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Epidemiological features of hypertension in a high-altitude population in Tibet, China: a cross-sectional study

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Abstract

Background Hypertension is a significant public health challenge in high-altitude areas of Tibet, China. This study aimed to investigate the current epidemiologic status of hypertension in Tibet and to provide insights for enhancing prevention and control strategies in this population.

Methods A cross-sectional study was conducted across seven cities in the Tibet autonomous Region. Using multi-stage stratified cluster sampling, 8,992 residents aged 35–75 were enrolled. Hypertension prevalence, awareness, treatment, control rates, and associated risk factors were analyzed. We conducted descriptive and logistic regression analyses in this study.

Results The crude and weighted hypertension prevalence rates were 46.5% and 46.7%, respectively. Stage 2 or higher hypertension accounted for 49.8% of cases. Among hypertensive individuals, 45.2% were aware of their diagnosis, 30.8% received treatment, and only 3.0% achieved blood pressure control. Risk factors included aging, urban residence, alcohol consumption, overweight, obesity, diabetes, and central obesity (all $p < 0.05$). Monotherapy was used by 94.2% of treated patients, predominantly calcium channel blockers (CCBs). Among CCBs, nifedipine was the most commonly used agent (38.2%), with women more likely to use CCBs and less likely to receive beta-blockers than men ($p < 0.05$).

Conclusions Hypertension in Tibet is characterized by high prevalence, multifactorial risk, and critically low rates of awareness, treatment, and control. Strengthening primary healthcare infrastructure and targeted health promotion programs are urgently needed to address this burden in high-altitude populations.

Keywords Hypertension, Prevalence, Public health, Tibet

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Introduction

Hypertension is the most common chronic non-communicable disease and a leading contributor to global morbidity and mortality [1]. Recent data indicate that approximately 1.4 billion individuals worldwide are affected by hypertension, yet only 21% achieve adequate control [2].Report on Hypertension highlights an alarming increase in hypertension prevalence, particularly in the WHO Western Pacific Region (including China), where the prevalence among adults rose from 24 to 28% between 1990 and 2019, with the number of affected individuals escalating from 144 million to 346 million [3]. Hypertension is the primary modifiable risk factor for cardiovascular disease, the leading cause of death in China [4, 5]. In China, rapid urbanization, aging demographics, and lifestyle changes have exacerbated the burden of hypertension [6, 7]. In 2012, hypertension affected approximately 23.2% of Chinese adults, with only 46.9% aware of their condition, 40.7% receiving antihypertensive treatment, and 15.3% achieving blood pressure control [8].

Significant regional disparities exist in hypertension awareness, treatment, and control across China [9–11], though previous studies predominantly focused on southeastern regions [9, 11, 12].

Tibet often termed the "Third Pole," represents one of the regions with the highest inhabited population globally. Emerging evidence suggests a higher prevalence of hypertension in Tibet compared to other Chinese regions, coupled with lower rates of treatment and control [13, 14]. However, comprehensive health surveys on hypertension in Tibet remain scarce, with most studies limited to specific districts or counties. Consequently, the current epidemiology of hypertension in Tibet remains poorly characterized.

This study aimed to investigate the epidemiology of hypertension in Tibet by assessing its prevalence, awareness, treatment, and control rates, and analyzing associations between hypertension and potential risk factors.

Methods

Study design and enrollment of participants

A cross-sectional survey was conducted between May 2021 and December 2023 as part of the Early Screening and Comprehensive Intervention Program for High-Risk Cardiovascular Populations. Approval was obtained from the Ethics Committee of Fuwai Hospital, Chinese Academy of Medical Sciences (No. 2014 – 574), and all participants provided written informed consent.

The survey utilized a multi-stage stratified cluster sampling method to select residents from seven cities in Tibet. The sampling strategy accounted for regional economic levels, geographic diversity, population size, and sociodemographic stability to ensure representativeness.

During the first stage, screening was conducted in all seven Tibetan prefectural and municipal cities, taking into account factors such as economic level and geographical location. In the second phase, local health and medical organizations identified one or two districts or counties in each city (prefecture), taking into account the size of the population and stability factors. In the third stage, two or three communities or villages were selected in each district or sub-district. In the final stage, the study was widely publicized through television, radio, newspapers, and other media, and residents were invited to participate in the study. Finally, we included 8,992 participants based on the following criteria: (1) Age 35–75 years (2) Residency in the target area for ≥6 months within the preceding 12 months.

Demographic comparisons with the 2020 Tibetan Census revealed a slight underrepresentation of males and urban residents in the final sample, though age distributions aligned with the target population (35–75 years). Overall, participant characteristics (gender, ethnicity, occupation) were comparable to the general Tibetan population of the same age group [15].

The participant inclusion/exclusion flowchart is presented in Supplementary Fig. 1.

Data collection

Participant information was collected through standardized face-to-face interviews conducted by trained medical staff using a structured questionnaire. This instrument was developed and validated by the National Center for Cardiovascular Diseases (NCCD) of China, specifically tailored for the China PEACE Million Persons Project Cohort Study (a nationwide government-sponsored population-based screening program). The primary objectives of this initiative include identifying high-risk cardiovascular disease populations and establishing high-quality biospecimen repositories alongside comprehensive clinical data collection [16].

The questionnaire encompasses factors such as age, residence, education level, marital status, annual income, medical history, prescription drug use, and lifestyle factors, including smoking and alcohol consumption. Additionally, data on height, weight, blood pressure, fasting lipid levels, and fasting blood glucose were collected through physical examinations and laboratory tests.

Waist circumference was assessed using a standardized protocol with non-elastic tape positioned horizontally at the midpoint between the lowest rib margin and iliac crest (approximately 1 cm superior to the umbilicus). Blood pressure measurements were obtained from all participants using calibrated automated oscillometric devices (Omron HEM-7430; Omron Healthcare, Kyoto, Japan) according to international guidelines.

After resting in a sitting position for at least 5 min, two measurements were taken on the right upper arm. If the difference in systolic blood pressure (SBP) or diastolic blood pressure (DBP) between the two readings was more than 10 mmHg, a third measurement was taken. The average of the two or three readings was then used. Glucose and lipid levels were assessed by collecting venous blood samples after at least 10 h of fasting. Blood glucose levels were measured using a blood glucose analyzer (BeneCheck PD-G001-2, Taiwan, China). Lipid profiles were determined with a rapid lipid analyzer (CardioChek PA Analyzer; Polymer Technology Systems, Indianapolis, IN, USA), including measurements of triglycerides (TG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C). All analytes (TC, TG, LDL-C, HDL-C, and glucose) were recorded in mmol/L.

For a detailed overview of the study design and data collection process, refer to Supplementary Fig. 2, which presents a flow diagram of the methodological framework.

Definition of variables

A smoker was defined as a participant who smoked at least 1 cigarette per day for the past 6 months and currently uses any tobacco product. An alcohol drinker was defined as a participant who consumed an average of at least one alcoholic beverage per week and was currently consuming alcohol.

According to the 2018 Chinese Guidelines for the Management of Hypertension [17], hypertension was defined as an average systolic blood pressure (SBP) ≥ 140 mmHg and/or an average diastolic blood pressure (DBP) ≥ 90 mmHg, or a self-reported history of hypertension, or the self-reported use of antihypertensive medications. Stage 2 hypertension was defined as an average SBP ≥ 160 mmHg and/or an average DBP ≥ 100 mmHg. Stage 3 hypertension was defined as an average SBP ≥ 180 mmHg and/or an average DBP ≥ 110 mmHg. Awareness of hypertension was defined as participants being diagnosed with hypertension prior to this study. Treatment of hypertension was defined as hypertensive patients who have taken antihypertensive medication within the past two weeks. Hypertension control was defined as effective maintenance of mean SBP < 140 mmHg and mean DBP < 90 mmHg in patients with hypertension.

Participants were classified as having dyslipidemia if they met one of the following criteria: triglycerides (TG) ≥ 2.3 mmol/L, total cholesterol (TC) ≥ 6.2 mmol/L, low-density lipoprotein (LDL) cholesterol ≥ 4.1 mmol/L, or high-density lipoprotein (HDL) cholesterol < 1.04 mmol/L, and were diagnosed with dyslipidemia [18]. Diabetes mellitus was defined as fasting plasma glucose ≥ 7.0 mmol/L, self-reported current use of insulin or oral hypoglycemic medication, or a history of a diagnosis of diabetes mellitus [19, 20].

Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Following the Chinese Obesity Working Group criteria [21], BMI categories were defined as: underweight (< 18.5 kg/m^2), normal (18.5–23.9 kg/m^2), overweight (24.0–27.9 kg/m^2), and obesity (≥ 28.0 kg/m^2).

Patient and public involvement

Patients and the public were not involved in the design of the study.

Quality control

Investigators received standardized training at national and provincial levels. Data entry was performed independently by two personnel, and daily logical checks were implemented to ensure data integrity.

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics (version 26.0). The 2020 China population census data were utilized to calculate weighted hypertension prevalence, ensuring the representativeness and generalizability of the findings. Categorical variables were presented as frequency (n) and percentage (%), while continuous variables are expressed as mean ± standard deviation (SD) or median (range), based on their distribution. Group comparisons (hypertensive vs. non-hypertensive) used chi-square/Fisher's exact tests for categorical variables. Multivariable. Logistic regression models were fitted to evaluate the association between potential risk factors and hypertension, with results presented as odds ratios (ORs) and 95% confidence intervals (CIs). A two-tailed p-value < 0.05 was considered statistically significant.

Results

Basic characteristics of the study population

A total of 8,992 participants (3,800 males and 5,192 females) were enrolled in this study, with a mean age of 52.58 years (SD = 10.40). As shown in Tables 1, 8 and 934 (99.3%) were Tibetan nationality, 7,468 (83.0%) resided in rural areas, and 8,186 (91.0%) were farmers or herdsmen. The majority of the participants did not have a history of common chronic disease including cardiovascular disease, diabetes, and hyperlipidemia; however, a high proportion exhibited central obesity (48.2%). The crude and weighted prevalence of hypertension was 46.5% (n = 4,177, 95% CI: 45.4–47.4) and 46.7% (95% CI: 45.6–47.7), respectively, with males showing a higher prevalence than females. There were significant differences in ethnicity, age, residential area; BMI, educational level, marital status; alcohol consumption, central obesity;

Table 1 Comparison of baseline characteristics between participants with and without hypertension

Characteristics	Total	No hypertension	Hypertension	*P*-value
	(*n* = 8,992)	**(*n* = 4,815)**	**(*n* = 4,177)**	
Sex				0.009*
Male	3800 (42.3%)	1974 (52.0%)	1826 (48.0%)	
Female	5192 (57.7%)	2841 (54.7%)	2351 (45.3%)	
Ethnicity				0.029*
Han	14 (0.2%)	5 (35.7%)	9 (64.3%)	
Tibetan	8934 (99.3%)	4794 (53.7%)	4140 (46.3%)	
Others	44 (0.5%)	16 (36.4%)	28 (63.6%)	
Age, years				<0.001*
35–39	1111 (12.4%)	916 (82.5%)	195 (17.6%)	
40–49	2553 (28.4%)	1800 (70.5%)	753 (29.5%)	
50–59	2890 (32.1%)	1388 (48.0%)	1502 (52.0%)	
60–69	1835 (20.4%)	577 (31.4%)	1258 (68.6%)	
70–75	603 (6.7%)	134 (22.2%)	469 (77.8%)	
Residence				0.002*
Rural	7468 (83.0%)	4053 (54.3%)	3415 (45.7%)	
Urban	1524 (17.0%)	762 (50.0%)	762 (50.0%)	
Occupation				0.534
farmers and herdsmen	8186 (91.0%)	4375 (53.4%)	3811 (46.6%)	
Not a farmer or herdsmen	806 (9.0%)	440 (54.6%)	366 (45.4%)	
Education level				<0.001*
Primary school or lower	7731 (86.0%)	4045 (52.3%)	3686 (47.7%)	
Middle school	1176 (13.0%)	712 (60.5%)	464 (39.5%)	
High school	24 (0.3%)	16 (66.7%)	8 (33.3%)	
College or above	61 (0.7%)	42 (68.9%)	19 (31.1%)	
Annual household income				0.073
≤ 50,000	8151 (90.6%)	4340 (53.2%)	3811 (46.8%)	
>50,000	841 (9.4%)	475 (56.5%)	366 (43.5%)	
Marital status				<0.001*
Single or divorced or widowed	803 (8.9%)	376 (46.8%)	427 (53.2%)	
Married or living with a partner	8189 (91.1%)	4439 (54.2%)	3750 (45.8%)	
body mass index				<0.001*
Underweight	345 (3.8%)	230 (66.7%)	115 (33.3%)	
Normal	4064 (45.2%)	2417 (59.5%)	1647 (40.5%)	
Overweight	2976 (33.1%)	1507 (50.6%)	1469 (49.4%)	
Obesity	1607 (17.9%)	661 (41.1%)	946 (58.9%)	
Current smoking				0.546
No	8321 (92.5%)	4448 (53.5%)	3873 (46.5%)	
Yes	671 (7.5%)	367 (54.7%)	304 (45.3%)	
Current drinker				<0.001*
No	8261 (91.9%)	4474 (54.2%)	3787 (45.8%)	
Yes	731 (8.1%)	341 (46.6%)	390 (53.4%)	
History of CVD				0.007*
No	8959 (99.6%)	4805 (53.6%)	4154 (46.4%)	
Yes	33 (0.4%)	10 (30.3%)	23 (69.7%)	
Dyslipidaemia				<0.001*
No	6260 (69.6%)	3427 (54.7%)	2833 (45.3%)	
Yes	2732 (30.4%)	1388 (50.8%)	1344 (49.2%)	
Diabetes				<0.001*
No	7581 (84.3%)	4117 (54.3%)	3464 (45.7%)	
Yes	1411 (15.7%)	698 (49.5%)	713 (50.5%)	
Central obesity				<0.001*

Table 1 (continued)

Characteristics	Total	No hypertension	Hypertension	*P*-value
	(*n* = 8,992)	**(*n* = 4,815)**	**(*n* = 4,177)**	
No	4655 (51.8%)	2758 (59.3%)	1897 (40.7%)	
Yes	4337 (48.2%)	2057 (47.4%)	2280 (52.6%)	

Abbreviation: CVD: Cardiovascular disease

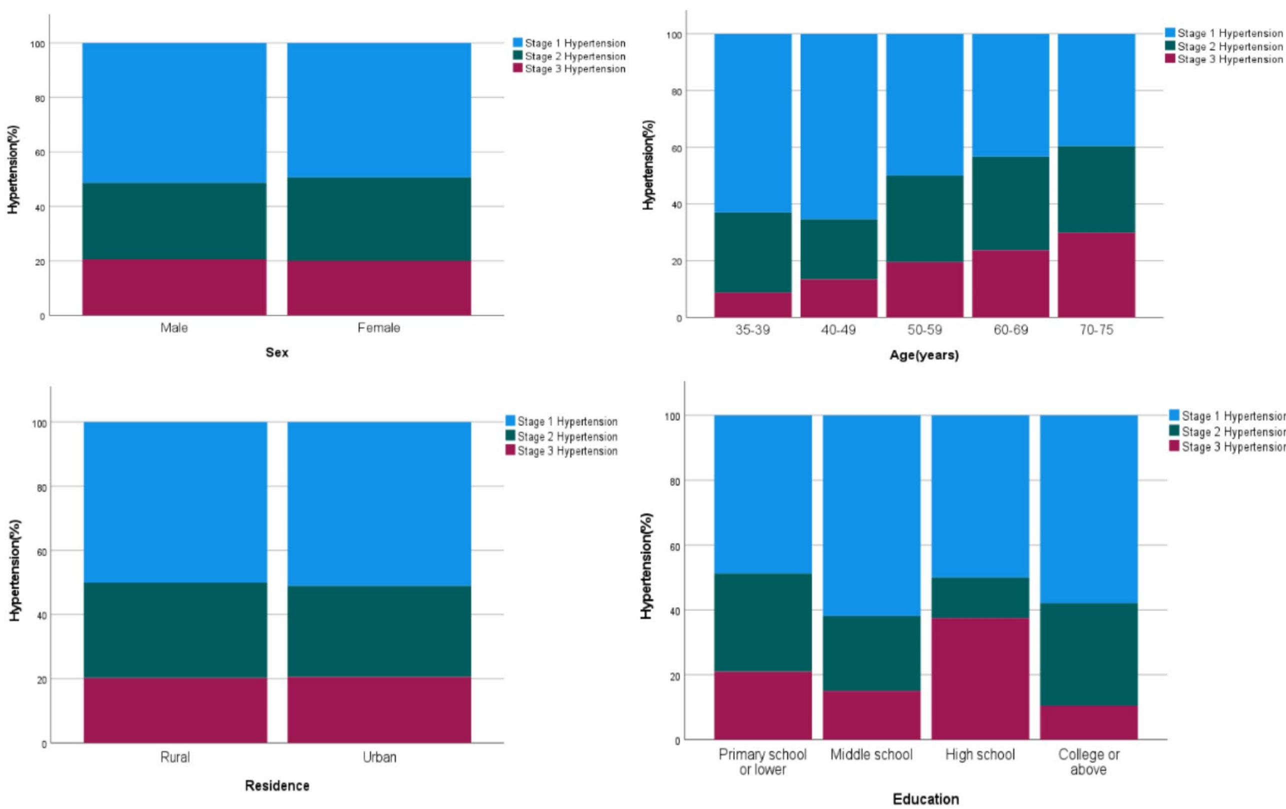

Fig. 1 Stratified analysis of hypertension in patients with different characteristics. This figure illustrates the prevalence of different stages of hypertension across various demographic categories. Blue bars represent stage 1 hypertension, green bars represent stage 2 hypertension, and red bars represent stage 3 hypertension. The distribution is analyzed by sex (male and female), residence (urban and rural), age groups, and education levels (from primary education to college and above)

history of cardiovascular, cerebrovascular diseases, diabetes or hyperlipidemia between hypertensive and non - hypertensive participants ($p < 0.05$) (Table 1).

Stratified analysis of hypertension by participant characteristic

Further analysis of hypertension severity revealed that 49.8% of hypertensive participants had blood pressure classified as Stage 2 or higher. Stratified comparisons of blood pressure levels by gender, residence area, age group, and educational level demonstrated significant differences in hypertension stage distribution across age groups and literacy levels ($p < 0.05$).

The proportion of Stage 2 or higher hypertension began to increase at age 40, while the proportion of Stage 3 hypertension rose markedly from age 35 onward. Additionally, the percentage of Stage 3 hypertension varied significantly by education level, with the lowest prevalence observed among participants with college-level or higher education (Fig. 1; Supplementary Table 1).

Multivariate logistic regression of risk factors for hypertension

A multivariate logistic regression analysis was conducted to identify factors associated with hypertension, incorporating all variables that showed significant differences between hypertensive and non-hypertensive groups. As shown in Fig. 2, increasing age, urban residence, alcohol drinking, overweight, obesity, diabetes mellitus, and central obesity were positively associated with hypertension risk. Hypertension risk escalated progressively with age, showing the following adjusted odds ratios (OR) : (OR:1.86, 95% CI: 1.56–2.23) for aged 40–49, (OR:4.78, 95% CI: 4.01–5.70) for those aged 50 – 59, (OR: 10.11,

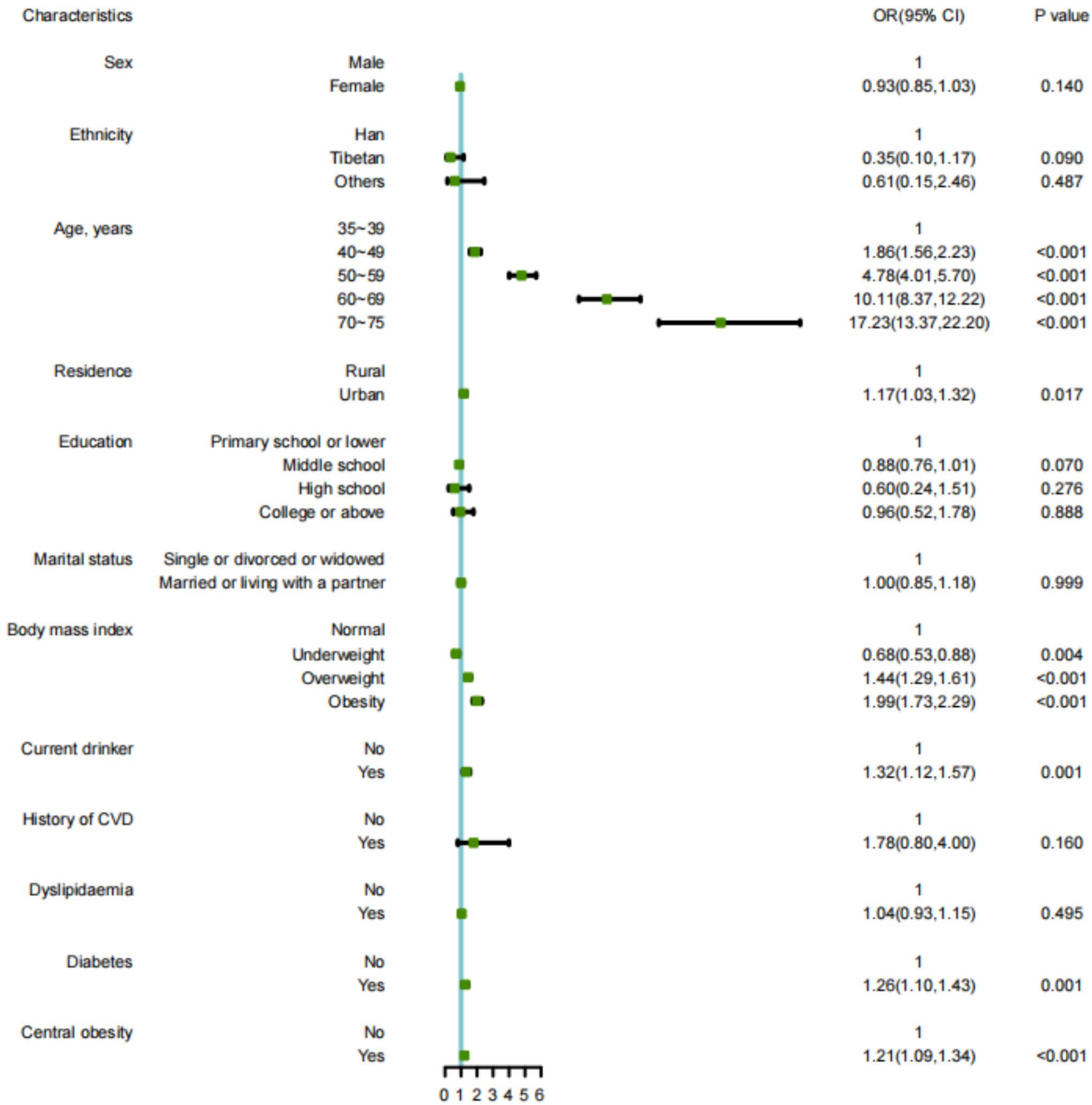

Fig. 2 The odds ratios (OR) and 95% confidence intervals (CI) for prevalence of hypertension from multifactorial logistic regression

95% CI: 8.37–12.22) for those aged 60–69, and (OR: 17.23, 95% CI: 13.37–22.20) for aged 70 years and older, respectively. Other significant risk factors included being overweight (OR: 1.44, 95% CI: 1.29 – 1.61), obesity (OR: 1.99, 95% CI: 1.73 – 2.29), drinking (OR: 1.32, 95% CI: 1.12–1.57), diabetes (OR: 1.26, 95% CI: 1.10– 1.43), central obesity (OR: 1.21, 95% CI: 1.09 – 1.34), Conversely, underweight participants exhibited a significantly reduced hypertension risk (OR: 0.68, 95% CI: 0.53–0.88).

Awareness, treatment, and control of hypertension among adults in Tibet

Among those with hypertensive patients, 45.2% ($n = 1,889$; 95% CI: 43.7–46.7), were aware of their condition, 30.8% ($n = 1,287$; 95% CI: 29.4– 32.2) were receiving antihypertensive treatment, and only 3.0% ($n = 127$; 95% CI: 2.9–3.3) achieved blood pressure control. Significant differences in awareness and treatment rates were observed across age groups ($p < 0.05$), with both metrics increasing progressively with age. Additionally, treatment and control rates were significantly higher in urban

Table 2 Awareness, treatment, and control of hypertension among all hypertension patients ($N = 4{,}177$) in our study

Variables	Aware ($n = 1{,}889$)	Treatment ($n = 1{,}287$)	Control ($n = 127$)
All	45.2 (43.7 to 46.7)	30.8 (29.4 to 32.2)	3.0 (2.9 to 3.2)
Sex			
Male	44.2 (41.9 to 46.5)	29.6 (27.5 to 31.7)	3.4 (2.6 to 4.2)
Female	46.0 (44.0 to 48.0)	31.7 (29.9 to 33.6)	2.8 (2.1 to 3.4)
P-value	0.265	0.144	0.239
Age, years			
35–39	12.3 (7.7 to 17.0)	6.2 (2.8 to 9.6)	0 (0 to 0)
40–49	25.2 (22.1 to 28.3)	14.6 (12.1 to 17.1)	2.3 (1.2to 3.3)
50–59	45.3 (42.8 to 47.9)	29.9 (27.7 to 32.2)	3.9 (2.9 to 4.9)
60–69	55.2 (52.4 to 57.9)	40.2 (37.5 to 42.9)	3.1 (2.1 to 4.1)
70–75	64.0 (59.6 to 68.3)	44.8 (40.3 to 49.3)	2.6 (1.1 to 4.0)
P-value	<0.001*	<0.001*	0.220
Residence			
Rural	44.6 (42.9 to 46.2)	29.4 (27.8 to 30.9)	2.8 (2.2 to 3.3)
Urban	48.2 (44.6 to 51.7)	37.3 (33.8 to 40.7)	4.2 (2.8 to 5.6)
P-value	0.071	<0.001*	0.039*

Data were presented as percentages (95% CI), and comparisons across different age groups were made using a Trend chi-square test

Table 3 The utilization of antihypertensive drugs in the treated hypertensive population

Type		All ($n = 1{,}287$)	Male ($n = 541$)	Female ($n = 746$)	*P*-value
Monotherapy	ACEIs	213 (17.6%)	93 (18.2%)	120 (17.6%)	0.645
	ARBs	48 (4.0%)	19 (3.7%)	29 (4.1%)	0.703
	DIUs	53 (4.4%)	23 (4.5%)	30 (4.3%)	0.862
	CCBs	676 (55.8%)	256 (50.0%)	420 (60.0%)	<0.001
	BBs	217 (17.9%)	120 (23.4%)	97 (13.9%)	<0.001
	Others	5 (0.4%)	1 (0.2%)	4 (0.6%)	0.291
	Total monotherapies	1212 (94.2%)	512 (94.6%)	700 (93.8%)	0.542
Combination therapy		75 (5.8%)	29 (5.4%)	46 (6.2%)	

Abbreviation: ACEIs: Angiotensin-converting enzyme inhibitors, ARBs: Angiotensin II receptor blockers, BBs: Beta-blockers, CCBs: Calcium channel blockers, DIUs: Diuretics

compared to rural areas ($p < 0.05$) (Table 2; Supplementary Table 2).

Antihypertensive medication utilization patterns

Among participants on antihypertensive medication, 1212 (94.2%) used monotherapy, while 75 (5.8%) received combination therapy. Among the commonly used antihypertensive medications, Calcium channel blockers were used by 55.8% of participants, beta blockers by 17.9%, angiotensin-converting enzyme inhibitors by 17.6%, diuretics by 4.4%, and angiotensin II receptor inhibitors by 4.0%. There was no difference between male and female hypertensives in terms of single or combination medications. However, among monotherapy users, women exhibited higher rates of calcium channel block utilization compared to men, whereas beta-blocker use was significantly lower in women ($p < 0.05$) (Table 3). Nifedipine was the most commonly used medication to treat hypertension in Tibetan adults, followed by bupicomide, amlodipine, and benazepril hydrochloride, there were differences between males and females in the selection of the nifedipine, bupicomide, and amlodipine drugs ($p < 0.05$). (Fig. 3; Supplementary Table 3).

Discussion

This cross-sectional study included 8,992 adults aged 35–75 years in the Tibet Autonomous Region and is the first large-scale epidemiologic investigation of hypertension in this high-altitude population. The age- and sex-standardized prevalence of hypertension was 46.7%, with significantly poorer awareness (< 50%), treatment (< 30%), and control (3%) of treated individuals rates. High-risk subgroups identified included older adults, urban residents, alcohol drinkers, and patients who were overweight/obese, centrally obese, or diabetic, emphasizing the need for targeted cardiovascular risk screening in these populations.

The prevalence of hypertension observed in Tibet is significantly higher than the national average (37.2% in China) and the prevalence of hypertension is recorded in high-income countries [10, 22]. Notably, the proportion of stage 2/3 hypertension cases in Tibet (23.1%) was 1.6 times higher than the national average (14.5%) [23]. This

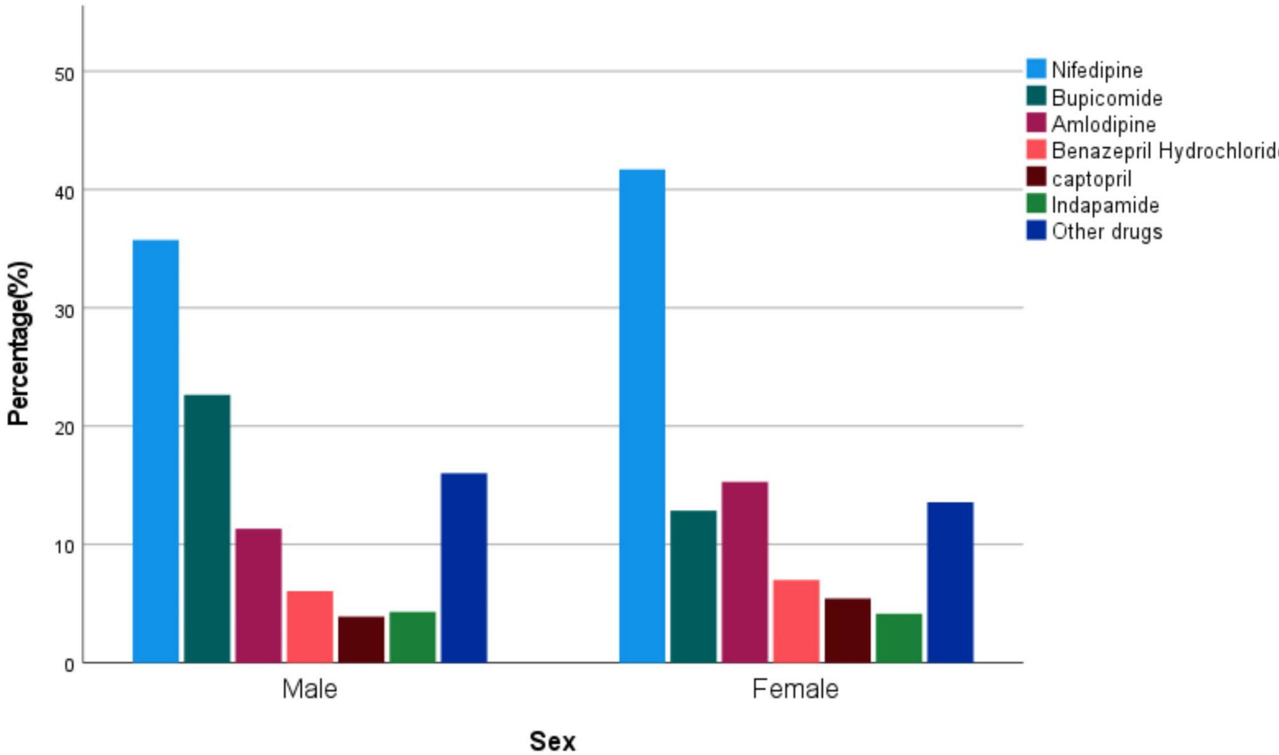

Fig. 3 Proportion of commonly used drugs for monotherapy of hypertension between genders

difference may be attributed to region-specific factors, including chronic exposure to high-altitude, low-pressure hypoxia, which may contribute to the development of hypertension through sympathetic nervous system activation, increased blood viscosity, and impaired endothelial function [24]. In addition, traditional dietary practices, such as the consumption of sodium-rich ghee tea, may increase the risk of hypertension, and previous studies have linked this practice to hypertension [25–27]. Disparities in healthcare infrastructure and health literacy, especially in rural areas, may further delay diagnosis and reduce treatment adherence [28, 29].

The alarmingly low control rate (3%) highlights systemic challenges in hypertension management, including suboptimal treatment options and socioeconomic barriers. Although clinical guidelines advocate combination therapy for severe hypertension [30, 31], monotherapy (primarily calcium channel blockers, such as nifedipine) is still widely used, with only 5.8% of patients receiving multidrug therapy. Inadequate provider training, high rates of clinician burnout, and insufficient patient education may affect treatment initiation and intensification [28, 32]. Socioeconomic constraints, including low educational attainment (below middle school) and low-income levels, further limit access to medications and preventive health services, especially in rural areas.

Significant differences in hypertension awareness, treatment, and control have been observed between urban and rural populations, consistent with national patterns of healthcare resource allocation [28, 29]. Rural areas face complex disadvantages such as limited access to specialized care, sparse health education programs, and financial barriers to ongoing disease management. These inequalities highlight the need for prioritized training programs for primary care providers and the expansion of community-based screening programs in underserved areas.

A multi-pronged strategy is needed to address the epidemic. Culturally adapted interventions targeting sodium reduction, particularly in traditional practices such as ghee tea consumption, may reduce dietary risk. Policy reforms, including subsidizing combination anti-hypertensive therapies and integrating hypertension education into public health campaigns targeting local literacy levels, can improve access to treatment.

In conclusion, this study highlights the critical interplay of environmental, cultural, and systemic factors that contribute to the high prevalence and poor management of hypertension in Tibet. Addressing this burden requires context-specific interventions that take into account altitude-related physiologic adaptations, traditional lifestyles, and health care inequalities.

Strengths and limitations of this study

To our knowledge, this study is the first large-scale epidemiologic investigation of hypertension among adults in Tibet, China, and provides an important insight into a high-altitude population that has historically been underrepresented in global hypertension studies. Strengths of the study include its methodological rigor and comprehensive scope. The inclusion of 8992 participants from 7 cities ensured a representative sample; and standardized protocols (e.g., blood pressure measurements and body mass index classifications aligned with those of the World Health Organization) improved the reliability of the data and comparability with other regional and global studies. By integrating multidimensional risk factors, such as lifestyle behaviors (e.g., alcohol consumption) and metabolic indicators (e.g., central obesity), the analysis provides a holistic view of the determinants of hypertension specific to Tibet. In addition, the proposed focus on specific cultural practices (e.g., consumption of sodium-rich ghee tea) highlights feasible targets for tailored public health interventions, bridging the gap between biomedical research and local realities.

However, there are some limitations that require careful interpretation of the findings. The multistage stratified cluster sampling method, while practical, may be underrepresentative of mobile or nomadic populations, as evidenced by subtle differences in gender and urban-rural distribution compared with census data. Although weights were adjusted for prevalence to improve generalizability, this still introduces potential selection bias. Cross-sectional designs inherently limit causal inference; associations between observed risk factors (e.g., age, alcohol consumption) and hypertension need to be validated by longitudinal studies to sort out temporal relationships and confounding variables. Reliance on self-reported behaviors. Such as smoking and alcohol consumption raises concerns about recall bias, which could be mitigated by biomarker validation in future work. In addition, although mechanisms associated with hypoxia have been proposed to explain the increased burden of hypertension in Tibet, the lack of direct physiologic measurements has led to an incomplete description of plateau-specific pathways. Despite these limitations, the findings have direct relevance for public health. The high prevalence of advanced hypertension (49.8% stage 2 or more) and the marked urban-rural disparities in care underscore the urgency of policy reforms, even as methodological improvements (e.g., randomized sampling, longitudinal cohorts) are made. By linking hypertension to the unique social context of Tibet, this work not only advances the scientific understanding of hypertension but also advocates for a multidisciplinary strategy that addresses the biological and structural determinants of cardiovascular health. Future studies should build on this foundation by integrating biomarkers, expanding geographic coverage, and evaluating culturally adapted interventions to reduce the growing burden of hypertension in high-altitude populations.

Conclusions

The prevalence of hypertension in Tibet surpasses the national average, with notably low levels of awareness, treatment, and control. A substantial proportion of hypertensive patients are classified as Stage 2 or higher, and the majority of prescribed medications consist of single-drug monotherapies, leading to exceedingly low control rates. Therefore, a multifaceted strategy, including improved healthcare infrastructure and culturally appropriate public health campaigns, is necessary to address the burden of hypertension in Tibet.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-22792-3.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

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Author contributions

Y.Y. and J.P. developed the methodology, implemented the software, performed formal data analysis, and drafted the initial manuscript. Z.Z. and Q.J. conducted the literature review and interpreted the data. Y.Y., J.P., and H.S. designed visual materials, including figures and tables. G.B., Q.C., and C.Y. led the conceptualization, design, and oversight of the entire study. All authors contributed to manuscript writing and revisions, critically evaluated the content to ensure research integrity, and approved the final version.

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Data availability

The raw data generated in this study are not publicly available due to ongoing research. However, datasets can be obtained from the corresponding author upon reasonable request, subject to ethical and legal restrictions.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Fuwai Hospital, Chinese Academy of Medical Sciences (approval number: 2014 – 574). All participants provided written informed consent before participating in the study. All procedures were in accordance with the Declaration of Helsinki (1964).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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

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