0·81 (0·71, 0·93)	245,897	47·14 (47·01, 47·28)	0·75 (0·65, 0·86)
Treated	650,485	41·70 (41·63, 41·78)	246,734	48·61 (48·47, 48·75)	1 (reference)	216,071	40·72 (40·59, 40·86)	0·85 (0·73, 0·98)	187,680	35·98 (35·85, 36·11)	0·69 (0·59, 0·81)
Combination therapy[a]	60,585	9·31 (9·24, 9·38)	27,573	11·18 (11·05, 11·30)	1 (reference)	18,948	8·77 (8·65, 8·89)	1·02 (0·81, 1·30)	14,064	7·49 (7·39, 7·61)	0·65 (0·51, 0·84)
Controlled	206,103	13·21 (13·16, 13·27)	95,162	18·75 (18·64, 18·85)	1 (reference)	61,874	11·66 (11·58, 11·75)	0·86 (0·71, 1·04)	49,067	9·41 (9·33, 9·49)	0·62 (0·51, 0·75)
Individual-level SES											
Aware	794,675	50·95 (50·87, 51·03)	129,238	54·57 (54·37, 54·77)	1 (reference)	216,170	49·29 (49·14, 49·43)	0·88 (0·87, 0·89)	449,267	50·80 (50·70, 50·91)	0·82 (0·81, 0·83)
Treated	650,485	41·70 (41·63, 41·78)	109,812	46·36 (46·16, 46·57)	1 (reference)	179,392	40·90 (40·76, 41·05)	0·89 (0·88, 0·90)	361,281	40·85 (40·75, 40·96)	0·80 (0·79, 0·81)
Combination therapy[a]	60,585	9·31 (9·24, 9·38)	14,839	13·51 (13·31, 13·72)	1 (reference)	19,791	11·03 (10·89, 11·18)	0·82 (0·80, 0·84)	25,955	7·18 (7·10, 7·27)	0·63 (0·61, 0·64)
Controlled	206,103	13·21 (13·16, 13·27)	45,575	19·24 (19·08, 19·40)	1 (reference)	59,060	13·47 (13·36, 13·57)	0·85 (0·84, 0·87)	101,468	11·47 (11·41, 11·54)	0·74 (0·73, 0·75)

Prevalence rates and their 95% CIs were estimated by the Clopper-Pearson method. ORs and 95% CIs were estimated from multivariable mixed models (with random effects to account for geographic autocorrelation), considering participants with high SES as the reference. Adjusted for age, sex (man, woman), marital status (married, unmarried, unknown), urbanity (urban, rural), region (central, eastern, western), smoking (current smoker, non-current smoker), drinking (current drinker, non-current drinker), and BMI category (low weight, normal, overweight, obese, unknown). SES: socioeconomic status. [a]Analysis for combination therapy was conducted among treated individuals.

Table 2: **Association between socioeconomic status and hypertension awareness, treatment, combination therapy and control.**

assessments of the association between SES at both area- and individual-level and hypertension care cascade based on a nationwide population-based cohort in China. In addition to the findings of a lower SES at both area- and individual-level independently associated with poorer hypertension treatment and control, which are consistent with most prior studies,[6–12] we also observed significant associations of SES at both levels with hypertension awareness and combination therapy. Notably, the association was progressively stronger among each step of hypertension care cascade, which could be explained by that the control for hypertension has the highest demand for resources of all the stages, while relying on long-term patient adherence and behavioral change. Residents in most advantaged areas or with high individual-level SES have easier access to medical resources, as well as the financial ability and health awareness to support long-term hypertension control, resulting in a stronger association of SES with hypertension control than with hypertension awareness and treatment. In the combination analysis, individuals with low SES at both levels had the poorest hypertension management. There are several aspects that could lead socioeconomic inequalities in hypertension care. From perspective of individual level, lower SES generally means lower health literacy, less affordable treatment, and greater chronic stress, which may be responsible for poorer hypertension management. For example, a short education and low equivalent household expenditure were more likely to have less knowledge of cardiovascular risk factors[22] and subsequently have a less healthy lifestyle and less chances to receive preventive medical care or keep blood pressure steady. At the area level, the allocation and accessibility of medical and health resources, as well as different influencing factors such as the social insurance system, could affect the occurrence and development of chronic diseases. In China, most of physicians with a bachelor's degree or higher provided care are predominantly located in advantaged areas.[23] According to a research about geographic disparity in hypertension care in China, residents in disadvantaged areas (measured by gross domestic product) are more likely to be undiagnosed, untreated and to have uncontrolled hypertension.[24] In addition, built environments such as healthy food outlets, recreational facilities, and parks have been reported measurable effects on CVD and the density of CVD risk factors.[3] Adverse community conditions may affect hypertension management by inhibiting an individual's ability to adhere to healthy lifestyle behaviors, generating chronic stress, and creating physiological changes.

Second, significant interactions between area-level SES and individual factors were observed in hypertension management, which highlights the interconnect of individual characteristics and social contexts, as

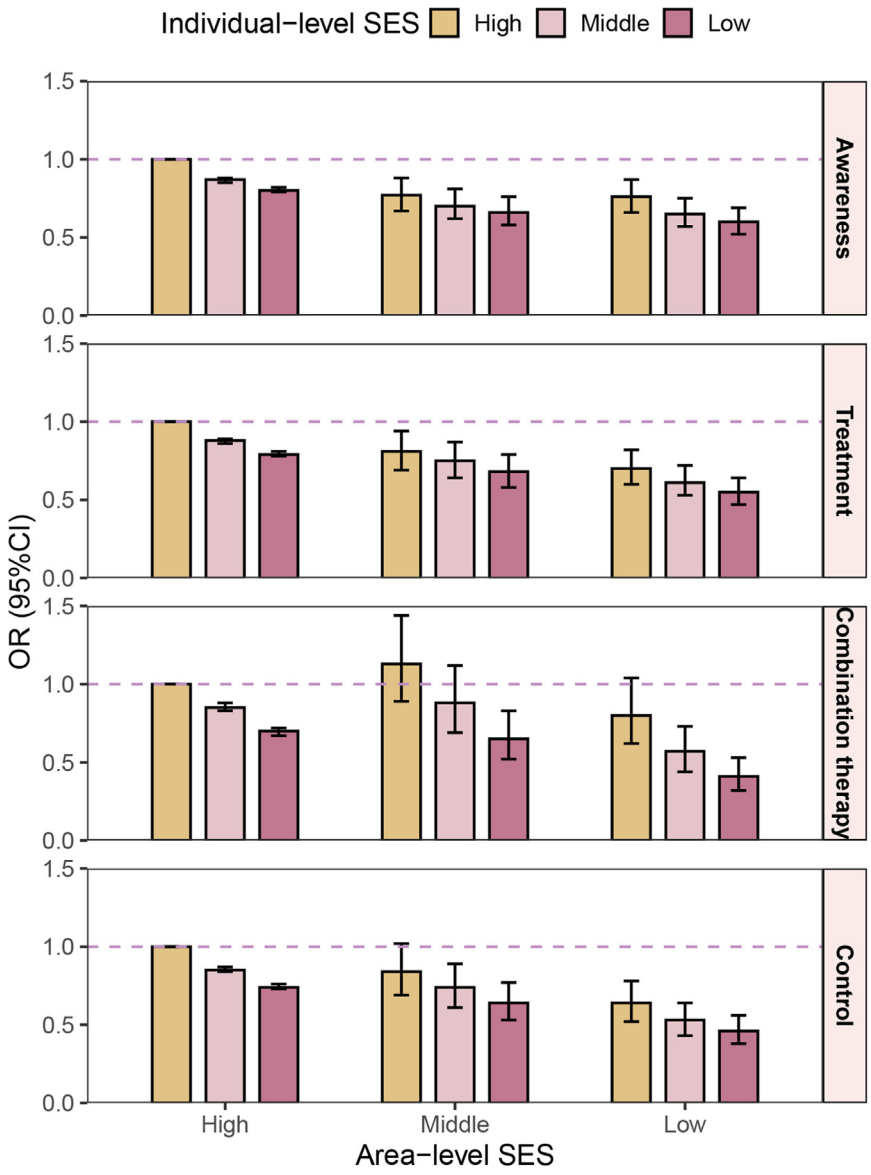

Fig. 1: **Combined association of area- and individual-level socioeconomic status with hypertension awareness, treatment, combination therapy and control**. Results are provided as ORs and 95% CIs from multivariable mixed models (with random effects to account for geographic autocorrelation), considering participants with high SES at both levels as the reference. Error bars indicate 95% confidence intervals. Adjusted for age, sex, marital status, urbanity, smoking, drinking, body mass index and region.

well as the difficulties in fully untangling, characterizing, and understanding the independent associations of individual and structural factors in chronic disease management. Stronger association in the young and individuals with high SES might be explained by the poor medication adherence in these population. A study about risk factors associated with medication non-adherence showed that young adults reported higher unintentional and intentional non-adherence rates than older adults, and higher SES (measured by income and employment) were more likely to be associated with non-adherence in young adults.[25] This phenomenon may be due to patients' poor knowledge and negative beliefs on medication. In this context, the improvement of area-level SES could lead to better medical facilities and health education, thus further strengthening the hypertension care. Significant interaction between area-level SES and urbanity was also observed for hypertension awareness, treatment and control, which the association was more pronounced in rural

	Area-level socioeconomic status			P for interaction
	High	Middle	Low	
Age				
<60	1 (reference)	0·77 (0·67, 0·89)	0·71 (0·61, 0·82)	<0·01
≥60	1 (reference)	0·90 (0·78, 1·04)	0·82 (0·70, 0·95)	
Sex				
Male	1 (reference)	0·80 (0·70, 0·93)	0·74 (0·64, 0·86)	<0·01
Female	1 (reference)	0·83 (0·72, 0·95)	0·76 (0·66, 0·88)	
Individual SES				
Low	1 (reference)	0·89 (0·76, 1·03)	0·80 (0·69, 0·94)	<0·01
Middle	1 (reference)	0·90 (0·78, 1·03)	0·88 (0·76, 1·02)	
High	1 (reference)	0·65 (0·57, 0·75)	0·61 (0·52, 0·71)	
Urbanity				
Urban	1 (reference)	0·89 (0·74, 1·07)	0·85 (0·67, 1·07)	<0·01
Rural	1 (reference)	0·78 (0·60, 1·01)	0·69 (0·53, 0·90)	

ORs and 95% CIs were estimated from multivariable mixed models (with random effects to account for geographic autocorrelation), considering participants with high SES as the reference. P-values (P < 0·05) for the interactions were estimated by additionally including a product term of subgroup factors and area-level SES in models. Adjusted for age, sex (man, woman), marital status (married, unmarried, unknown), individual-level SES (low, middle, high), urbanity (urban, rural), region (central, eastern, western), smoking (current smoker, non-current smoker), drinking (current drinker, non-current drinker), and BMI category (low weight, normal, overweight, obese, unknown) when appropriate.

Table 3: **Associations between area-level SES and hypertension awareness by age, sex, individual-level SES, urbanity and region.**

	Area-level socioeconomic status			P for interaction
	High	Middle	Low	
Age				
<60	1 (reference)	0·82 (0·70, 0·96)	0·67 (0·57, 0·79)	<0·01
≥60	1 (reference)	0·91 (0·77, 1·07)	0·74 (0·62, 0·87)	
Sex				
Male	1 (reference)	0·85 (0·72, 0·99)	0·70 (0·59, 0·82)	<0·01
Female	1 (reference)	0·85 (0·73, 1·00)	0·70 (0·60, 0·83)	
Individual SES				
Low	1 (reference)	0·92 (0·77, 1·09)	0·74 (0·62, 0·88)	<0·01
Middle	1 (reference)	0·93 (0·81, 1·08)	0·87 (0·74, 1·02)	
High	1 (reference)	0·68 (0·59, 0·79)	0·57 (0·49, 0·67)	
Urbanity				
Urban	1 (reference)	0·94 (0·76, 1·16)	0·85 (0·65, 1·10)	<0·01
Rural	1 (reference)	0·73 (0·54, 1·00)	0·58 (0·42, 0·79)	

ORs and 95% CIs were estimated from multivariable mixed models (with random effects to account for geographic autocorrelation), considering participants with high SES as the reference. P-values (P < 0·05) for the interactions were estimated by additionally including a product term of subgroup factors and area-level SES in models. Adjusted for age, sex (man, woman), marital status (married, unmarried, unknown), individual-level SES (low, middle, high), urbanity (urban, rural), region (central, eastern, western), smoking (current smoker, non-current smoker), drinking (current drinker, non-current drinker), and BMI category (low weight, normal, overweight, obese, unknown) when appropriate.

Table 4: **Associations between area-level SES and hypertension treatment by age, sex, individual-level SES, urbanity and region.**

areas. This difference likely results from generally greater accessibility of blood pressure screening for individuals across SES levels in urban areas compared to those in rural areas. Consistent with our results, a study in Bangladesh also reported stronger association between household wealth and hypertension awareness in rural communities.[5] However, major healthcare reform launched in 2009 initiating basic public health services, including hypertension management for all patients over 35 years old.[26] In addition, since 2012 all types of healthcare institutions have been required to measure blood pressure at the first diagnosis for individuals over 35.[27] Since then, there has been a notable increase in primary healthcare access, the number of medical practitioners and health-care facility beds per 1000 people, and improvements in the management of chronic diseases.[23] As our study population was recruited between 2015 and 2022, they likely benefited from these reforms and changes, which may have reduced the observed disparities in hypertension care.

Third, we first reported association between area-level SES and combination therapy for reducing blood pressure. Interestingly, stronger associations were observed in groups of the elderly, females and individuals with low SES. The rate of combination therapy is related to both medication demands among population and the quality of healthcare services, including prescribing behaviour by clinicians. The quality of healthcare services and medical resources are associated with area-level SES. Together, these factors explain the stronger association between area-level SES and combination therapy in these vulnerable populations. Physiological and health conditions may account for more needs for combination therapy in these vulnerable populations. Numerous studies confirmed that increasing blood pressure occur with ageing, thus older people often require combination therapy to control blood pressure more effectively. In China, Stage 2 and above hypertension was more prevalent among those with low individual-level SES (lower education or annual household income).[28] For women, especially postmenopausal women, hormonal changes may affect the presentation and treatment of hypertension,[29] and the socioeconomic gradient is greater in women for cardiovascular conditions,[30] which contributes to their combination therapy rate being more sensitive to area-level SES.

Implications

Our study has some potential public health implications for improving health equity. Firstly, our findings showed that lower SES at both area- and individual-level were associated with poor hypertension management in China. However, most current health system efforts focus on individual patient care, which are generally effective. But current health care does not address disparities in disease management across population subgroups. Health system interventions, such as improvements in social welfare and social norms that are related to health and inequitably distributed in the community, could lead to massive improvements focused on hypertension. Therefore, targeted health

policies for disadvantaged areas are urgent needed, including improving health delivery system by increasing the number of healthcare institutions and qualified medical staffs, improving the quality of healthcare especially primary healthcare, and enhancing the coverage of medical insurance. To effectively implement health policies in disadvantaged areas, multisectoral collaborations between health and non-health sectors are required based on the Helsinki Statement on Health in All Policies. Secondly, it's crucial for policy makers to implement specific interventions targeted different stage of hypertension care cascade and populations. Given the stronger relationship between area-level SES and hypertension control and the significant modification of treatment on the relationship, financial support for people in disadvantaged areas should be provided to improve drug access and medication adherence. 2019 ACC/AHA Guideline on the Primary Prevention of Cardiovascular Diseases suggested that clinicians should evaluate the social determinants of health that affect individuals to inform treatment decisions.[31] Standardized screening tools can improve data collection in individual- and area-level SES. The purpose of screening for data related to SES may be to adjust clinical decisions to be more sensitive to a patient's social situation.[32] Interventions should focus on addressing hypertension awareness and medication adherence in younger or male individuals while addressing combination therapy in older or female individuals on treatment. The information on individual characteristics can be used to implement population management programs that support identified needs. For example, Kaiser Permanente Southern California had a multifaceted quality improvement hypertension program with aim to improve identification and treatment of patients with hypertension and address the gap in BP control between race/ethnicity and the disparity in BP control between Black and White patients was reduced from before to after this quality improvement program.[33] As recent evidence has indicated that low–dose combinations with three or more blood pressure lowering agents are a potentially useful initial or early treatment strategy,[34] single pill combination could be utilized with the added benefit of improving medication compliance, especially for the elderly, women and those with low individual SES.

Limitations

This study has several limitations. First, participants' county-level areas did not cover all counties in China. But a total of 472 county-level areas (accounting for 16%) and over 1.5 million participants in this study, covering about most of all prefecture-level cities and 31 provinces in China, could broadly represent the diversity in area-level SES, risk factors, and hypertension management all over the country and allow robust analyses.

	Area-level socioeconomic status			P for interaction
	High	Middle	Low	
Age				
<60	1 (reference)	0·80 (0·66, 0·97)	0·59 (0·48, 0·72)	<0·01
≥60	1 (reference)	0·88 (0·72, 1·07)	0·62 (0·51, 0·77)	
Sex				
Male	1 (reference)	0·80 (0·66, 0·97)	0·56 (0·46, 0·69)	<0·01
Female	1 (reference)	0·88 (0·72, 1·06)	0·66 (0·54, 0·81)	
Individual SES				
Low	1 (reference)	0·87 (0·71, 1·07)	0·61 (0·50, 0·76)	<0·01
Middle	1 (reference)	0·91 (0·75, 1·10)	0·76 (0·62, 0·94)	
High	1 (reference)	0·65 (0·54, 0·79)	0·51 (0·41, 0·63)	
Urbanity				
Urban	1 (reference)	0·90 (0·70, 1·17)	0·62 (0·45, 0·87)	<0·01
Rural	1 (reference)	0·65 (0·44, 0·94)	0·45 (0·31, 0·67)	

ORs and 95% CIs were estimated from multivariable mixed models (with random effects to account for geographic autocorrelation), considering participants with high SES as the reference. P-values (P < 0·05) for the interactions were estimated by additionally including a product term of subgroup factors and area-level SES in models. Adjusted for age, sex (man, woman), marital status (married, unmarried, unknown), individual-level SES (low, middle, high), urbanity (urban, rural), region (central, eastern, western), smoking (current smoker, non-current smoker), drinking (current drinker, non-current drinker), and BMI category (low weight, normal, overweight, obese, unknown) when appropriate.

Table 5: **Associations between area-level SES and hypertension control by age, sex, individual-level SES, urbanity and region.**

Second, changes in administrative boundaries could have influenced the actual areas in which participants lived. However, we matched the information of area-level SES with participants using the unique administrative code and failed matches were excluded. County-level areas without huge regional changes were included in this way. Third, the association between area-level SES and hypertension management might be overestimated because the composite value was generated from 2010 census data. That was less than the level of social development during the baseline survey. In future studies, real-time estimates of area-level SES are required, and the impact of area-level SES changes on outcomes are warranted. Forth, recall bias might exist in self-reported assessments of lifestyle factors and medication use, even using the standardized questionnaire interview and drug packaging (boxes) check. Fifth, a large number of potential confounders was included in the regression models, but residual and unmeasured confounding is inevitable. Sixth, our study design is cross-sectional, which limits the interpretation of reported associations as causally related. Finally, since the study was conducted in a Chinese population, the generalizability of the findings to other population should be taken with caution.

In China, area-level socioeconomic inequalities in hypertension care cascade and combination therapy exist. Integrated action to improve the capability of healthcare providers and enhance hypertension care in disadvantaged areas is one of the effective strategies for reducing health-related inequalities in China. Future

studies with more area-level social determinants of health are needed to further understand and promote health equity.

Contributors

Xi Li conceived the ChinaHEART project and take responsibility for its all aspects. JL, Xi Li, and WP conceived this article. WP wrote the manuscript, with further contributions from SL, Xuan Liu, BC, XB, CW, XZ, YY, JC, WX, LS, HY, WH, YZ, Xi Li and JL. WP completed all the statistical analysis. SL directly accessed and verified the underlying data reported in the manuscript. All authors had access to all data, interpreted data, contributed to critical revisions, and read and approved the final version of the article. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Data sharing statement

The data are not publicly available. The China Health Evaluation And risk Reduction through nationwide Teamwork (ChinaHEART) project only provides conditional data access for qualified researchers with legitimate requests; a formal application and research proposal is required. Please contact cvd-project@nccd.org.cn to seek approval for data access.

Editor note

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Declaration of interests

No financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2025.101544.

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