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 a ected by hypertension, yet only 21% achieve adequate control [2].Report on Hypertension highlights an alarming increase in hypertension prevalence, particularly in the WHO Western Paci c Region (including China), where the prevalence among adults rose from 24 to 28% between 1990 and 2019, with the number of a ected individuals escalating from 144 million to 346 million [3]. Hypertension is the primary modi able 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 a ected 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].

Signi cant regional disparities exist in hypertension awareness, treatment, and control across China [9–11],

After resting in a sitting position for at least 5 min, two measurements were taken on the right upper arm. If the di erence in systolic blood pressure (SBP) or diastolic blood pressure (DBP) between the two readings was more than 10 mmHg, a third measurement was taken. e average of the two or three readings was then

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

Strati□ed analysis of hypertension by participant characteristic

Further analysis of hypertension severity revealed that

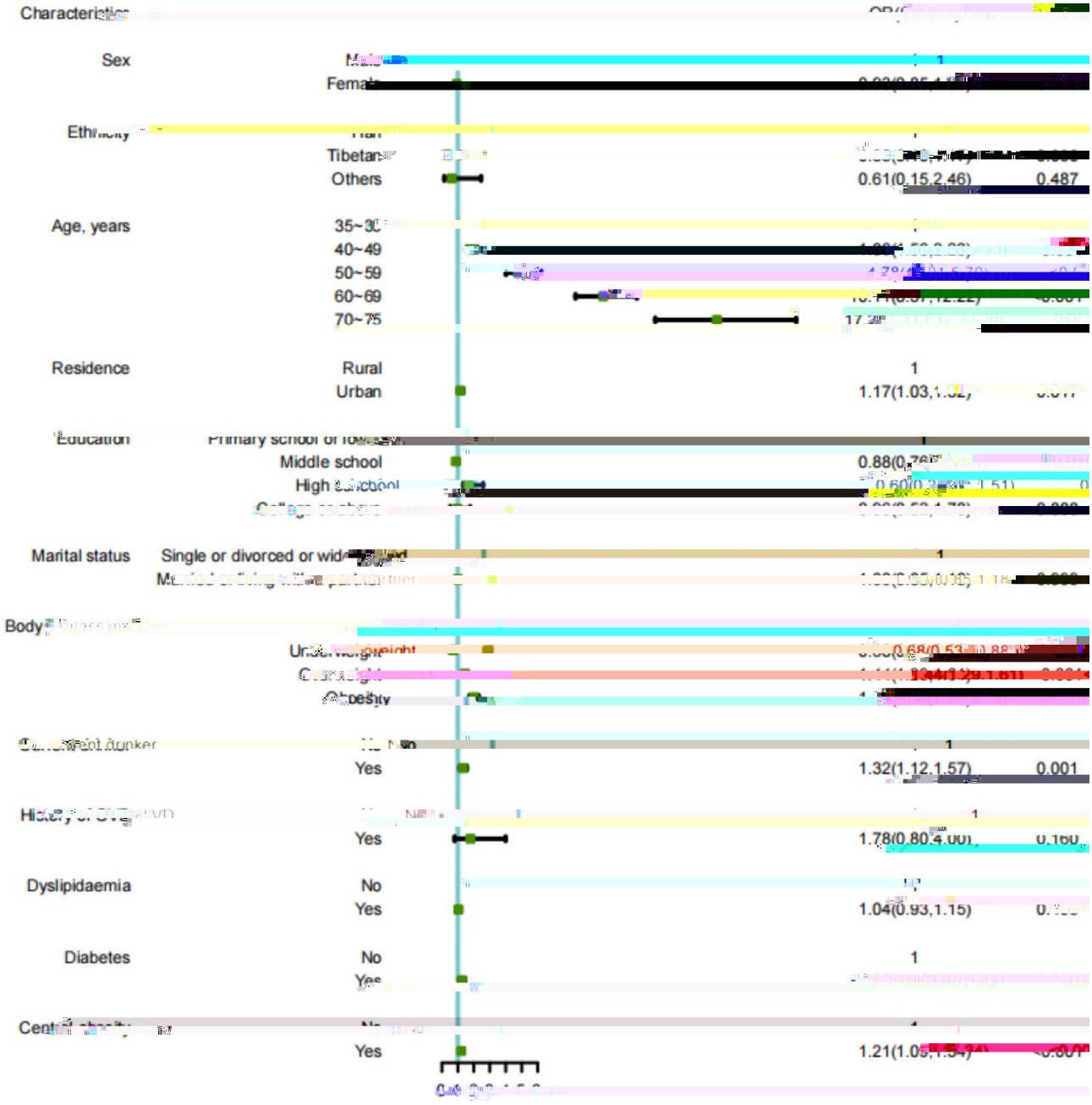

Fig. 2 The odds ratios (OR) and 95% con□dence intervals (CI) for prevalence of hypertension from multifactorial logistic regression

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 signi cant 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 signi cantly 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. Signi - cant di erences 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 signi cantly higher in urban

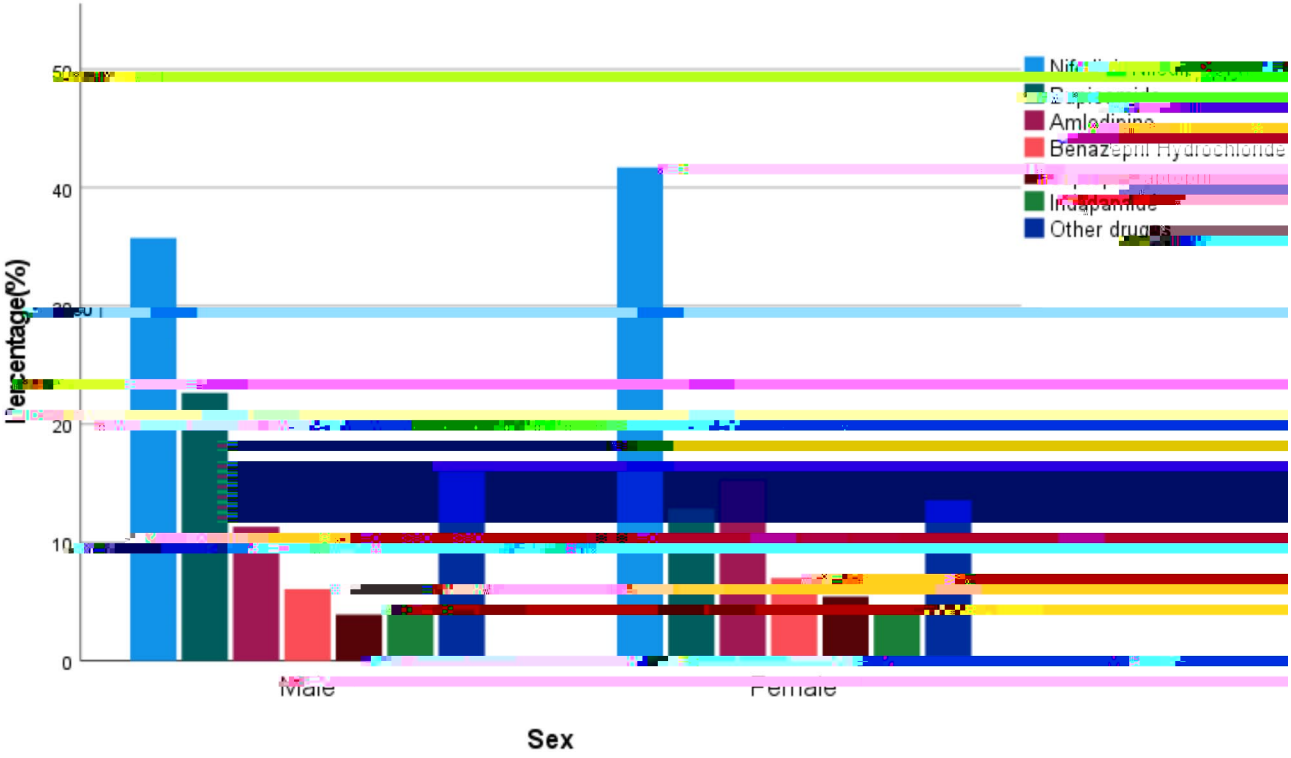

Fig. 3 Proportion of commonly used drugs for monotherapy of hypertension between genders

di erence may be attributed to region-speci c 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].

e 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 insu cient patient education may a ect treatment initiation and intensi cation [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.

Signi cant di erences 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 nancial barriers to ongoing disease management. ese 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-speci c 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 rst 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. e inclusion of 8992 participants from 7 cities ensured a representative sample; and standardized protocols (e.g., blood pressure measurements and body mass index classi cations 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 speci c to Tibet. In addition, the proposed focus on speci c 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 ndings. e multistage strati ed cluster sampling method, while practical, may be underrepresentative of mobile or nomadic populations, as evidenced by subtle di erences 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-speci c pathways. Despite these limitations, the ndings have direct relevance for public health. e 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 scienti c 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

e 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 classi ed as Stage 2 or higher, and the majority of prescribed medications consist of single-drug monotherapies, leading to exceedingly low control rates. erefore, 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

Acknowledgements

Patient and public involvement

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

Received: 11 November 2024 / Accepted: 14 April 2025
Published online: 10 May 2025

References

1. Poulter NR, Prabhakaran D, Caul□eld M. Hypertens Lancet. 2015;386(9995):801–12.
2. Mills KT, Stefanescu A, He J. The global epidemiology of hypertension. Nat Rev Nephrol. 2020;16(4):223–37.
3. Global report on. Hypertension: the race against a silent killer. World Health Organ. https://iris.who.int/handle/10665/372896
4. GBD 2013 Mortality and Causes of Death Collaborators. Global, regional,