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Relationship between hypertension and geographic altitude: a cross-sectional survey among residents in Tibet

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Abstract

Objective: This study aimed to assess the prevalence of hypertension (HT) among individuals living at different altitudes in Tibet.

Methods: We conducted a stratified cluster survey among 1,631 participants in Tibet living in areas at three different altitudes.

Results: Mean systolic and diastolic blood pressure and body mass index (BMI) values were highest at the lowest altitudes. After adjusting for age and sex, the prevalence of HT at low, medium, and high altitudes was 40.6%, 32.5%, and 20.4%, respectively. The prevalence of HT decreased with increasing altitude and increased with increasing age and BMI value.

Conclusion: Increasing altitude tended to decrease BMI levels, and as a consequence, the prevalence of HT was reduced. National policies and guidelines for HT in Tibet should focus on this relationship.

Keywords

High altitude, hypertension, body mass index, Tibet, prevalence, policy

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Introduction

Hypertension (HT) is a modifiable risk factor for cardiovascular diseases.[1,2] HT caused 9.4 million deaths and accounted for 7% of the disease burden in 2010.[3]

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In China, the prevalence of HT is increasing, with 29.6% of adults found to have HT in 2014.[4]

Increased blood pressure was estimated to be responsible for 2.3 million cardiovascular deaths among Chinese people in 2009.[5] Because of the large variation in geographic, demographic, and socioeconomic characteristics in different regions of China, the prevalence and incidence, as well as population awareness, access to treatment, prevention and control of HT differ widely across the country.

Tibet, the highest region on Earth, is located in southwest China. The altitude in Tibet varies from 1,200 meters to 5,600 meters above sea level. The prevalence of HT in 2014 among native Tibetan people in Lhasa, the capital city, was 51.2%, much higher than the average prevalence in China.[4,6] In different parts of the world, the effect of high altitude on the risk of HT remains unclear. Two recent systematic reviews investigating the relationship between high altitude and the prevalence of HT showed a positive but weak linear relationship between the prevalence of HT and altitude in Tibet.[7,8] Although statistical significance was not reached in either review, there seems to be an increase in HT prevalence with increased altitude among Tibetans. A few reports from India, Peru, and Nepal have shown a decline in the prevalence of HT at extreme altitudes over 3,700 to 4,000 meters above sea level.[9–11] This effect appears to be global and should be true at altitudes as high as 4,000 meters above sea level.

The objective of this study, therefore, was to assess the prevalence of HT among individuals living at three different altitudes in Tibet and to confirm the lower prevalence of HT at extreme altitudes, independent of other HT-related factors. A secondary aim was to determine factors associated with HT among native Tibetans, independent of altitude.

Methods

Study setting

The Tibetan Autonomous Region (TAR) is the second largest provincial-level autonomous region in China. The TAR is bordered on the north and east by the Central China Plain, on the west by India, and on the south by Nepal, India, and Bhutan.

This study was conducted in three different areas in Tibet with varying altitudes. The area with the lowest altitude was Bomi County of Nyingchi City, located in the eastern part of the TAR at 2,700 to 3,035 meters above sea level. The medium-altitude study area was Dagze District of Lhasa City, located in the center of the TAR at 3,719 to 3,970 meters above sea level. The area with the highest altitude was Nagarze County of Lhokha City, located in the southeastern TAR at 4,462 to 4,505 meters above sea level.

Study design, sample size, and participants

A stratified cluster survey was conducted from September to December 2017. In each of the three counties, two townships within 50 km of the county center were selected. Ten villages from each township were chosen using a simple random sampling technique, resulting in 60 villages as primary sampling units. Ultimately, the sample size for each county was calculated as 550 individuals, with an estimated prevalence 51.2%,[6] type I error of 0.05, and the design effect at 1.3. Eligible individuals were those aged between 20 and 80 years who had resided in the village for at least 1 year, identified using the resident information database of villages. Those with severe mental dysfunction, pregnancy, or severe complications of HT were excluded.

Data collection

We invited eligible participants to the nearest primary health center or village committee through local health and medical service centers. After participants provided their informed consent, we measured their waist circumference, body weight, and height with participants wearing no shoes or overcoat, using a height and weight scale (Su Hong RGZ-120). Scales were calibrated before measurement at each field site, to reduce measurement error. Height was measured to the nearest centimeter with the vertical ruler and weight to the nearest kilogram with the spring balance of the scale.

After weight and height measurement, participants were interviewed by trained medical students from the Medical College of Tibet University. Participants then rested in a quiet room for at least 5 minutes before a first blood pressure (BP) measurement was taken, using an Omron HEM-7201 automatic digital BP monitor (Omron Corp., Kyoto, Japan).[12] After wrapping the cuff of the appropriate size around the participant's upper arm, the arrow marking was placed on the median aspect of the arm to ensure correct placement of the measuring apparatus on the brachial artery. BP was measured twice every 60 seconds in all participants. A third measurement was taken in those who had discordant BP values of greater than 10 mmHg in the previous two measurements. The arithmetic mean of all BP measurements was taken for the final result. All measurements were carried out by trained research staff, according to World Health Organization (WHO) and National Guidelines.

Variables

Dependent variables were systolic and diastolic blood pressure (SBP and DBP, respectively). According to the criteria of the Seventh Report of the Joint National Committee guideline, HT in this study was defined as SBP $\geq$140 mmHg and/or DBP $\geq$90 mmHg.[13]

Independent variables included biological factors such as BMI and family history of HT; sociodemographic factors such as age, sex, and education; and health-related behaviors such as consumption of tobacco (both smokers and non-smokers) and alcohol in the past 1 year. BMI was calculated as weight (kg) divided by the square of height (m^2). To facilitate comparison with other studies, we used the cutoff points for overweight and obesity according to the protocol for Asian populations, in which BMI 23.0 to 27.5 kg/m^2 is defined as overweight and BMI = $\geq$27.5 kg/m^2 is considered obese.[14]

Statistical analysis

Characteristics of participants at the three altitudes were compared using chi-square tests for categorical variables and the Kruskal–Wallis test or analysis of variance for continuous variables, as appropriate. Weighting based on the survey design was used to adjust the estimates, and raking was performed to adjust the sampling weights of the data based on known population characteristics in 2010.[15] Pearson's chi-square statistic was used to compare the characteristics among participants with HT at different altitudes. Risk factors of HT were identified using survey-weighted generalized linear modeling.

Variables with a p-value $<$0.2 in the univariate analysis were included in the initial multivariate model. The final multivariate model was determined based on a backward stepwise process and included only variables with *p*-values $<$0.05. All data were entered into Epidata version 3.1 (http://www.epidata.dk/) and analyzed using R version 3.5.1 (The R Project for Statistical Computing, Vienna, Austria).

Ethics

This study was approved by the Ethical Review Committee of Prince of Songkla University, Thailand (REC: 60-114-18-5) and received a letter of permission from Tibet University. All invited individuals agreed to participate in the study by providing their informed consent. Participants were informed that they could withdraw from the study at any time.

Results

Basic characteristics of participants

We assessed a total of 1,650 individuals living in study areas at three different altitudes. Most participants were permanent residents registered in the village registration system and had been living in the area for more than 5 years. After excluding 19 participants enrolled in the study but who failed to complete either a physical examination or a questionnaire survey, 1,631 participants had available data of sociodemographic and anthropometric characteristics. As there was clear evidence of an unbalanced distribution between the data sample and the general Tibetan population, raking adjustment was applied to the raw data. The raw BP measurement of participants according to different altitudes are shown in Table 1. Among the total participants, 614 (37.6%) were male and 1,017 (62.4%) were female. Six hundred and ninety (42.3%) participants had a family history of HT. The median and interquartile range (IQR) of BMI among all study participants was 23.7 and 21.3 to 26.4 kg/m^2, respectively. The percentage of participants who were single/separated, and those who had no education, a family history of HT, and high BMI was largest in the lowest altitude area. The median (IQR) SBP and DBP were 128.0 mmHg (115.5–146.0) and 84.0 mmHg (76.0–95.0), respectively. The prevalence of HT and the median SBP and DBP tended to increase with decreasing altitude and were significantly associated with different altitudes ($p < 0.001$).

Table 2 shows weighted estimates of the parameters of interest. Alcohol consumption was significantly associated with different altitudes ($p = 0.023$). The association between tobacco use and HT was the same as that in the unweighted analysis. In Table 2, the estimated BMI and waist circumference of people living at the lowest altitude (in Bomi) were highest and differed from those living at medium and high altitudes (in Dageze and Nagarze, respectively). BMI was not significantly different between people living at medium and high altitudes in Dageze and Nagarze (from 3,719 to 4,505 meters above sea level).

In the weighted analysis, the prevalence of HT at the three different altitudes varied with age of the population. Therefore, the age- and sex-standardized prevalence was used for further analysis. Table 3 shows the effect of various baseline characteristics and demographic factors (marital status, education level, occupation, and tobacco consumption) among individuals with HT at different altitudes. At all three altitudes, participants who were diagnosed with HT were more likely to be living in rural areas and working as farmers, living with their spouse, and did not use tobacco; those living at the lowest altitude were more likely to have a poor education.

Table 4 summarizes the risk factors of HT in the multivariate analysis. After adjusting for age, the prevalence of HT for all participants and among males and females was 29.8%, 36.7%, and 22.4%, respectively. After adjustment for other potential confounding factors, altitude ($p = 0.001$), family history of HT ($p < 0.001$), marital status ($p = 0.015$), and BMI ($p < 0.001$) were significantly associated with HT. The prevalence of HT decreased with increasing altitude. The HT prevalence increased with increasing participant age and BMI value. HT was more prevalent among participants with a family history of HT (odds ratio (OR) 1.89), male sex (OR 1.74), and among

Table 1. Sociodemographic and anthropometric characteristics and BP measurement in participants living at three altitudes (raw data of 1631 individuals).

Variable	All	Bomi 2700–3035 (masl) Male = 199 Female = 343	Dageze 3719–3970 (masl) Male = 220 Female = 323	Nagarze 4462–4505 (masl) Male = 195 Female = 351	*p*-value*
Sociodemographic characteristics					
Sex, n (%)					
Male	614	199 (36.7)	220 (40.5)	195 (35.7)	0.226
Female	1017	343 (63.3)	323 (59.5)	351 (64.3)	
Marital status, n (%)					
Single/separated	240	181 (33.4)	52 (9.6)	7 (1.3)	<0.001
Married	1391	361 (66.6)	491 (90.4)	539 (98.7)	
Age group (years), n (%)					
20–39	343	150 (27.7)	92 (16.9)	101 (18.5)	
40–59	968	261 (48.2)	359 (66.2)	348 (63.7)	<0.001
60–80	320	131 (24.1)	92 (16.9)	97 (17.8)	
Education, n (%)					
None	882	379 (69.9)	189 (34.8)	314 (57.5)	
Primary school	658	139 (25.6)	325 (59.9)	194 (35.5)	<0.001
Middle school and above	91	24 (4.5)	29 (5.3)	38 (7.0)	
Occupation, n (%)					
Agricultural	1468	522 (96.3)	528 (97.2)	418 (76.6)	
Herdsman	111	4 (0.7)	12 (2.2)	95 (17.4)	<0.001
Other	52	16 (3.0)	3 (0.6)	33 (6.0)	
Monthly household income (RMB), n (%)					
≤2500	1444	470 (86.7)	500 (92.1)	474 (86.8)	
2501–5000	160	65 (12.0)	40 (7.4)	55 (10.1)	<0.001
≥5001	27	7 (1.3)	3 (0.6)	17 (3.1)	
Tobacco use, n (%)					
Yes	416	91 (16.8)	211 (38.9)	114 (20.9)	
No	1215	451 (83.2)	332 (61.1)	432 (79.1)	<0.001
Alcohol use, n (%)					
Yes	315	115 (21.2)	99 (18.2)	101 (18.5)	0.386
No	1316	427 (78.8)	444 (81.8)	445 (81.5)	
Family history of HT, n (%)					
Yes	690	283 (52.2)	216 (39.8)	191 (35.0)	<0.001
No	941	259 (47.8)	327 (60.2)	355 (65.0)	
Anthropometric characteristics, median (IQR)					
WC (cm)	79.0 (72.0, 85.5)	83.0 (75.0, 92.0)	77.0 (72.0, 83.0)	78.0 (72.0, 82.0)	<0.001
BMI (kg/m^2)	23.7 (21.3, 26.4)	24.4 (21.7, 27.6)	23.0 (20.9, 25.6)	23.5 (21.3, 26.0)	<0.001
BP measurement					
SBP (mmHg), median (IQR)	128.0 (115.5, 146.0)	135.0 (119.0, 157.2)	129.5 (117.8, 145.5)	121.0 (112.0, 135.0)	<0.001
DBP (mmHg), median (IQR)	84.0 (76.0, 95.0)	88.6 (78.0, 101.0)	85.5 (78.0, 96.0)	80.2 (73.0, 89.0)	<0.001
HT, n (%)					
Yes	658	287 (53.0)	228 (42.0)	143 (26.2)	<0.001
No	973	255 (47.0)	315 (58.0)	403 (73.8)	

Note: Data are presented as number and percentage or median and interquartile range (IQR).
*For comparison, categorical variables were tested using the chi-squared test; the Kruskal–Wallis test was used for continuous variables.
Abbreviations: HA, high altitude; HT, hypertension; BMI, body mass index; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; masl, meters above sea level.

Table 2. Sociodemographic and anthropometric characteristics and BP measurement of participants living at three altitudes (weighted results).

Characteristics	LA (Bomi) 2700–3035 (masl)	MA (Dageze) 3719–3970 (masl)	HA (Nagarze) 4462–4505 (masl)	*p*-value
Sociodemographic characteristics, % (95% CI)				
Sex				
Male	49.9 (45.2–54.7)	56.2 (47.6–64.8)	51.5 (47.2–55.8)	0.557
Female	50.1 (45.3–54.9)	43.8 (35.2–52.4)	48.5 (44.2–52.8)	
Marital status				
Single/separated	26.3 (21.4–31.3)	9.7 (6.0–13.3)	1.4 (0.0–3.1)	<0.001
Married	73.7 (68.7–78.6)	90.3 (86.6–94.0)	98.6 (96.9–100.3)	
Age group (years)				
20–39	64.3 (60.5–68.1)	49.3 (41.6–57.0)	52.5 (48.2–56.7)	<0.001
40–59	24.3 (21.2–27.3)	41.3 (34.5–48.0)	37.3 (33.7–40.9)	
60–80	11.4 (9.5–13.2)	9.4 (6.4–12.3)	10.2 (8.5–11.9)	
Education				
None	58.3 (52.4–64.1)	30.9 (25.4–36.3)	43.3 (37.9–48.7)	<0.001
Primary school	33.1 (27.4–38.7)	62.5 (56.8–68.2)	41.3 (35.3–47.2)	
Middle school and above	8.6 (4.8–12.6)	6.6 (3.5–9.7)	15.4 (10.3–20.6)	
Occupation				
Agricultural	95.3 (92.4–98.2)	96.4 (93.9–99.0)	74.6 (69.2–80.0)	<0.001
Herdsman	0.5 (0.0–0.1)	2.4 (0.5–4.5)	14.5 (10.6–18.5)	
Other	4.2 (1.4–7.0)	1.1 (0.0–2.8)	10.6 (6.4–15.3)	
Household income/month (RMB)				
≤2500	84.5 (80.2–88.9)	93.2 (90.5–95.8)	82.2 (77.1–87.3)	
2501–5000	14.0 (9.8–18.1)	6.4 (3.8–9.0)	13.1 (8.6–17.6)	0.006
≥5000	1.5 (0.0–3.1)	0.4 (0.0–0.1)	4.7 (1.7–7.8)	
Tobacco use	20.7 (15.7–25.6)	44.0 (37.8–50.2)	27.5 (21.8–33.2)	<0.001
Alcohol use	30.6 (24.9–36.3)	17.8 (13.4–22.2)	24.7 (19.3–30.1)	0.023
Family history of HT	54.9 (49.1–60.7)	33.7 (28.1–39.2)	27.8 (23.0–32.6)	<0.001
Anthropometric data, mean (95% CI)				
WC (cm)	84.6 (83.3–85.9)	77.8 (76.7–78.9)	77.8 (76.6–78.9)	<0.001
BMI (kg/m^2)	24.7 (24.2–25.1)	23.2 (22.8–23.6)	23.4 (22.9–23.8)	<0.001
BP measurement, mean (95% CI)				
SBP (mmHg)	132.2 (129.8–134.6)	128.6 (126.4–130.8)	121.9 (120.1–123.7)	<0.001
DBP (mmHg)	86.1 (84.5–87.7)	84.7 (83.4–86.1)	79.9 (78.5–81.2)	<0.001
HT (%)	40.6 (35.1–46.1)	32.5 (27.1–37.9)	20.4 (16.1–24.6)	<0.001

Note: Data are presented as survey mean and (95% CI). For multiple comparisons of reweighting, analysis of variance was used for continuous variables and the chi-square test was used for categorical variables.
Abbreviations: LA, low altitude; MA, medium altitude; HA, high altitude; WC, waist circumference; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; CI, confidence interval; masl, meters above sea level.

those who were single or separated (OR 1.90), compared with the reference groups.

Discussion

More than 140 million people, accounting for about 2% of the world's population including Tibetans, live in high-altitude regions.[16] Although a progressive decline in barometric pressure, air temperature, and air humidity are observed with increasing altitude, the relationship between hypoxia and HT remains uncertain in different populations.[7,16,17] In the present study, the age- and sex-standardized overall prevalence of HT was 29.8%, which is consistent

Table 3. Baseline characteristics of participants with HT at different altitudes, after raking.

	Study areas, masl			
Characteristics	Bomi 2700–3500 (Mean = 2830) % (95% CI)	Dageze 3719–3970 (Mean = 3798) % (95% CI)	Nagarze 4462–4505 (Mean = 4490) % (95% CI)	*p*-value
Sex				
Male	64.1 (56.9–71.3)	60.4 (47.2–73.5)	64.4 (55.0–73.9)	0.8523
Female	35.9 (28.7–43.1)	39.6 (26.5–52.8)	35.6 (26.1–45.0)	
Marital status				
Single/separated	37.9 (29.9–45.9)	10.9 (5.0–16.9)	0 (0)	$<$0.001
Married	62.1 (54.1–70.1)	89.1 (83.1–95.0)	100 (100–100)	
Age group (years)				
20–39	41.2 (32.5–50.0)	27.4 (16.0–38.9)	25.9 (12.4–39.4)	0.109
40–59	35.9 (29.5–42.3)	51.5 (41.6–61.3)	48.5 (37.8–59.1)	
60–80	22.8 (18.2–27.5)	21.1 (14.4–27.8)	25.7 (18.4–32.9)	
Education				
None	59.1 (50.5–67.7)	37.7 (28.6–46.8)	40.9 (30.9–50.7)	0.01
Primary school	36.5 (27.9–45.1)	55.8 (46.7–65.0)	45.5 (34.2–56.8)	
Middle school and above	4.4 (0.5–8.3)	6.5 (1.0–11.9)	13.6 (2.7–24.5)	
Occupation				
Agricultural	91.9 (86.1–97.7)	94.0 (88.6–99.4)	68.8 (57.7–79.8)	$<$0.001
Herdsman	1.0 (0.0–2.2)	2.7 (0.5–4.8)	19.0 (10.1–27.9)	
Other	7.1 (1.3–12.8)	3.3 (0.0–8.3)	12.2 (3.2–31.2)	
Household monthly income (RMB)				
$\leq$2500	84.1 (77.3–90.9)	91.4 (87.6–95.2)	80.4 (70.6–90.2)	0.39
2501–5000	13.3 (7.1–19.5)	8.6 (4.8–12.4)	14.1 (5.0–23.1)	
$\geq$5001	2.6 (0.0–6.0)	0.0 (0)	5.5 (0.6–10.4)	
Tobacco use				
Yes	23.4 (15.8–30.9)	46.3 (37.1–55.6)	34.3 (23.0–45.6)	0.008
No	76.6 (69.1–84.2)	53.6 (44.4–62.9)	65.7 (54.4–77.0)	
Alcohol use				
Yes	27.7 (19.4–36.1)	24.5 (17.1–31.8)	29.1 (18.1–40.1)	0.794
No	72.3 (63.9–80.6)	75.5 (68.2–82.9)	70.9 (59.9–81.9)	
Family history of HT				
Yes	54.1 (45.8–62.4)	47.1 (38.2–56.1)	52.5 (41.2–63.8)	0.6315
No	45.9 (37.6–54.2)	52.9 (43.9–56.1)	47.5 (36.2–58.8)	
BMI (kg/m^2)				
$\leq$18.4	5.0 (1.1–9.0)	3.7 (1.2–6.1)	1.5 (0.0–3.7)	0.014
18.5–22.9	21.9 (15.4–28.4)	37.8 (29.4–46.2)	30.2 (20.1–40.4)	
23.0–27.4	36.2 (28.2–44.2)	39.9 (31.0–48.8)	46.4 (35.3–57.5)	
$\geq$27.5	36.8 (28.6–45.1)	18.6 (11.1–26.2)	21.8 (11.1–32.6)	

Notes: Data are presented as survey mean (SE) and 95% CI. For the multiple comparisons the Pearson chi-square statistic (Rao and Scott adjustment) was used.
Abbreviations: HT: hypertension; SE, standard error; BMI, body mass index; CI, confidence interval; masl, meters above sea level.

with a national survey in China during 2010.[4] Our results are also comparable with a systematic review conducted among Tibetan adults living at different altitudes, with reported prevalence rates ranging from 23% to 56%.[7]

We conducted this study in three areas at different altitudes and found that the

Table 4. Risk factors of HT-weighted generalized linear models.

Variables	HT % (95% CI)	OR (95% CI)	*p* (LR test)
Total	29.8 (26.9–32.7)		
Sex			
Female	22.4 (18.8–26.1)	1	0.001
Male	36.7 (31.4–42.0)	1.74 (1.24–2.45)	
Marital			
Married	26.7 (23.7–29.8)	1	0.015
Single/separated	52.5 (42.8–62.3)	1.90 (1.14–3.18)	
Age group (years)			
20–39	17.9 (13.3–22.6)	1	
40–59	38.4 (34.8–41.9)	3.33 (2.27–4.88)	<0.001
60–80	66.4 (60.3–72.4)	10.39 (6.50–16.62)	
Education			
None	31.5 (27.8–35.2)	1	0.654
Primary school	30.7 (25.5–35.8)	1.23 (0.85–1.78)	
Middle school and above	19.9 (9.2–30.6)	1.11 (0.49–2.53)	
Family history of HT			
No	23.2 (19.7–26.6)	1	0.001
Yes	40.2 (35.0–45.4)	1.89 (1.32–2.71)	
Altitude (masl)			
2700–3035	40.6 (35.1–46.1)	1	<0.001
3719–3970	32.5 (27.1–37.9)	0.78 (0.50–1.21)	
4462–4505	20.4 (16.1–24.6)	0.41 (0.26–0.65)	
BMI status (Asian standard, 2004; WHO)			
≤22.9	20.6 (16.9–24.3)	1	
23.0–27.4	31.3 (26.5–36.2)	1.74 (1.20–2.53)	<0.001
≥27.5	50.8 (41.8–59.8)	3.49 (2.10–5.79)	

Note: Likelihood ratio (LR) analysis of the regression model.
Abbreviations: HT, hypertension; BMI, body mass index; Ref., the reference group of each predictor; OR, odds ratio; CI, confidence interval; masl, meters above sea level; WHO, World Health Organization.

prevalence of HT was significantly lower at higher altitudes. Our finding concurs with a study carried out in Northern India, which reported that the prevalence of HT among people residing at higher altitude was relatively low.[9] There are a few possible explanations for this finding. Living under hypoxic conditions may have both beneficial and harmful effects on health, with some populations developing protective mechanisms.[16] Thus, participants residing at higher altitudes might be protected against chronic hypoxia from birth and may subsequently have a lower tendency to develop high BP later in life.

Another explanation might be the different lifestyles and diets among participants living in the three study areas. Townships at the lowest altitude have become more developed than the other study areas, after adoption of The Western Development Strategy.[18] The Economic and Social Development Plan (13th Five-Year-Plan) of the Chinese government promoted urban residence for people who were previously registered as living in rural areas, and assisted people who moved from rural to urban areas in finding stable employment and adapting to the urban lifestyle.[19] Thus, people in the lowest-altitude study area may have better education and may have more modern, sedentary occupations and lifestyles, which are risk factors of HT.[9] Overweight and obesity are important modifiable risk factors of HT.[9,20] In this study, participants with the highest BMI lived at the lowest altitude, thus affecting the prevalence of HT. Similarly, some studies have reported altitude exposure being inversely related to BMI.[21,22] Migration to and settlement at lower altitudes from higher ones may have effects that we could not identify in this study. People who move to lower altitudes may increase their risk of HT by adopting an urban lifestyle. These individuals will also be located closer to health care centers and will therefore be more likely to be diagnosed with HT. However, people at high altitudes who are physically healthy may not migrate to lower areas; they may continue their traditional lifestyle habits, such as being physically active and eating a low-calorie diet, thereby reducing their risk of HT. Being located far from health centers, they are also less likely to be diagnosed with HT.

Sex is known to have an important influence on blood pressure.[23] Many studies have shown that men are more likely than women to have increased BP, resulted in a higher prevalence of metabolic risk factors for HT in men.[8,20] Advanced age is associated with the development and progression of HT owing to aging effects such as atherosclerotic changes and impaired renal function.[24] Most studies have shown that HT prevalence increases with increasing age.[9,20] Our findings agree with those studies; male participants and older age groups (60–80 years) had a significantly higher prevalence of HT.

Our finding that being single (never married/separated/widowed) had a positive relationship with HT agreed with the findings of other studies reporting that marital status modifies sex differences in HT, and men who were never married have a higher risk of HT than married men.[25,26] Marriage may be related to mechanisms affecting the occurrence of HT.[27] Married couples may have a higher subjective quality of life than other groups,[28] as they have more material resources, better access to social support, and less stress.[29]

In this study, we found that the consumption of alcohol and tobacco differed among the three study areas. This can be explained in that residents at different altitudes have different cultural customs and behaviors regarding alcohol and tobacco consumption. In our study, consumption of tobacco included snuff taking. Overall, the percentage of alcohol and tobacco consumption was low. There are several possible explanations for these findings. Local production of homemade alcohol called "chang" or highland barley wine makes the measurement of alcohol use difficult as the percentage of alcohol in this beverage differs among clans and villages. In recent decades, the Chinese government launched Healthy China 2030, which includes strengthening the antismoking policy in public places, with reports confirming its success.[30] However, such enforcement is not in place in rural Tibet. According to public health government officers on our research team, study participants might have underreported their rates of smoking and drinking alcohol.

This study has some strengths. Although all study areas were in high, mountainous regions of Tibet, this study was conducted at three different altitudes to give a better understanding of the relationship between HT and altitude. We used national census data to adjust the sampling weights, thus providing more precise findings. Nonetheless, some limitations should be acknowledged. Owing to cold weather at the study sites, it was not possible for participants to remove all of their warm clothing during measurement of weight and waist circumference. We also did not measure daily salt intake in

Tibetan foods and drinks consumed. The main source of salt intake is from butter tea, which people drink throughout the day, and the salt content of this tea varies from household to household.

Conclusion

We found that the age- and sex-adjusted prevalence of HT in Tibet was not different from that in other provinces of China. Those living at higher altitudes (4,490 meters above sea level) tended to have lower BMI values, which indicates that the prevalence of HT among residents at higher altitudes was much lower (about 50%) than that among residents living at low altitudes (2,830 meters above sea level). These findings may provide new insights into the prevention and treatment of HT, resulting in a reduction of subsequent cardiovascular problems in Tibet. The government policy has been focused on urbanization; however, this might have negative effects on the health status of the community. National policies and guidelines on health promotion should be carefully monitored, especially in high-altitude areas of China, such as Tibet.

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Author contributions

CS, HS,VC, and OZLB conceived and designed the study; DJ and BSZM designed the study and secured funding; CS searched the literature, performed data analysis, and wrote the article; HS revised this article and supervised the study.

Declaration of conflicting interest

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