Mortality from cerebrovascular diseases in China: Exploration of recent and future trends

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Abstract

Background: Cerebrovascular disease (CVD) ranks among the foremost factors responsible for mortality on a global scale. The mortality patterns of CVDs and temporal trends in China need to be well-illustrated and updated.

Methods: We collected mortality data on patients with CVD from Chinese Center for Disease Control and Prevention's Disease Surveillance Points (CDC-DSP) system. The mortality of CVD in 2020 was described by age, sex, residence, and region. The temporal trend from 2013 to 2019 was evaluated using joinpoint regression, and estimated rates of decline were extrapolated until 2030 using time series models.

Results: In 2019, the age-standardized mortality in China (ASMRC) per 100,000 individuals was 113.2. The ASMRC for males ($137.7/10^5$) and rural areas ($123.0/10^5$) were both higher when stratified by gender and urban/rural residence. The central region had the highest mortality ($126.5/10^5$), the western region had a slightly lower mortality ($123.5/10^5$), and the eastern region had the lowest mortality ($97.3/10^5$). The age-specific mortality showed an accelerated upward trend from aged 55–59 years, with maximum mortality observed in individuals over 85 years of age. The age-standardized mortality of CVD decreased by 2.43% (95% confidence interval, 1.02–3.81%) annually from 2013 to 2019. Notably, the age-specific mortality of CVD increased from 2013 to 2019 for the age group of over 85 years. In 2020, both the absolute number of CVD cases and the crude mortality of CVD have increased compared to their values in 2019. The estimated total deaths due to CVD were estimated to reach 2.3 million in 2025 and 2.4 million in 2030.

Conclusion: The heightened focus on the burden of CVD among males, rural areas, the central and western of China, and individuals aged 75 years and above has emerged as a pivotal determinant in further decreasing mortalities, consequently presenting novel challenges to strategies for disease prevention and control.

Keywords: Cerebrovascular diseases; Mortality; Epidemiology; Global Burden of Disease; China; COVID-19 pandemic

Introduction

Cerebrovascular disease (CVD) is one of the most common life-threatening neurological events and leading causes of death worldwide.[1] Previous Global Burden of Disease (GBD) studies showed that the disease burden of CVD ranked first in China and fifth in the US among 135 diseases.[2] CVD refers to all disorders in which an area of the brain is temporarily or permanently affected by ischemia or bleeding in one or more of the cerebral blood vessels during a pathological process. According to International Classification of Diseases, 10th Revision (ICD-10) coding, I60–I69 represent the spectrum of CVD [Supplementary Materials, http://links.lww.com/CM9/B613], which comprises stroke, carotid stenosis, vertebral stenosis, intracranial stenosis, aneurysms, and vascular malformations. Before the 2000s, epidemiological research focused on the burden of CVD, but the specific subtype of CVD (e.g., stroke) was more frequently investigated after 2010. According to the China Stroke Statistics from 2013 to 2017, the prevalence and incidence rate of stroke increased faster than in other countries, and stroke became the leading cause of death in China.[3–7] Nonetheless, few studies have been published on the morbidity and mortality of other

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subgroups of CVD or CVD as a whole. Additionally, the GBD findings rely on multiple model estimates and fits, while our research draws on data obtained directly from China's largest death surveillance system. This enables us to analyze disparities between urban and rural areas, as well as evaluate regional health inequalities. To further reduce CVD mortality and identify the weak points with the greatest need for addressing the CVD burden in China, we aimed to explore current and future variations in CVD mortality (after 2013) and to provide evidence to guide policy decisions and health care planning more effectively.

Methods

Data sources

Based on the Chinese Center for Disease Control and Prevention's Disease Surveillance Points (CDC-DSP) system, we collected mortality data on patients with CVD (ICD-10: I60–I69) from 2013 to 2020. The death information of residents in China from 2013 to 2020 was derived from the white book "Chinese Death Cause Monitoring Results Datasets" of the corresponding years. The variables in this study included sex, age, residence (urban and rural areas), and region (eastern China, central China, and western China).

The monitoring system encompassed 208 urban points and 397 rural points, which were distributed in 31 provinces and autonomous regions (province-level municipalities), with a population of approximately 340 million people, which accounted for one-fourth of the country's total population. In the 605-point monitoring system, the eastern region (Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Liaoning, Shandong, Shanghai, Tianjin, and Zhejiang) covered approximately 152 million people (26% of the eastern population), the central region (Anhui, Henan, Heilongjiang, Hubei, Hunan, Jilin, Jiangxi, and Shanxi) covered approximately 100 million people (23% of the central region population), and the western region (Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shaanxi, Sichuan, Tibet, Xinjiang, Yunnan, and Chongqing) covered approximately 86 million people (23% of the western region population). The system collected information on all deaths that occurred in each jurisdiction, including household and non-household registration, as well as the yearly death information of Hong Kong, Maco, and Taiwan citizens, and expatriate citizens from departments of medical institutes, community health facilities, and township health facilities. Death information was collected using layer-by-layer quality audits, which embodied a stable and well-representative set of cause of death surveillance data at national and provincial levels. The mortality was calculated after deleting a small proportion of DSP points that were of poor quality. The age-specific population data for this study were extracted from the National Bureau of Statistics of China (http://data.stats.gov.cn).

Data assessment

The estimated number of deaths associated with CVD could be expressed as:

$$\text{Death} = \sum_{k}^{n} R(k) \times P(k)$$

where $k = 1$, $n =$ number of the stratum, $R(k)$ was the age-specific mortality, and $P(k)$ was the corresponding population. The stratum was divided according to the 19 standardized age groups (0–1 years, 1–84 years in 5-year intervals, and ≥85 years) in the CDC-DSP. We also stratified the death population by the ≤34 years, 35–44 years, 45–54 years, 55–64 years, 65–74 years, 75–84 years, and ≥85 years age groups in our statistical analysis. The 2010 population census of China and the World Health Organization (WHO) world census population (2000–2025) were used to determine the age-standardized mortality in China (ASMRC) and the age-standardized mortality worldwide (ASMRW), respectively. Given that sex was an influential demographic factor, age and sex standardization was used to show trends in mortality of CVD (ASMRC) by residence and trends in mortality of CVD (ASMRC) by region.

Considering the impact of the coronavirus disease 2019 (COVID-19) pandemic on the trend of CVD mortality, we divided our study into two stages: pre-COVID-19 (2013–2019) and post-COVID-19 (2020). We assumed that the mortality trends from 2013 to 2019 would continue for the next several decades, despite the impact of short-term events. We applied the estimates of the annual rate of change in mortality during the period from 2013–2019 to the national age-specific mortalities in 2019 and projected the age-specific mortalities until 2030. Particularly, we compared the predicted 2020 data with the actual data. This projection was made separately for each sex and age group. The formula was:

$$M_x^{t_0 + t} = {}_nM_x^{t_0} \times ({}_nC_x^* + 1)^t$$

where ${}_nM_x$ was the mortality in the age interval $(x, x + n)$, x represented the starting age, n represented the interval, and $x+n$ represented the ending of the certain age group, t_0 was the baseline year 2019, t was the length of the projection period, and C^* was the annual rate of mortality change observed over the period from 2013–2019.[8] Past decreases in mortality were larger in younger groups, whereas different variations in mortalities were observed in elderly groups. To account for this age effect, the factor C^* was estimated for the ≤34 years, 35–44 years, 45–54 years, 55–64 years, 65–74 years, 75–84 years, and ≥85 years age groups. The absolute number of CVD deaths was projected by multiplying the projected age-specific mortality and the projected age-specific numbers up to 2030. The latter number was obtained from Population Pyramids of the World (http://www.PopulationPyramid.net).

Statistical analysis

Statistics, such as the number of deaths and mortalities due to CVD, were estimated depending on the CDC-DSP system. GraphPad Prism for Windows (version 9.0; GraphPad Software, Boston, MA, USA) and fitting joinpoint models (joinpoint regression program, version

4.9.1.0; National Cancer Institute, Bethesda, America) were used to examine the temporary trends in mortalities from 2013 to 2019. The trends were expressed as annual percentage changes (APCs) and average APCs (AAPCs), and *Z*-tests were employed to ascertain whether the APCs were significantly different from zero, using three levels, described as "increase","decrease", and "stable". All statistical significance was assessed at the 0.05 level and all tests were two-sided.

Results

CVD in 2013 and 2019 according to the Chinese CDC-DSP

In 2019, approximately 414,000 deaths from CVD in China were recorded in the CDC-DSP, with a crude mortality of approximately 149.6 (95% confidence interval [CI], 149.1–150.0) per 100,000 individuals. Compared with 2013, the absolute number of CVD deaths and the crude death rate of CVD increased by 8.1% and 4.9%, respectively, in 2019. Weighted by the age distribution of a specific standardized population, we calculated the age-standardized mortality. The ASMRC and ASMRW of CVD in 2019 were $113.2/10^5$ and $104.3/10^5$, respectively, and were lower than those in 2013 ($124.7/10^5$ and $114.3/10^5$). From 2013 to 2019, CVD mortality decreased significantly across all age groups except for the 45–54 years and over 85 years age groups, whose AAPCs were –0.91% (95% CI, –4.51–2.82%) and 2.07% (95% CI, 0.22–3.95%), respectively. The age-standardized mortalities of different sexes, urban-rural areas, and regional areas all decreased except for the rate in individuals who resided in western China, who had an AAPC of –0.83% (95% CI, –2.80–1.18%) from 2013–2019; however, this decrease was not statistically significant. Both males and those living in rural areas had higher mortalities than the remaining portion of the population throughout the study period. Individuals living in central, western, and eastern China exhibited a declining regional gradient in mortalities in that order, among which mortalities in eastern China were remarkably lower than the rates in the other areas [Table 1].

Table 1: Jointpoint analysis of temporal trends in CVD mortalities, stratified by age, sex, urban-rural, and regional classifications using cause of death monitoring datasets, 2013–2019.

	2013		2019		
Characteristics	No.	Mortality (1/100,000)	No.	Mortality (1/100,000)	AAPC (95% CI) (%)
Total	227,236,284			276,873,145	
Crude	323,936	142.6 (142.1, 143.0)	414,097	149.6 (149.1, 150.0)	0.84 (0.60, 1.09)
Age adjusted*		124.7 (124.5, 124.9)		113.2 (113.0, 113.4)	–2.43 (–3.81, –1.02)
Age groups (years)					
≤34	1838	1.8 (1.8, 1.9)	1748	1.5 (1.4, 1.5)	–3.61 (–4.95, –2.25)
35–44	6457	16.5 (16.1, 16.9)	5115	13.0 (12.7, 13.4)	–5.07 (–7.33, –2.76)
45–54	18,401	49.9 (49.2, 50.6)	21,265	43.0 (42.8, 43.2)	–0.91 (–4.51, 2.82)
55–64	42,995	150.8 (149.3, 152.2)	43,685	125.1 (123.9, 126.2)	–2.61 (–3.48, –1.73)
65–74	74,091	538.2 (534.4, 542.1)	96,155	419.3 (416.7, 421.9)	–3.96 (–5.73, –2.16)
75–84	121,286	1622.0 (1613.0, 1631.1)	147,157	1483.4 (1475.9, 1490.9)	–2.72 (–5.33, –0.04)
≥85	58,868	3924.7 (3893.7, 3955.8)	98,972	4611.3 (4583.3, 4639.4)	2.07 (0.22, 3.95)
Sex*					
Male	183,362	151.9 (151.7, 152.1)	232,189	137.7 (137.5, 137.9)	–2.39 (–3.72, –1.04)
Female	140,574	99.5 (99.3, 99.7)	181,908	90.4 (90.2, 90.6)	–2.94 (–3.99, –0.95)
Urban–rural*					
Urban	88,268	102.5 (102.3, 102.6)	122,907	94.9 (94.7, 95.1)	–2.14 (–3.96, –0.29)
Rural	235,668	135.5 (135.3, 135.7)	291,190	123.0 (122.8, 123.2)	–2.41 (–3.93, –0.86)
Region*					
Eastern	129,497	113.6 (113.4, 113.8)	156,862	97.3 (97.1, 97.5)	–3.22 (–4.32, –2.10)
Central	119,842	138.9 (138.7, 139.1)	151,274	126.5 (126.3, 126.7)	–2.55 (–4.20, –0.87)
Western	74,597	123.7 (123.5, 123.9)	105,961	123.5 (123.4, 123.7)	–0.83 (–2.80, 1.18)

Data are presented as *n*, or rate (95% CI). No. indicates the absolute deaths due to CVD recorded in the CDC-DSP. *Indicates the ASR standardized to the 2010 Chinese population census. AAPC: Average APC; APC: Annual percent change; ASR: Age-standardized rate; CDC-DSP: Chinese Center for Disease Control and Prevention's Disease Surveillance Points; CI: Confidence interval; CVD: Cerebrovascular disease.

Age-specific mortalities of CVD stratified by residence and sex

Consistent with previous studies, the age-specific mortalities of CVD generally increased with age in 2019. Notably, the results also showed an accelerated upward trend from 55–59 years of age that peaked in those over 85 years of age. A common characteristic that males had higher mortalities than females was found in all the 18 age groups except for the 5–9-year age group. For the 5–9- and 10–14-year age groups, mortalities in urban areas were higher than those in rural areas, while other age groups exhibited the opposite trend. Male rural dwellers older than 85 years had the highest mortality of CVD [Figure 1 and Supplementary Table 1,http://links.lww.com/CM9/B613].

Age-specific mortalities of CVD stratified by region and sex

In terms of geographical regions, central China had the highest ASMRC ($126.5/10^5$), followed by western China ($123.5/10^5$) and eastern China ($97.3/10^5$) in 2019 [Table 1]. However, the mortalities of the corresponding age groups below 15–19 years decreased in the regions of western ($0.681/10^5$), eastern ($0.446/10^5$), and central ($0.354/10^5$) of China in that order. There was a tendency for higher mortality rates to be observed in males and the elderly population across all regions, and males in western China over 85 years of age had the highest age-specific mortality ($5253.5/10^5$) [Supplementary Table 2, http://links.lww.com/CM9/B613].

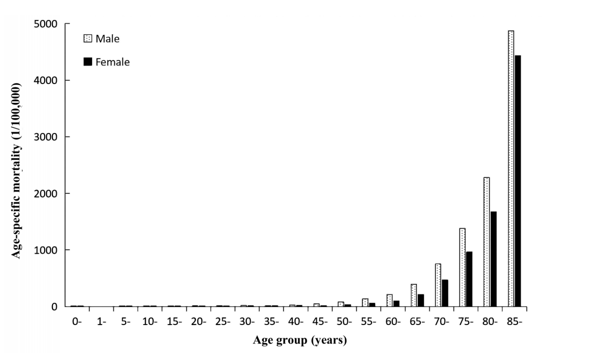

Figure 1: Age-specific mortality of CVD by sex in China, 2019. Males have higher mortalities than females, except for the 5–9-year age group. Above 15–19-year age group, mortality of CVD was increased with age. CVD: Cerebrovascular disease.

Trends in mortality of CVD from 2013 to 2019

The temporal trends in CVD mortality from 2013 to 2019 by age group, sex, residence, and region were shown in Figures 2 and 3. Overall, the age-standardized mortalities of CVD in China demonstrated a steady downward trend until 2019. Such a pattern was also observed when different genders, residences, and geographical regions were investigated except in western China (AAPC = –0.83%, P >0.05) [Table 1 and Figure 3A–C]. Using joinpoint regression, the APC of ASMRC from 2013 to 2019 showed zero joinpoints regardless of sex, residence, and region. With regard to different age groups, declining trends in the age-specific mortality could also be observed in the ≤34 years, 35–44 years, 55–64 years, 65–74 years, and 75–84 years age groups throughout the study period. The 45–54 years age group showed a stable trend (P >0.05), with an AAPC of –0.91% (95% CI, –4.51–2.82%) [Table 1 and Figure 2A]. We further stratified the 45- to 54-year-old individuals into urban and rural subgroups and found that the AAPC was –2.38% (95% CI, –2.92–1.84%, P <0.001) in urban areas and –0.38% (95% CI, –4.31–3.72%, P = 0.818) in rural areas. It was especially noteworthy that the CVD mortality continuously increased only in individuals over 85 years of age, with an AAPC of 2.07% (95% CI, 0.22–3.95%) [Table 1 and Figure 2B]. Additional comparisons of trends in CVD mortality among different residences and regions using age–sex standardized mortalities are presented in Supplementary Figure 1, http://links.lww.com/CM9/B613, and Supplementary Tables 3–4, http://links. lww. com/CM9/B613 along with the results of the joinpoint analysis.

Projection for CVD mortality in the future

The projected age-standardized CVD mortalities for 2025 and 2030 are presented in Table 2. Compared with the rate in 2019, the age-standardized mortalities for 2025 and 2030 will be reduced to almost 86% and 76%, respectively. However, the estimated number of deaths will increase for both genders in 2025 (males approximately 1.29 million, females approximately 1.01 million) and in 2030 (males approximately 1.33 million, females approximately 1.07 million). In terms of age groups, the mortality of CVD will continue to decrease except for in those over 85 years of age. Notably, the projected number of deaths will decrease for age groups under 75 years; however, the number of deaths will increase for the 75–85 years (in 2025 approximately 0.68 million, in 2030 approximately 0.86 million) and ≥85 years (in 2025 approximately 0.69 million, in 2030 approximately 0.91 million) age groups.

CVD mortality during the COVID-19 pandemic

The WHO first received a report of pneumonia from China on December 31, 2019, at which point a new type of coronavirus was confirmed as the cause of the infection.[9] Soon after, COVID-19 rapidly became a global pandemic in 2020 and fully altered people's way of life, which, in turn, affected CVD mortality.[10,11] In 2020, both the absolute number of CVD cases and the crude mortality of CVD have increased from the 2019 values; however, the age-standardized mortality decreased further when stratified by sex, region, and residence and was even lower than our estimate [Supplementary Table 5, http://links.lww.com/CM9/B613]. Specifically, an obvious change was identified in the mortality trend in the over 85 years ($3966.2/10^5$) age group, which quickly decreased from the original upward trend to the 2017 level.

Discussion

CVDs include a variety of abnormalities that disrupt blood flow in the brain, among which stroke accounts for the highest proportion and importance. According to

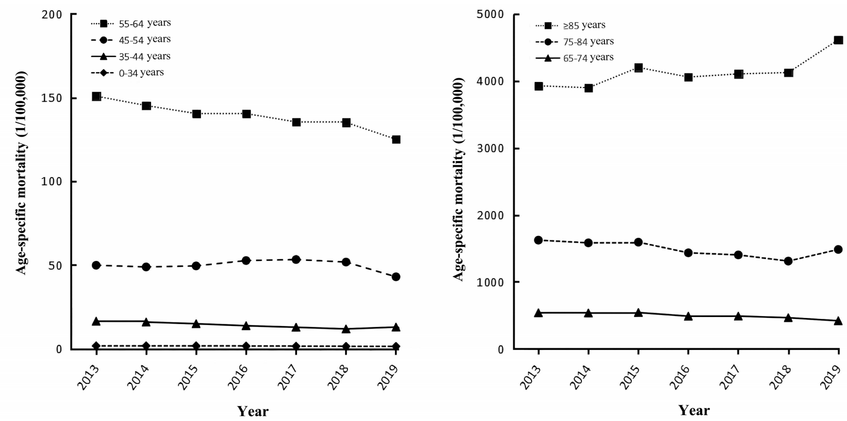

Figure 2: Age-specific mortality from CVD for different age groups from 2013 to 2019. (A) For the age groups from 0 years to 64 years. (B) For the age groups from 65 years to over 85 years. CVD: Cerebrovascular disease.

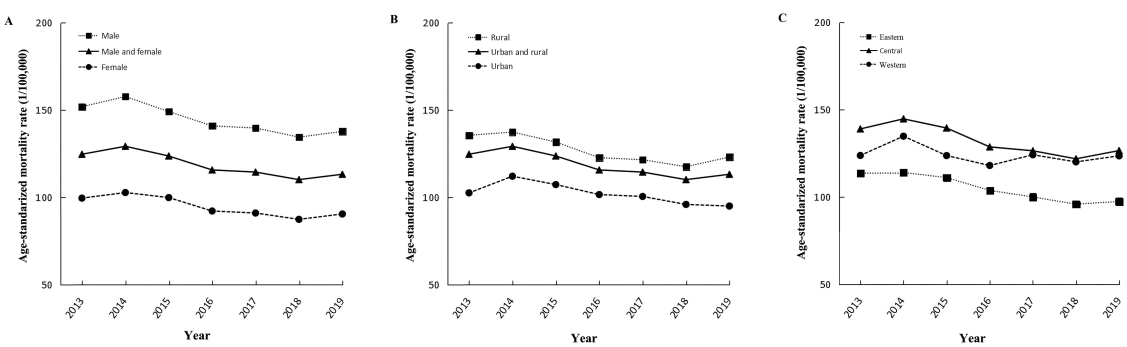

Figure 3: Trends in mortality of CVD (ASMRC) by sex (A), by residence (B), and by region (C) in China from 2013 to 2019. ASMRC: Age-standardized mortality in China; CVD: Cerebrovascular disease.

Table 2: Age-standardized CVD mortalities projected for 2025 and 2030, stratified by age and sex in China.

	2025		2030	
Variables	**Mortality (1/100,000)**	**Ratio (2025/2019)**[†]	**Mortality (1/100,000)**	**Ratio (2030/2019)**[‡]
Total[*]	97.7 (97.5, 97.9)	0.86	86.4 (86.2, 86.6)	0.76
Sex[*]				
Male	119.1 (118.9, 119.3)	0.86	105.6 (105.4, 105.8)	0.77
Female	75.6 (65.4, 75.8)	0.84	65.1 (64.9, 65.3)	0.72
Age groups (years)				
≤34	1.2 (1.0, 1.4)	0.80	1.0 (0.8, 1.2)	0.67
35–44	9.5 (9.3, 9.7)	0.73	7.3 (7.1, 7.5)	0.56
45–54	25.8 (25.6, 26.0)	0.95	24.7 (24.5, 24.9)	0.90
55–64	106.7 (106.5, 106.9)	0.85	93.5 (93.3, 93.7)	0.75
65–74	329.0 (328.8, 329.2)	0.78	268.8 (268.6, 269.0)	0.64
75–84	1257.2 (1257.0, 1257.4)	0.85	1095.3 (1095.1, 1095.5)	0.74
≥85	5214.5 (5214.3, 5214.7)	1.13	5777.0 (5776.8, 5777.2)	1.25

Data are presented as rate (95% CI). [*]Indicates the age-adjusted mortality per 100,000 people. [†]Indicates the value for 2025 as a ratio of the 2019 value. [‡] Indicates the value for 2030 as a ratio of the 2019 value. CI: Confidence interval; CVD: Cerebrovascular disease.

the China Stroke Statistics 2019, stroke was the third-leading cause of death behind malignant tumors and ischemic heart disease, and its mortality accounted for 22.33% of all causes of death in 2018. When stratified by sex, stroke was the second most common cause of death for both males (behind malignant tumors) and females (behind ischemic heart disease).[2] Although the age-standardized mortality has continued to decrease during the last decade, the stroke burden in China has not actually been reduced. According to a GBD study in 2017, the years of life lost (YLLs) and disability-adjusted life-years (DALYs) for stroke in 2017 increased by 14.6% and 46.8%, respectively, compared with those in 1990 in China.[4] Additionally, in the review of Global

Stroke Statistics (2019), China was listed as one of the top 10 countries for crude stroke mortality and was in the top 3 when the mortality was adjusted to the current world population, which reminds us of the unfavorable situation of CVD in China.[12] Large artery atherosclerosis (including carotid stenosis, vertebral stenosis, intracranial atherosclerosis), aneurysms, and vascular malformations are the other pivotal components of CVD and are important causes of ischemic stroke and hemorrhagic stroke; additionally, the causes of death of individuals with these diseases are generally recorded as stroke in the death registration system. Actually, studies of stroke mortality are representative of CVD in the real world. Although we primarily focused on CVD, previous studies on stroke were similarities to our research.

Data in our study were extracted from the CDC-DSP system, which covers approximately one-quarter of the total Chinese population. The results indicated an estimated 2.15 million deaths (crude rate, 149.6 per 100,000 people) due to CVD that occurred in China in 2019. After adjustment according to the WHO standardized population, in 2018, China presented a significantly higher ASMRW of $102.0/10^5$ compared with the United States ($37.6/10^5$)[13] and Europe ($85.0/10^5$ in 2017)[14], and a relatively higher rate than most of other BRICS countries–Russia ($115.16/10^5$), South Africa ($85.07/10^5$), India ($71.76/10^5$), and Brazil ($51.38/10^5$) (The data can be obtained from the website: https://www.worldlifeexpectancy. com/cause-of-death/stroke/by-country; the current data have been updated to 2020). Obviously, as an important emerging economy, China is facing the fact that stroke control lags far behind that in developed countries, even some developing countries. Geographic or national disparities in stroke incidence, described by the term "stroke belt," have existed for decades and are expected to persist in the future. Environmental, dietary, cultural, economic, and genetic factors were considered to be the dominant factors that, together, determine the variations in stroke incidence, prevalence, and mortality.[15] For example, the likelihood of a higher CVD burden tends to occur among men and black adults in high-latitude and low-income countries.[12] Such variations observed across regions within a country could also be explained by a similar social–economic model. During the period of 2013–2019, two regions (eastern and central) of China demonstrated a downward trend, while western China displayed a stable trend in the age-standardized mortality of CVD. These changes may be explained by the following features. First, the Chinese government has committed to a series of health care reform plans over the past 30 years aimed at solving the problem of expensive medical treatments. This health care policy has focused on strengthening the medical insurance coverage of residents and narrowing the gap between different regions, for which the increasingly close age-adjusted mortality of CVD from 2013 to 2019 (especially for western and central China) was a piece of important evidence. Second, the previous stable trend in western China reminded us that in western regions, the current prevention and control of CVD may require additional improvement and may need to be more targeted to the local economic situation and people's living habits. Third, the stroke mortality was mainly determined by the incidence rate and treatment outcome. Several investigations have revealed a positive association between first-ever stroke and unhealthy lifestyles, such as physical inactivity, unhealthy diet, deleterious use of alcohol, and smoking.[16] Residents' self-awareness of disease prevention and control is closely related to the average level of education and is negatively associated with stroke mortality. Disconcertingly, the increase in residents' income first encouraged the growth of unhealthy behaviors, while the promotion of education, health awareness, and medical resources remained relatively low. What is not optimistic is that until 2013, the provinces with the highest smoking rate (Inner Mongolia, Gansu) and that with the fastest rising smoking rate (Gansu) were both located in the central and western regions.[17] On the contrary, the China Education Report 2019 showed that the highest educational innovation level and better-quality outcomes were in the eastern region. The educational sector in western China has not only demonstrated a great level of enthusiasm, but it has also yielded numerous commendable outcomes in terms of innovation. In contrast, the central region is not highly motivated overall, and the central "depression" phenomenon is reasonably apparent. Considering the above factors, it is not difficult to comprehend the short-term rebound of CVD mortality in western China and the long-standing gap between central and eastern China in this survey.

Various studies based on the GBD database have demonstrated that the income level of countries was also implicated in stroke morbidity and mortality. From the GBD 2019 study, World Bank lower-income and lower-middle-income countries accounted for the bulk of the global stroke burden (86.0% [85.9–86.9] of deaths and 89.0% [88.9–89.3] of DALYs). Additionally, the low-income group had an age-standardized stroke mortality 3.6 (3.5–3.8) times higher and an age-standardized stroke-related DALY value 3.7 times higher than the high-income group. A shift in the burden of stroke has been observed worldwide during the past 3 decades, which involves a relatively small decrease in the high-income group and large increases in the low-income to upper-middle-income groups. According to the China Stroke Statistics 2019, the annual crude stroke mortality of rural residences was higher than that of urban residences from 2005 to 2018, with a downward trend from 2009–2012 followed by a slight increase from 2013–2018, which was specifically apparent in rural areas.[16] In our study, the impact of economic factors on age-standardized CVD mortality was partly reflected in the above subgroup analysis by region, and yet the impact became more significant in the rural-urban classification. From 2013 to 2019, urban and rural areas sustained a downward trend in the age-standardized CVD mortality, whereas the rate in rural areas was always higher than urban. We ratiocinated that the local economy not only directly limited the development and construction of hospitals and other medical facilities but also increased exposure to suboptimal health status (high body mass index (BMI), high fasting plasma glucose, high systolic blood pressure), unhealthy behaviors (smoking, alcohol overconsumption, low physical activity), and environmental stress (ambient particulate matter pollution, high temperature), the latter of which possibly resulted in a short-term increase in age-standardized CVD mortality in rural areas (after 2018) and required more attention.

As with other non-communicable diseases, irreversible factors, such as sex and age, have profound impacts on stroke mortality.[18] In the period studied, the trend of the age-standardized CVD mortality displayed nearly parallel changes for both sexes but with long-existing disparities.[19] The synchronous variations indicated virtually equal effects of multiple control and preventive measures on CVD mortality in different sexes. However, the continuing higher rate of CVD mortality in men *vs*. women could be predominantly initiated by genetic, hormonal, and metabolic factors, and partly driven by individual behaviors that can be modified. It is evident that CVD morbidity and mortalities significantly increase with age. The mean age of Chinese people with incident stroke was 65.5 years in men and 67.6 years in women (average of 66.4 years).[16] Our results were in agreement with previous studies showing that the age-specific and age-standardized mortalities of CVD were markedly higher among middle-aged and elderly people in China, especially in those aged over 55 years. An upward trend in the CVD mortality was observed in individuals aged over 85 years from 2013 to 2019. Additionally, we found that all the other age groups under 85 years showed decreasing trends in CVD mortality from 2013–2019, except the middle-aged group of individuals aged 45–54 years. Further analysis found that people aged 45–54 years also had decreased CVD mortality in urban areas but not in rural areas, which suggests that suboptimal prevention and treatment of CVD in the rural population might be the reason for the emergence of a plateau in CVD mortality in this age group. Importantly, people aged 45–54 years are the major labor force in society and families. However, sufficient awareness and associated awareness of the prevention of CVD are lacking among middle-aged people in rural areas, which usually leads to their disability or even death after a CVD attack and eventually results in a serious toll on their families. Therefore, more attention must be paid to the prevention and control of CVD among middle-aged people in rural areas. Aging is associated with an increased risk of hypertension, diabetes, dyslipidemia, and obesity, among other conditions which eventually lead to CVD or cardiovascular disease. In recent years, a trend toward a plateau of stroke incidence and mortalities in middle-aged individuals has been observed in high-income countries (USA, Europe) and even in some developing countries (China, Brazil). Such a trend might reflect increased exposure to some risk factors for stroke, including high blood pressure, high BMI, and high fasting plasma glucose, which suggests that the importance of primary prevention can never be overemphasized.

We further projected CVD mortality in 2025 and 2030 by assuming that the mortality trend would persist for the next decade. Compared with 2019, the total number of deaths in 2025 and 2030 will increase by approximately 7% and 11%, respectively. The absolute number of CVD deaths for males and females will likewise continue to increase due to population expansion. Although individuals between 75 years and 84 years of age experience a decreasing trend in the CVD mortality, the anticipated number of deaths will still rise as a result of the higher speed at which the population ages. Only the age group over 85 years will experience both an increased CVD mortality and number of deaths, which highlights the great underlying pressure on the elderly in the near future. Due to the coming era of demographic shifts and an aging population, the significance of primary and secondary prevention of CVD should not be ignored, as sufficient decreases in CVD incidence rates have not been achieved.

Several limitations of this research should be clarified. First, deaths from CVD were determined directly by the death certificate, and thus, the reliability of the conclusion primarily depended on the accuracy of the database. After years of continuous improvement in systematic monitoring capacity, the results from the CDC-DSP have been acknowledged by international and domestic scholars. However, the upgrading of CDC-DSP monitoring points in 2013 altered the trends in mortality to a certain extent, which reduced the comparative significance to previous results. Second, some dimensions of the monitoring data cannot be further explored. For example, the study of the death-to-morbidity ratio was restricted due to a lack of morbidity data. Third, we only analyzed the mortality of CVD and variations in its trend. However, the current study on different subtypes of stroke remains uncertain and requires further investigation. Fourth, to predict future changes in CVD mortality, we constructed an exponential equation using the parameters of the joinpoint regression model. This approach, a simple yet effective predictive model for long-term stable and short-term volatile trends, was adopted by Kunst *et al*[8] and is also suitable for our study. However, this approach still treats the number of deaths as a time series of counts to be projected in advance based on a prior trend in the change in counts, rather than as a decomposition into age, period, and cohort effects. This means that this model is less recommended than the Nordpred model[20-21] if the age structure of the future population changes significantly.

In conclusion, the age-standardized mortality of CVDs decreased from 2013 to 2019 in China. The heightened focus on the burden of CVD among males, rural areas, central and western China, and individuals aged 75 years and above has emerged as a pivotal determinant in further decreasing mortality rates, consequently presenting novel challenges to strategies for disease prevention and control.

Conflicts of interest

None.

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