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Subtype-specific trends in premature cardiovascular mortality and potential gains in life expectancy in Hainan, China, 2014–2024

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Abstract

Background. We examined premature mortality from cardiovascular and cerebrovascular diseases (CVDs) in Hainan Province during 2014–2024, including trends, population and geographic differences, and subtype-specific potential gains in life expectancy.

Methods. Cause-of-death surveillance data were corrected for underreporting. Years of life lost (YLL) and age-standardised YLL rates quantified burden. Joinpoint regression assessed trends.

Regional comparisons used Kruskal–Wallis tests with Holm correction; Global Moran's I assessed spatial autocorrelation. Cause-deleted life tables estimated theoretical potential life expectancy gains.

Results. CVD-related YLL increased from 304372.12 person-years in 2014 to 515851.41 person-years in 2024; the age-standardised YLL rate rose from 4240.12 to 5245.28 per 100000. In 2024, ischaemic heart disease, ischaemic stroke and haemorrhagic stroke accounted for 30.25%, 22.68% and 18.18% of total CVD-related YLL, respectively, or 71.11% combined. Ischaemic stroke showed the fastest increase in age-standardised YLL rate, with an average annual percent change of 7.91% (95% confidence interval: 6.15%–10.35%). Hypertensive diseases and ischaemic heart disease also increased significantly, whereas pulmonary heart disease and diseases of the pulmonary circulation declined. Except for rheumatic heart disease, age-standardised YLL rates were higher in males. Burden generally increased with age. The eastern region had a descriptively lower burden than the central and western regions; no regional comparison remained significant after Holm correction, and no significant global spatial autocorrelation was detected. In 2024, life expectancy at birth was 81.32 years. Eliminating ischaemic heart disease and ischaemic stroke deaths yielded the largest theoretical gains, at 1.87 and 1.54 years, respectively.

Conclusions. Premature cardiovascular mortality burden increased in Hainan. Ischaemic heart disease and ischaemic stroke were the main contributors to burden and life expectancy loss. Prevention should prioritise these subtypes, males and older adults, with local planning informed by descriptive burden patterns.

Contributions to the literature

• Long-term mortality surveillance adds local evidence on how the burden of individual cardiovascular diseases has changed in Hainan, beyond studies of overall disease burden.

• Combining years of life lost with theoretical gains in life expectancy provides complementary information for population health planning.

• Comparisons by disease subtype, sex and age help identify prevention priorities; geographic patterns can inform local planning while acknowledging statistical uncertainty.

Keywords: Cardiovascular diseases; Premature mortality; Years of life lost; Life expectancy; Cause-deleted life table; Hainan; China

Introduction

Cardiovascular and cerebrovascular diseases (CVDs) are among the leading causes of death and loss of healthy life worldwide [1．] .In 2019, CVDs caused approximately 17.90 million deaths globally, accounting for 32% of all deaths and the largest share of deaths from non-communicable diseases (NCDs)[2．] .According to the Report on Cardiovascular Health and Diseases in China 2024, incident cardiovascular disease cases increased from 5.3007 million in 1990 to 12.3411 million in 2019. CVDs caused 5.013 million deaths in China in 2021, and incidence and mortality are projected to continue rising[3．4．]. Against this growing national burden, Hainan Province also faces substantial challenges in CVD prevention and control. Hainan is a tropical island province in southern China and represents a distinctive population setting for cardiovascular health research. In recent years, the province has experienced continued population ageing and substantial population mobility, while healthcare resources and chronic disease management capacity vary across geographic areas. Reports indicate that CVDs remained the leading cause of death in Hainan during 2018–2022. Their contribution to loss of life expectancy exceeded that of malignancies, respiratory diseases and other major disease groups. Stroke and ischaemic heart disease were the principal contributors to this burden [5．7．].

Previous studies of CVD burden have largely relied on Global Burden of Disease (GBD) estimates. Although these estimates facilitate comparisons, their dependence on model parameters and assumptions may limit their accuracy for specific local populations. Most studies have also examined CVDs collectively or focused on a single disease category. Systematic comparisons of premature mortality burden and effects on life expectancy across ischaemic heart disease, ischaemic stroke, haemorrhagic stroke and hypertensive diseases remain limited.

We therefore used cause-of-death surveillance data from Hainan Province, correcting deaths recorded during 2014–2024 for underreporting. We quantified the premature mortality burden of CVDs and their major subtypes using years of life lost (YLL) and examined temporal trends in age-standardised YLL rates. We further assessed differences by sex, age and geographic area and used cause-deleted life tables to estimate subtype-specific potential gains in life expectancy. By integrating long-term mortality surveillance, subtype-specific disease burden and life expectancy analysis, this study aimed to identify priority CVD subtypes and population groups for prevention and to provide evidence for more targeted cardiovascular health planning in Hainan and other rapidly ageing populations with similar demographic transitions.

Methods

Study design and setting

This observational study used mortality surveillance data from Hainan Province, China, during 2014–2024.

Data sources

Sources and processing of mortality data

Mortality data were obtained from the Hainan Province cause-of-death surveillance system. We extracted individual CVD death records for 2014–2024 using the underlying cause of death. Records included year of death, sex, age, city or county, and International Classification of Diseases, 10th Revision (ICD-10) code. CVDs were classified using ICD-10 codes for the underlying cause of death. Eight subtypes were defined: hypertensive diseases (I10–I15); ischaemic heart disease (I20–I25); rheumatic heart disease (I01, I02.0, I05–I09); pulmonary heart disease and diseases of the pulmonary circulation (I26–I28); ischaemic stroke (I63, I69.3); haemorrhagic stroke (I60–I62, I69.0–I69.2); unspecified stroke (I64, I69.4); and other CVDs (I00–I99 excluding the preceding codes). Mortality data were corrected using annual death underreporting rates to improve accuracy[8．10．]. Rates for 2014–2024 were obtained from internal annual underreporting surveys in Hainan Province. This

correction reduced the influence of underreporting on mortality estimates and provided the basis for subsequent disease burden calculations.

Sources and processing of population data

Population data were based on the sixth (2010) and seventh (2020) national population censuses and annual total population figures published in statistical yearbooks. Interpolation and extrapolation were used to estimate age- and sex-specific populations for 2014–2024. These estimates were used to calculate YLL, YLL rates and life expectancy indicators. Standard five-year age groups were used to ensure comparability across years. Age was classified as <1 year, 1–4 years, five-year intervals from 5–9 to 90–94 years, and ≥95 years. These age groups were used consistently across the study period.

Sources of the standard population and parameters

Age standardisation used the population structure of the seventh national population census [11．13．]to account for differences in age composition across years and populations. YLL calculations used the standard life table from GBD 2021.

Statistical analysis

Calculation of mortality burden

Years of life lost were used to quantify the premature mortality burden of CVDs. YLL was calculated as follows:

$$YLL=\sum N\times L$$

N denotes the number of deaths in the corresponding age and sex group after correction for underreporting. L denotes the years of life lost at each age of death, defined as the corresponding remaining life expectancy in the GBD 2021 standard abridged life table.

$$YLL\text{rate} = \frac{YLL}{P} \times 100000$$

P denotes the population of the corresponding age and sex group during the same period.

Age-standardised rates were calculated using the standard population from the seventh national population census in 2020:

$$\text{Age-standardised YLL rate} = \frac{\Sigma \text{ standard population age composition} \times \text{age-specific YLL rate}}{\Sigma \text{ standard population age composition}}$$

Temporal trend analysis

The Joinpoint Regression Program (6.0.1) was used to analyse temporal trends in age-standardised YLL rates for CVD subtypes during 2014–2024. Annual percent change (APC), average annual percent change (AAPC) and their 95% confidence intervals (CIs) were calculated. A two-sided $P < 0.05$ was considered statistically significant.

Regional differences and spatial analysis

To improve the stability of city- and county-level burden estimates, mortality and population data for 2023–2024 were pooled. Age-standardised YLL rates for major CVD subtypes were calculated for 18 cities and counties and compared across the eastern, central and western regions of Hainan. The Kruskal–Wallis test compared the distributions of age-standardised YLL rates across regions. P values for the six disease subtypes were adjusted for multiple testing using the Holm method. Global Moran's I assessed spatial autocorrelation in disease burden at the city and county level. $P < 0.05$ was considered statistically significant. The eastern region comprised Haikou, Sanya, Wenchang, Qionghai, Wanning and Lingshui. The central region comprised Wuzhishan, Ding'an, Tunchang, Qiongzhong, Baoting and Baisha. The western region comprised Danzhou, Dongfang, Chengmai, Lingao, Ledong and Changjiang.

Calculation of cause-deleted life expectancy

Abridged life tables covering the full age range were used to calculate annual life expectancy at birth in Hainan Province during 2014–2024. Cause-deleted life tables were then constructed

separately for the major CVD subtypes. Annual all-cause deaths and deaths from each target subtype were corrected using the corresponding annual underreporting rate. We calculated the proportion of all-cause deaths attributable to each target subtype within each age group. Survival probabilities were recalculated assuming complete elimination of deaths from the target subtype, with mortality risks from other causes remaining unchanged. We then obtained cause-deleted life expectancy at birth and calculated potential life expectancy gains (PLEG). The corrected number of deaths (D_x^{adj}), the age-group survival probability after eliminating CVD deaths (p_x^{-CVD}), and the gain in cause-deleted life expectancy (Δe_0) were calculated using the following equations. Here, D_x^{adj} denotes the corrected number of deaths, D_x denotes the reported number of deaths, and u is the death underreporting rate. p_x denotes the survival probability for age group x in the conventional life table, and r_x is the proportion of all-cause deaths in that age group attributable to the target CVD subtype. e_0 denotes life expectancy, e_0^{-CVD} denotes life expectancy at birth after eliminating CVD deaths, and Δe_0 denotes PLEG.

$$D_x^{adj} = \frac{D_x}{1-u}$$

$$p_x^{-CVD} = p_x^{1-r_x}$$

$$\Delta e_0 = e_0^{-CVD} - e_0$$

Sensitivity analysis

To assess the influence of uncertainty in estimated age-specific population denominators on life expectancy and potential life expectancy gain (PLEG) estimates, a sensitivity analysis was conducted for 2024. While holding the sex-specific total population constant, the estimated population aged 65 years and older was decreased and increased by 5%, respectively, with the population younger than 65 years adjusted proportionally to maintain the same total population. Life tables and subtype-specific PLEGs were recalculated under each scenario and compared with the baseline estimates.

Results

YLL burden and temporal trends for CVDs overall and major subtypes from 2014 to 2024

The premature mortality burden of CVDs increased overall in Hainan Province during 2014–2024. CVD-related YLL rose from 304372.12 person-years in 2014 to 515851.41 person-years in 2024, an increase of 69.48%. The age-standardised YLL rate increased from 4240.12 to 5245.28 per 100000, an increase of 23.71%.

In 2024, ischaemic heart disease accounted for the largest YLL burden, at 156043.37 person-years, representing 30.25% of total CVD-related YLL. Ischaemic stroke and haemorrhagic stroke followed, at 116991.57 and 93794.44 person-years, respectively, accounting for 22.68% and 18.18%. Together, these three subtypes contributed 71.11% of total CVD-related YLL. Compared with 2014, ischaemic stroke showed the largest increase, rising from 41117.39 to 116991.57 person-years, an increase of 184.53%. Unspecified stroke and hypertensive diseases followed, increasing by 97.69% and 90.05%, respectively. YLL from ischaemic heart disease also increased substantially, by 87.49%. By contrast, YLL from rheumatic heart disease and pulmonary heart disease and diseases of the pulmonary circulation declined by 11.41% and 31.84%, respectively (Table 1, Fig. 1).

Table 1. YLL burden of CVDs and subtypes in Hainan in 2014 and 2024

Disease category	YLL(person-years)			Age-standardised YLL rate（/10 万）		
	2014	2024	Change (%)	2014	2024	Change (%)

Total CVDs	304372.12	515851.41	69.48%	4240.12	5245.28	23.71%
Hypertensive diseases	26431.35	50234.01	90.05%	380.28	502.91	32.25%
Ischaemic heart disease	83225.38	156043.37	87.49%	1184.42	1576.99	33.14%
Rheumatic heart disease	8153.28	7222.75	-11.41%	111.80	74.49	-33.37%
Pulmonary heart disease and diseases of the pulmonary circulation	9505.99	6478.91	-31.84%	134.43	65.52	-51.26%
Ischaemic stroke	41117.39	116991.57	184.53%	601.75	1200.87	99.56%
Haemorrhagic stroke	74001.40	93794.44	26.75%	1002.92	972.11	-3.07%
Unspecified stroke	9865.60	19503.09	97.69%	145.20	204.94	41.14%
Other CVDs	52071.74	65583.27	25.95%	679.32	647.45	-4.69%

Note: YLL, years of life lost. Age-standardised YLL rates were directly standardised using the age structure of the seventh national population census in 2020 and are expressed per 100000. Percentage change = (value in 2024 − value in 2014)/value in 2014 × 100%.

Joinpoint regression showed that trends in age-standardised YLL rates differed across CVD subtypes during 2014–2024. Rates increased significantly for hypertensive diseases (AAPC = 5.96%, 95% CI: 1.74%–10.45%, P = 0.008) and ischaemic heart disease (AAPC = 3.68%, 95% CI: 1.84%–5.79%, P < 0.001). Significant increases were also observed for ischaemic stroke (AAPC = 7.91%, 95% CI: 6.15%–10.35%, P < 0.001) and unspecified stroke (AAPC = 3.92%, 95% CI: 1.33%–6.58%, P = 0.003). Ischaemic stroke had the largest average annual increase. Pulmonary heart disease and diseases of the pulmonary circulation showed a significant decline (AAPC = −4.79%, 95% CI: −9.07% to −0.22%, P = 0.039). AAPCs for rheumatic heart disease, haemorrhagic stroke and other CVDs were −3.21%, 0.25% and 0.05%, respectively. None of these overall trends was statistically significant (all P > 0.05; Table 2).

Table 2. Joinpoint trends in age-standardised YLL rates by CVD subtype in Hainan during 2014–2024

Disease category	时间段	APC(%)	Pvalue	AAPC(%)	Pvalue
Hypertensive diseases	2014—2024	5.96*（1.74~10.45）	0.008	5.96 (1.74~10.45)	0.008
Ischaemic heart disease	2014—2022	6.59*（5.23~11.70）	0.002	3.68* (1.84~5.79)	< 0.001
	2022—2024	-7.16 (-16.23~2.69)	0.147		
Rheumatic heart disease	2014—2020	3.01 (-2.46~36.59)	0.226	-3.21 (-8.06~2.29)	0.172
	2020—2024	-11.85* (-33.79~-3.40)	0.026		
Pulmonary heart disease and diseases of the pulmonary circulation	2014—2024	-4.79*（-9.07~-0.22）	0.039	-4.79* (-9.07~-0.22)	0.039
Ischaemic stroke	2014—2022	9.98*（8.33~20.61）	<0.001	7.91* (6.15~10.35)	< 0.001
	2022—2024	0.02（-8.97~8.43）	0.733		
Haemorrhagic stroke	2014—2021	3.43*（1.94~6.25）	<0.001	0.25 (-0.97~1.45)	0.592
	2021—2024	-6.81* (-14.32~-2.11)	0.002		
Unspecified stroke	2014—2024	3.92* (1.33~6.58)	0.003	3.92* (1.33~6.58)	0.003
Other CVDs	2014—2024	0.05 (-2.92~3.09)	0.980	0.05 (-2.92~3.09)	0.980

Note: AAPC, average annual percent change; CI, confidence interval; *P < 0.05.

YLL burden of CVDs by sex and age

The YLL burden of CVD subtypes showed different distributions by sex in Hainan Province in 2024 (Table 3). Except for rheumatic heart disease, age-standardised YLL rates were higher in males than in females for all subtypes. Ischaemic heart disease had the greatest burden, with rates of 2145.30 and 1005.14 per 100000 in males and females, respectively. The male rate exceeded the female rate by 1140.16 per 100000, the largest absolute difference between sexes. Ischaemic stroke followed, with rates of 1562.57 and 857.14 per 100000 in males and females, respectively. Corresponding rates for haemorrhagic stroke were 1343.55 and 591.88 per 100000. Other CVDs, hypertensive diseases and unspecified stroke also showed higher burdens in males. The difference for rheumatic heart disease was small, with a slightly higher rate in females (75.40 per 100000) than in males (73.12 per 100000).

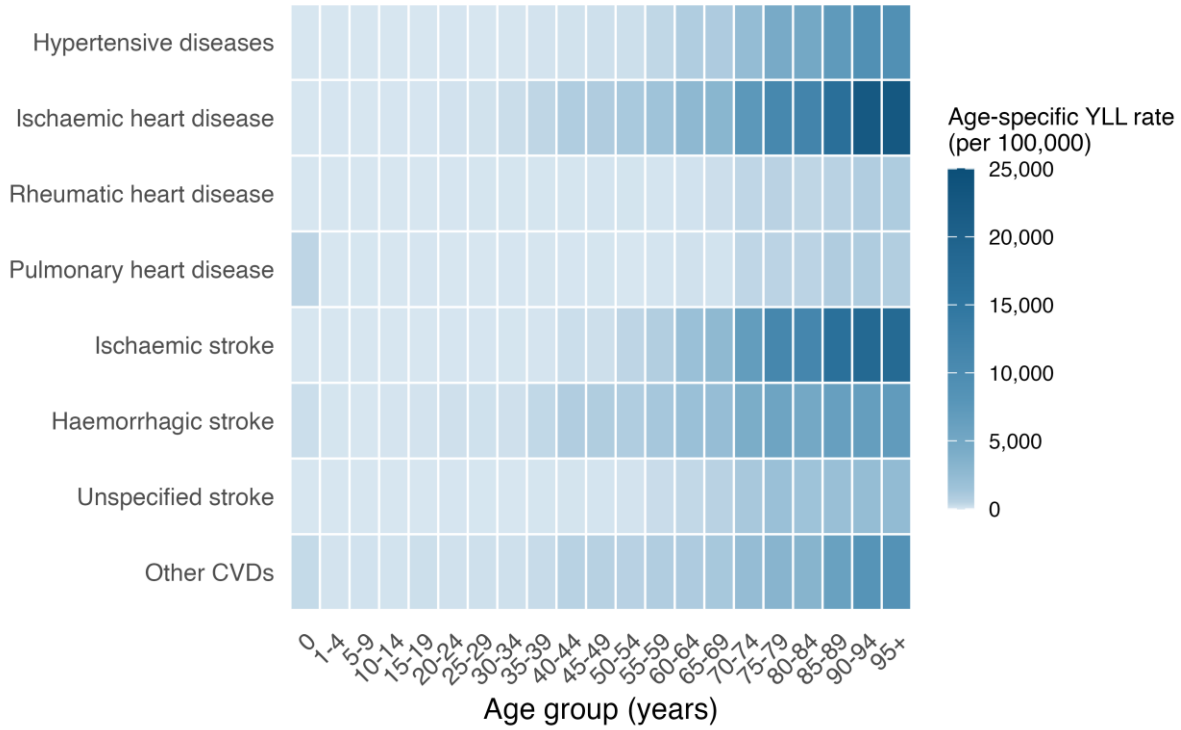
Table 3. YLL burden of CVD subtypes by sex in Hainan in 2024

Disease subtype	Male		Female	
	YLL	Age-standardised YLL rate	YLL	Age-standardised YLL rate
Hypertensive diseases	28370.90	626.67	21863.56	379.85
Ischaemic heart disease	99839.76	2145.30	56204.10	1005.14
Rheumatic heart disease	3389.81	73.12	3832.53	75.40
Pulmonary heart disease and diseases of the pulmonary circulation	3831.36	84.69	2646.99	48.40
Ischaemic stroke	69104.25	1562.57	47886.17	857.14
Haemorrhagic stroke	63354.74	1343.55	30438.66	591.88
Unspecified stroke	12077.43	269.62	7424.95	140.36
Other CVDs	43505.90	887.87	22074.80	395.73

YLL, years of life lost; CVDs, cardiovascular and cerebrovascular diseases. YLL is expressed in person-years; age-standardised YLL rates are per 100000.

The YLL burden of CVDs generally increased with age and was particularly pronounced in the oldest age groups (Fig. 2). Ischaemic heart disease showed the clearest age gradient. Its age-specific YLL rate rose from 2745.49 per 100000 at ages 60–64 to 7538.12 at ages 70–74, reaching 22741.41 at ages 95 and older. The age-specific YLL rate for ischaemic stroke also generally increased with age. Rates were 1858.72 and 6748.09 per 100000 at ages 60–64 and 70–74, respectively. The rate reached 18349.56 per 100000 at ages 90–94, then declined slightly to 18080.45 at ages 95 and older. The burden of haemorrhagic stroke increased at an earlier age, reaching 814.32 per 100000 at ages 40–44. It subsequently increased overall, reaching 6965.61 per 100000 at ages 95 and older. Hypertensive diseases showed a more pronounced increase in older age groups. Rates reached 9121.08 and 9117.22 per 100000 at ages 90–94 and 95 and older, respectively. Unspecified stroke and other CVDs also imposed greater burdens in the oldest age groups. Their respective rates at ages 95 and older were 2458.64 and 8656.19 per 100000.

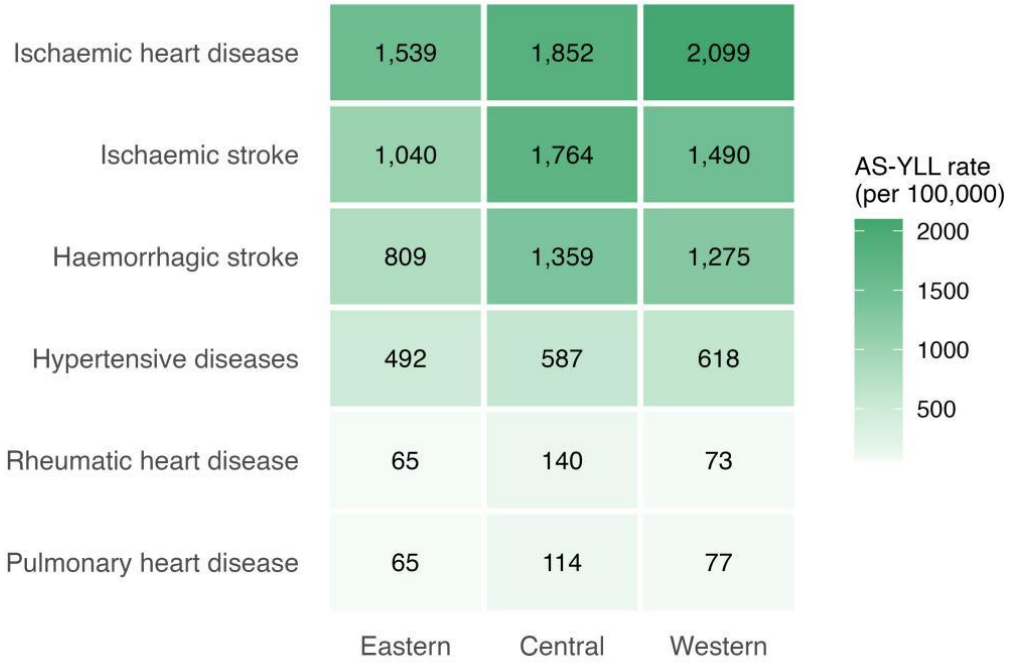
Fig. 2. Age-specific YLL rates by CVD subtype in Hainan in 2024



Regional differences and spatial distribution of CVD YLL burden

Age-standardised YLL rates for major CVD subtypes varied descriptively across the eastern, central and western regions of Hainan Province during 2023–2024 (Fig. 3). Rates for all six major subtypes were lower in the east than in the central and western regions. The central region had higher rates for ischaemic stroke, haemorrhagic stroke, rheumatic heart disease, and pulmonary heart disease and diseases of the pulmonary circulation. These rates were 1764.49, 1358.68, 140.26 and 114.44 per 100000, respectively. The western region had the highest rates for ischaemic heart disease and hypertensive diseases, at 2098.54 and 617.54 per 100000, respectively.

Fig. 3. Age-standardised YLL rates by CVD subtype and region in Hainan during 2023–2024



Kruskal–Wallis tests used the 18 cities and counties as analytical units. The regional distribution of age-standardised YLL rates for ischaemic stroke differed significantly before multiple-testing correction ($\chi^2 = 6.678$, $P = 0.036$). Regional differences for the other subtypes were not statistically significant. After Holm correction across the six subtype comparisons, no regional difference remained statistically significant.

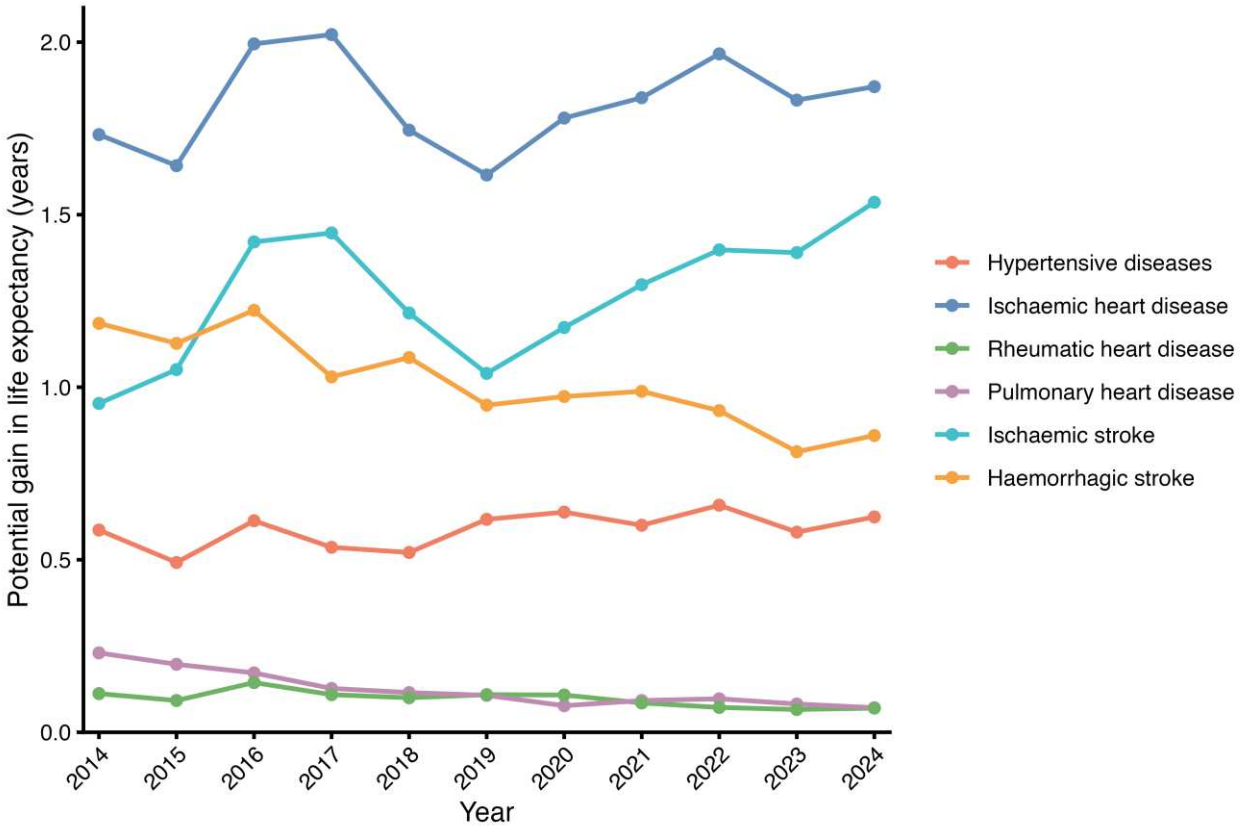
Further city- and county-level spatial analysis showed that the distribution of high-burden areas differed across disease subtypes. Global Moran's I detected no significant global spatial

autocorrelation for any of the six major subtypes (all $P > 0.05$). Thus, there was no statistical evidence of global spatial clustering in CVD YLL burden at the city and county level in Hainan Province.

Cause-deleted life expectancy for CVDs in Hainan Province from 2014 to 2024

Potential life expectancy gains associated with eliminating deaths from individual CVD subtypes showed different temporal patterns during 2014–2024 (Fig. 4). Ischaemic heart disease had the largest PLEG in every year, remaining relatively high despite some fluctuations. PLEG for ischaemic stroke increased overall, particularly in recent years. By contrast, PLEG for haemorrhagic stroke generally declined over the study period. PLEG for hypertensive diseases remained relatively stable. PLEG for rheumatic heart disease and pulmonary heart disease and diseases of the pulmonary circulation remained low and generally declined. In 2024, ischaemic heart disease and ischaemic stroke remained the two leading subtypes contributing to loss of life expectancy.

Fig. 4. Potential life expectancy gain trends by CVD subtype in Hainan during 2014–2024



In 2024, life expectancy at birth was 77.99 years for males, 85.19 years for females and 81.32 years for the total population (Table 4). Eliminating ischaemic heart disease deaths would increase life expectancy in the total population from 81.32 to 83.19 years. The corresponding PLEG was 1.87 years, or 2.30%, the largest gain among the subtypes. Ischaemic stroke ranked second, with a cause-deleted life expectancy of 82.86 years and a PLEG of 1.54 years, or 1.89%. Eliminating deaths from haemorrhagic stroke and hypertensive diseases would increase life expectancy by 0.86 and 0.62 years, respectively. The corresponding percentage gains were 1.06% and 0.77%. Rheumatic heart disease and pulmonary heart disease and diseases of the pulmonary circulation had smaller effects, each with a PLEG of approximately 0.07 years.

Table 4. Cause-deleted life expectancy and potential gains by CVD subtype and sex in Hainan, 2024

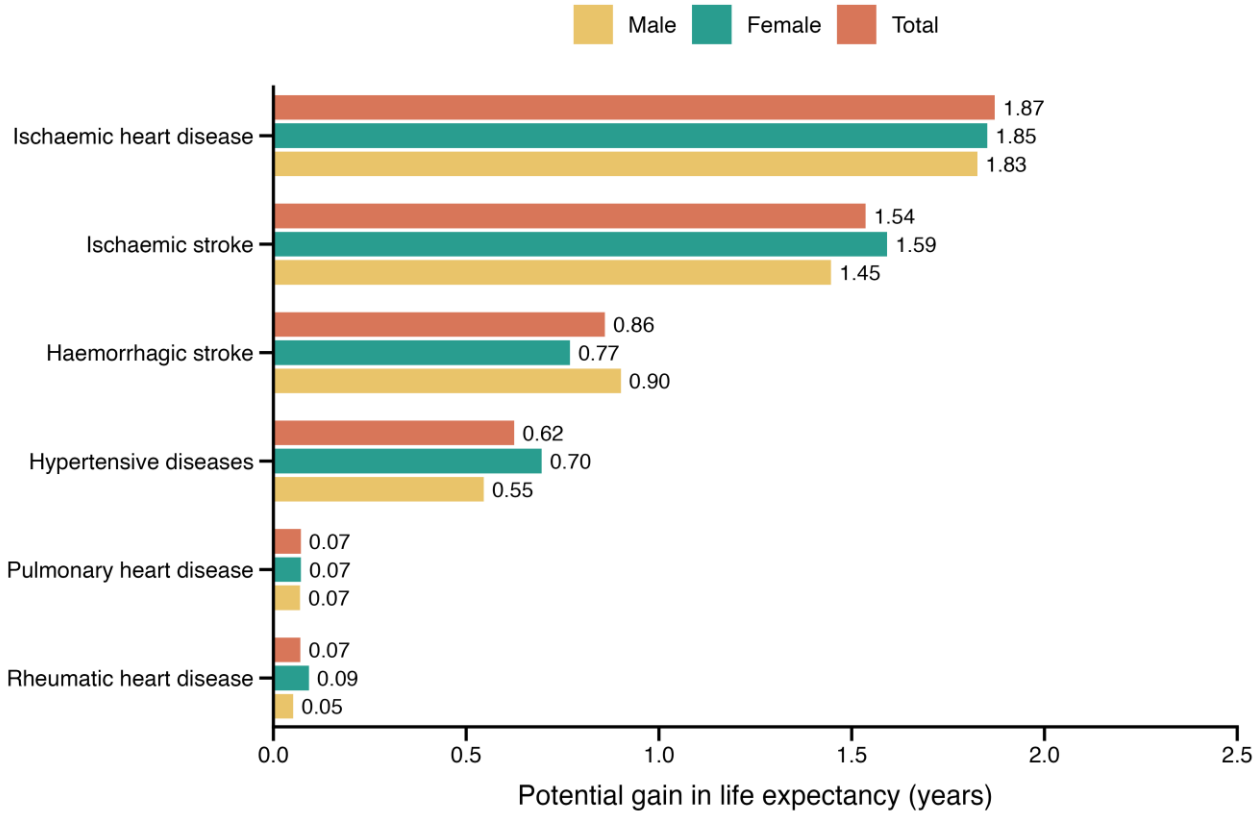
sex	Disease subtype	Life expectancy (years)	Cause-deleted life expectancy (years)	PLEG (years)	PLEG rate (%)
male	Hypertensive diseases	77.99	78.53	0.55	0.7
	Ischaemic heart disease		79.81	1.83	2.34
	Rheumatic heart disease		78.04	0.05	0.07
	Pulmonary heart disease		78.06	0.07	0.09
	Ischaemic stroke		79.43	1.45	1.85
	Haemorrhagic stroke		78.89	0.90	1.16
female	Hypertensive diseases	85.19	85.89	0.70	0.82
	Ischaemic heart disease		87.05	1.85	2.17
	Rheumatic heart disease		85.29	0.09	0.11
	Pulmonary heart disease		85.27	0.07	0.08
	Ischaemic stroke		86.79	1.59	1.87
	Haemorrhagic stroke		85.96	0.77	0.90
total	Hypertensive diseases	81.32	81.94	0.62	0.77
	Ischaemic heart disease		83.19	1.87	2.30
	Rheumatic heart disease		81.39	0.07	0.09
	Pulmonary heart disease		81.39	0.07	0.09

Ischaemic stroke	82.86	1.54	1.89
Haemorrhagic stroke	82.18	0.86	1.06

PLEG, potential life expectancy gains; CVDs, cardiovascular and cerebrovascular diseases. Gains are theoretical under complete elimination of the target cause, with mortality from other causes unchanged.

Although females had higher observed life expectancy than males, sex patterns in potential life expectancy loss differed across subtypes. Ischaemic heart disease had the largest effect in both sexes, with PLEGs of 1.83 years in males and 1.85 years in females. PLEG for ischaemic stroke was slightly higher in females than in males, at 1.59 and 1.45 years, respectively. Haemorrhagic stroke showed a greater burden in males, with PLEGs of 0.90 years in males and 0.77 years in females. PLEG for hypertensive diseases was higher in females than in males, at 0.70 and 0.55 years, respectively. Potential life expectancy losses from rheumatic heart disease and pulmonary heart disease and diseases of the pulmonary circulation were low in both sexes (Fig. 5).

Fig. 5. Potential life expectancy gains by CVD subtype and sex in Hainan in 2024



Sensitivity analysis showed that, when the estimated population aged 65 years and older was varied by ±5%, total life expectancy at birth ranged from 80.9 to 81.7 years, compared with 81.3 years in the baseline scenario. PLEG estimates for all major CVD subtypes changed by less than 4% relative to baseline, and the ranking of subtypes remained unchanged, indicating that the main life-expectancy findings were robust to plausible uncertainty in the estimated age structure.

Discussion

Both total YLL and the age-standardised YLL rate for CVDs increased overall in Hainan Province during 2014–2024, differing from trends reported nationally [**Error! Reference source not found.**14．]. Previous burden studies in Hainan also identified circulatory diseases as persistent leading causes of death and disease burden [7．]. These findings indicate that CVDs remain an important constraint on improvements in population health in Hainan. The increase after age standardisation suggests that population ageing alone does not account for the growing burden.

Persistent accumulation and inadequate control of hypertension, diabetes, dyslipidaemia, obesity and other risk factors may also contribute. A 2023 survey in Hainan reported weighted prevalences of 13.7% for diabetes and 20.7% for prediabetes among adults. The age-standardised prevalence of dyslipidaemia among adults during the same period was 39.40%. These findings suggest that abnormal glucose and lipid metabolism remain common and may contribute to the continuing increase in CVD burden [15．17．].

Ischaemic heart disease, ischaemic stroke and haemorrhagic stroke were the principal contributors to disease burden. Increases in ischaemic diseases were substantially greater than that in haemorrhagic stroke, consistent with national findings [14．]. This pattern suggests that ischaemic diseases have become increasingly important contributors to premature mortality from CVDs in Hainan Province.

The age-standardised YLL rate increased most markedly for ischaemic stroke and also rose for ischaemic heart disease. Ischaemic stroke and ischaemic heart disease both fall within the spectrum of atherosclerotic cardiovascular and cerebrovascular diseases. They share pathological processes, including atherosclerosis, chronic inflammation, plaque rupture and thrombosis, and risk factors such as elevated blood pressure and abnormal glucose and lipid metabolism[**Error! Reference source not found.**]. A previous Hainan study found that 40.2% of adults with diabetes in 2018–2020 also had hypertension and 51.6% had dyslipidaemia [19．]. The Hainan prospective cohort study conducted during the same period reported a hypertension prevalence of 37.1% among residents aged 35–74 years [20．]. The concurrent increases in these two ischaemic diseases may therefore reflect prolonged exposure to shared risk factors. The larger increase in ischaemic stroke may reflect the combined long-term effects of hypertension, smoking and abnormal glucose and lipid metabolism [21．22．].

The age-standardised YLL rate for haemorrhagic stroke increased during 2014–2021 but declined during 2021–2024. The earlier increase may have been related to the cumulative effects and suboptimal control of major risk factors such as hypertension[23．43．], whereas the more recent decline may reflect improvements in standardised hypertension management, stroke care capacity, and the healthcare delivery system[38．. In addition, mortality data in this study were corrected using annual underreporting rates; therefore, temporal variation in the completeness of mortality surveillance and in the magnitude of underreporting correction may also have influenced the estimated trends[8．-10．. Accordingly, the decline observed after 2021 should be interpreted cautiously as a phase-specific change, and its persistence requires confirmation using a longer time series.

The age-standardised YLL rate for hypertensive diseases also increased, consistent with findings from China [24．]. This suggests that long-term hypertension management remains a weakness in CVD prevention and control. In 2020, hypertension awareness, treatment and control rates among Hainan residents aged 30 years and older were 42.4%, 35.4% and 11.0%, respectively. All three rates were below national levels [**Error! Unknown switch argument.**], indicating continuing gaps in early detection and standardised treatment. Hypertension can directly damage target organs, including the heart, brain and kidneys, and is an important upstream risk factor for ischaemic heart disease and ischaemic stroke [26．]. Hainan should maintain progress in hypertension prevention and control and haemorrhagic stroke care while placing greater emphasis on ischaemic CVDs. Integrated management of blood pressure, lipids, glucose and body weight, together with smoking interventions, could reduce premature mortality from ischaemic stroke and ischaemic heart disease.

Except for rheumatic heart disease, age-standardised YLL rates for major CVD subtypes were higher in males than in females. The sex difference was particularly pronounced for ischaemic heart disease, consistent with previous research[27．]. Differences in risk factor exposure may help explain this pattern. Unhealthy behaviours, including smoking and alcohol consumption, are more common in males. A 2023 survey of 32857 permanent residents in Hainan reported weighted current smoking prevalences of 62.22% in males and 1.38% in females. Smoking can promote endothelial injury, inflammation, thrombosis and atherosclerosis, causing irreversible damage to the heart and blood vessels [28．30．]. Oestrogen also provides some cardiovascular protection in females before menopause [31．]. The age-standardised YLL rate for rheumatic heart disease was higher in females, consistent with its global epidemiological pattern [32．]. Possible explanations include stronger immune responses to group A streptococcal infection and greater autoimmune susceptibility in females. Increased haemodynamic load during pregnancy may also make pre-existing valvular lesions clinically apparent [33．,34．. Alongside population-wide CVD prevention, Hainan should strengthen health education and risk factor management, particularly smoking interventions, among males.

Age-specific YLL rates for major CVD subtypes generally increased with age in Hainan Province. Ischaemic heart disease and ischaemic stroke imposed substantial burdens in people older than 70 years, whereas haemorrhagic stroke already imposed a considerable burden at ages 40–44. These findings broadly agree with previous research and support prioritising older adults in efforts to reduce premature mortality from CVDs[29．]. Ageing involves degenerative changes in vascular structure and function and increasing atherosclerosis. Hypertension, diabetes, dyslipidaemia, atrial fibrillation and other risk factors also accumulate, increasing the risk of cardiovascular and cerebrovascular events in older adults [35．36．].Population ageing continues in Hainan. The seventh

national census showed that the proportions aged 60 years and older and 65 years and older increased by 3.32 and 2.36 percentage points, respectively, compared with 2010[5．]. The demands of CVD prevention and control among older adults are therefore likely to increase. Haemorrhagic stroke also caused appreciable loss of life expectancy in middle age, consistent with a Korean stroke cohort study [37．]. Its effects on younger and middle-aged adults should therefore receive attention. This may relate to lifestyle risk factors, including obesity, smoking and heavy alcohol consumption, occurring at progressively younger ages. Prevention should prioritise older adults while also addressing risky behaviours earlier in life. Early detection and intervention among younger and middle-aged adults may help reduce premature mortality.

CVD-related YLL burden showed regional heterogeneity in Hainan Province. The eastern region generally had a lower burden, whereas some subtypes imposed greater burdens in the central and western regions. Previous city- and county-level research found higher overall medical resource levels in core areas such as Haikou, Sanya and Qionghai. Central and western areas generally had fewer healthcare resources, and some lacked a leading medical centre[38．]. This pattern broadly accords with our findings. Differences in YLL burden may relate to healthcare accessibility, primary care capacity for chronic disease management, and treatment capacity for acute cardiovascular and cerebrovascular events [39．]. We detected no significant global spatial autocorrelation for the major disease subtypes. Regional differences were not statistically significant after Holm correction. The nonsignificant Global Moran’s I results do not establish the absence of local clusters or their stability over time. Areas with relatively high stroke burdens could strengthen screening and standardised management of hypertension and diabetes, alongside early stroke recognition and treatment. Areas with higher burdens of ischaemic heart disease and hypertensive diseases could prioritise comprehensive cardiovascular risk management. They could also improve prehospital transfer and coordinated regional care for acute cardiovascular events.

Cause-deleted life expectancy analysis identified ischaemic heart disease as the leading CVD contributor to loss of life expectancy throughout the study period. Life expectancy loss associated with ischaemic stroke increased overall. Eliminating deaths from ischaemic heart disease and ischaemic stroke would theoretically increase life expectancy by 1.87 and 1.54 years, respectively. Previous research in Hainan found that circulatory diseases caused the greatest life expectancy loss among major disease groups [7．]. Our findings further support the importance of CVDs for life expectancy and identify ischaemic heart disease and ischaemic stroke as the principal contributors.

A Chinese study covering 2005–2020 reported a marked decline in life expectancy loss from intracerebral haemorrhage and an increase in loss from ischaemic stroke [40．]. These trends agree with the direction of our findings. Approximately 50% of intracerebral haemorrhage is related to hypertension, suggesting substantial potential for prevention. Progressive improvements in standardised hypertension management and acute treatment have improved care for patients with intracerebral haemorrhage [41．43．]. Ischaemic stroke is associated with hypertension and multiple other risk factors, including smoking, abnormal glucose and lipid metabolism, and obesity, making prevention more challenging [44．]. Further gains in life expectancy in Hainan require sustained hypertension prevention and control and continued improvements in haemorrhagic stroke care. Greater emphasis should also be placed on primary prevention, standardised acute treatment and secondary prevention of ischaemic stroke, alongside integrated management of multiple risk factors.

This study has several limitations. First, mortality data came from the cause-of-death surveillance system. Although underreporting was corrected, differences in diagnosis, coding and reporting quality may still introduce bias. Second, age- and sex-specific populations for some years were estimated from census and annual population data. Substantial population mobility in Hainan may affect the accuracy of these denominators. A sensitivity analysis for 2024 indicated that varying the estimated population aged 65 years and older by ±5% changed subtype-specific PLEG estimates by less than 4% and did not alter their ranking, suggesting that the principal conclusions were robust

to moderate uncertainty in the estimated age structure. Third, we assessed only mortality-related YLL and did not include years lived with disability (YLD), so the estimates do not capture the full CVD burden. Fourth, city- and county-level analyses did not incorporate risk factor, socioeconomic or healthcare resource data, limiting explanations of regional differences. Future studies could integrate chronic disease risk factor surveillance, electronic medical records, healthcare service, population and socioeconomic data from Hainan. These data could clarify factors underlying temporal changes and regional differences in CVD burden. Further assessment of burden attributable to major risk factors and their effects on life expectancy could inform targeted CVD prevention and control in Hainan Province.

Conclusions

Overall, the premature mortality burden of CVDs increased in Hainan Province during 2014–2024, with a growing concentration in ischaemic diseases. Males and the oldest age groups generally bore greater burdens. Geographic differences were descriptive and were not statistically significant after Holm correction. Ischaemic heart disease and ischaemic stroke were the principal CVD subtypes affecting life expectancy. Future prevention should strengthen integrated management of hypertension and abnormal glucose and lipid metabolism. Strategies should also be tailored to the disease burden profiles of different populations and regions.

List of abbreviations

AAPC, average annual percent change; APC, annual percent change; CI, confidence interval; CVDs, cardiovascular and cerebrovascular diseases; GBD, Global Burden of Disease; ICD-10, International Classification of Diseases, 10th Revision; NCDs, non-communicable diseases; PLEG, potential life expectancy gains; YLD, years lived with disability; YLL, years of life lost.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Hainan Medical University(approval number:HYMLL-2026-007)and was conducted in accordance with the Declaration of Helsinki and relevant ethical guidelines and regulations. The requirement for informed consent was waived by the Ethics Committee.

Consent for publication

Not applicable.

Clinical Trial Number

Not applicable.

Availability of data and materials

The individual-level mortality surveillance data analysed in this study are not publicly available because of data management and privacy restrictions. The data may be available from the corresponding author upon reasonable request and subject to approval by the relevant data authority.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

LSH was responsible for study design, data curation and statistical analysis, data visualisation, interpretation of the results, and drafting the original manuscript. ZD contributed to the study design, methodological discussion, interpretation of the results, and critical revision of the manuscript. RWL contributed to data curation and verification, interpretation of the results, and revision of the

manuscript. LY, CSK, and XTT provided access to the cause-of-death surveillance data, supported data acquisition, and contributed to data quality verification. WYT contributed to the literature review, data verification, and revision of the manuscript. WT contributed to data curation, verification of the results, and revision of the manuscript. ZDL contributed to research coordination, interpretation of the findings, and revision of the manuscript. TJL contributed to methodological guidance, interpretation of the findings, and critical revision of the manuscript for important intellectual content. ZDX supervised the overall study, contributed to the study design, critically reviewed the manuscript for important intellectual content, approved the final version, and served as the corresponding author. All authors read and approved the final manuscript.

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Additional files

Additional file 1

Supplementary Table S1. Regional comparison and spatial autocorrelation of age-standardised CVD YLL rates in Hainan, 2023–2024

Additional file 2

Supplementary Fig. S1. Spatial distribution of age-standardised CVD YLL rates in Hainan, 2023–2024

Supplementary Files

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