BMC Public Health

RESEARCH

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Global burden of stroke in adolescents and young adults (aged 15–39 years) from 1990 to 2019: a comprehensive trend analysis based on the global burden of disease study 2019

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Summary

Introduction The incidence of stroke is rising among individuals aged 15–39. Insufficient research targeting this age group hampers the development of effective strategies. This study analyzes data from the Global Burden of Disease Study 2019 (GBD 2019) to examine trends from 1990 to 2019 and propose future interventions.

Methods Data on ischemic strokes, intracerebral hemorrhage, and subarachnoid hemorrhage from 1990 to 2019 was collected from the Global Health Data Exchange (GHDx) platform. We used the Annual Average Percentage Change (AAPC) to assess global trends in incidence, prevalence, Disability-Adjusted Life Years (DALYs), and mortality rates across various stroke categories. Joinpoint models identified significant years of trend inflection. Trend analyses were segmented by age, gender, and Sociodemographic Index (SDI).

Findings From 1990 to 2019, the global incidence of ischemic stroke within the adolescents and young adults (AYAs) cohort declined from 1990 to 1999, further decreased from 2000 to 2009, and then increased from 2010 to 2019. The overall AAPC *p*-value showed no significant difference. Mortality rates for ischemic strokes were consistently reduced during this period. The overall incidence rate of intracerebral hemorrhage has exhibited a downward trend. Meanwhile, the incidence rate of subarachnoid hemorrhage decreased from 1990 to 2009, yet saw a resurgence from 2010 to 2019. Male ischemic stroke incidence grew more than female incidence, but both absolute incidence and rates were higher for females. Differences in SDI levels were observed, with the fastest increase in incidence occurring in low-middle SDI regions, followed by high SDI regions, and the smallest increase in low SDI regions. Conversely, the most rapid decline was noted in high-middle SDI regions, with no significant change observed in middle SDI regions.

Conclusion A concerning trend of increasing ischemic stroke incidence, DALYs, and prevalence rates has emerged in the global 15–39 age group, especially among those aged 30–39. This increase is evident across regions with varying SDI classifications. To combat this alarming trend among adolescents and young adults, enhancing preventive

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efforts, promoting healthier lifestyles, strengthening the healthcare system's responsiveness, and maintaining vigilant epidemiological monitoring is essential.

Keywords Global burden of diseases, Stroke, Ischemic stroke, Subarachnoid hemorrhage, Intracerebral hemorrhage, Adolescents and young adults

Introduction

Although strokes are commonly perceived by the general public as a health issue predominantly affecting middle-aged and elderly individuals, emerging research suggests a silent increase in incidence among adolescents and young adults aged 15–39, posing a significant health challenge [1, 2]. Globally, strokes rank as the second leading cause of mortality after ischemic heart disease [3] and the third leading contributor to Disability-Adjusted Life Years (DALYs) in 2019 [4]. This rise in incidence among younger populations is especially concerning, as it occurs during their peak years of vitality.

Attributable to lifestyle changes, increasing environmental stresses, and genetic predispositions [5, 6], the incidence of stroke within this age group is on the rise. More concerning is the fact that the average age of stroke onset is decreasing [7], resulting in a growing number of young individuals experiencing compromised work capacities, leading to familial distress and an increased allocation of societal resources towards stroke management and prevention [7, 8]. The consequences of strokes in younger individuals are profound: they may face extended recovery periods and risk enduring physical impairments, including significant declines in cognitive performance and functionality [8–10]. From a socioeconomic perspective, these young patients may encounter unemployment [11], reduced quality of life, and strained family relationships, placing considerable burdens on both society and the healthcare system [2, 12, 13].

While there has been increasing attention to strokes in young individuals in recent academic discourse, research on the disease burden among those aged 15–39 remains notably limited [14–16]. This age group represents a significant proportion of the global population and is undergoing critical personal development and transitions. However, current literature predominantly concentrates on middle-aged and elderly populations, leaving a noticeable gap in understanding strokes in younger cohorts. Therefore, there is an urgent need for standardized and comparable research techniques to provide a comprehensive assessment of the stroke disease burden in young adults and adolescents at global, regional, and national levels [5].

Using data from the GBD 2019, this study aims to systematically analyze the evolving trends in stroke occurrences from 1990 to 2019 within this age group, thereby addressing the existing research gap. Our objectives are multifaceted: (a) evaluate global trends in incidence, prevalence, DALYs, and mortality rates for ischemic strokes, intracerebral hemorrhage, and subarachnoid hemorrhage from 1990 to 2019; (b) identify significant years of change for the indicators above; (c) undertake a stratified analysis of global trends based on age groups, gender, and SDI; and (d) explore regional and national trends and their implications for current developmental trajectories.

Methods

Study population and data collection

In our analysis of the GBD 2019, we obtained repeated cross-sectional data from the Global Health Data Exchange (GHDx) platform (https://vizhub.healthdata.org/gbd-results/). This dataset encompasses the global burden of 369 diseases and injuries across 204 countries and territories from 1990 to 2019 [17].

For our analysis, we extracted data specific to ischemic stroke, intracerebral hemorrhage, and subarachnoid hemorrhage. According to the clinical criteria of the World Health Organization (WHO), stroke is defined as a sudden onset of focal neurological deficits lasting over 24 h or leading to death. Consequently, the stroke data collected by GBD comprises multiple level-four stroke subtypes [4, 18], consistent with our analytical dataset.

The GBD 2019 provides data on incidence, prevalence, DALYs, Years of Life Lost (YLL), Years Lived with Disability (YLD), incidence cases, and prevalence cases. The Age-Standardized Rate (ASR) serves as a pivotal statistical tool, facilitating the comparison of disease incidence or mortality rates across various geographical regions and time periods by employing a global standard population structure. YLL further provide an estimate of the number of years lost due to premature death from specific causes, taking into consideration the age and gender at the time of death, thereby offering an assessment of the health loss attributed to early mortality. YLD focus on the decline in quality of life resulting from diseases or injuries, estimating the affected years of health by accounting for the severity and duration of the disease. DALYs amalgamate YLL and YLD, presenting a composite metric that reflects the total health loss due to diseases, injuries, and their premature mortality. DALYs are instrumental in evaluating the effectiveness of public health interventions and prioritizing health resource allocation. Rates are age-standardized and reported per 100,000 individuals. To establish the upper and lower bounds of the 95% Uncertainty Interval (UI), GBD utilizes its analytical modeling

method, generating 1,000 estimates for each value. The 25th and 975th values in this ordered sequence of estimates define the 95% lower and upper bounds, respectively. The methodologies employed by GBD 2019 are documented in previously published associated literature [17].

Sociodemographic Index (SDI)

The 2019 GBD study employed the SDI to evaluate the influence of social and economic factors on health outcomes across different countries. The SDI is a composite metric computed as the geometric mean of three components: total fertility rate for individuals under 25 years, average years of education for those aged 15 and older, and lag-distributed income per capita. In this index, a value of 0 signifies the lowest level of education, lowest per capita income, and highest fertility rate, while a value of 1 indicates the opposite [17]. The SDI categorizes countries into five quintiles based on their scores: low, low-middle, middle, high-middle, and high. By incorporating diverse sociodemographic factors, the SDI offers a more comprehensive and academically rigorous assessment of the conditions impacting health outcomes in each locale.

Statistical analysis

Our objectives comprise four main aspects:

a) Global Trends (1990–2019): This study aimed to assess the global trends for ischemic stroke, intracerebral hemorrhage, and subarachnoid hemorrhage from 1990 to 2019 for incidence, prevalence, DALYs, and mortality rates. We used age-specific rates and average annual percentage changes (AAPCs) to discern data trends over various periods. Log-linear regression was employed to compute AAPCs, representing a weighted mean of annual percentage changes. The magnitude of the AAPC indicates the annual rate of change (increase, decrease, or stability). For instance, an AAPC of 0.1 denotes an annual growth rate of 0.1%. We interpreted AAPC values along with their 95% confidence intervals (CIs) to indicate incidence trends. The analysis segmented the data from 1990 to 2019 into four intervals: 1990–1999, 2000–2009, 2010–2019, and the entire period from 1990 to 2019.
b) Joinpoint Regression Analysis: We used the Joinpoint model [19] to identify years that exhibited significant changes. Joinpoint regression allowed us to determine trends by fitting the simplest model to log-scaled data. Segments were connected using joinpoints; a model with zero joinpoints corresponds to a straight line. Additional joinpoints were added, and their significance was tested using the Monte Carlo permutation method. The final model was selected based on expert judgment and the Weighted Bayesian Information Criterion. Our analysis was conducted with a maximum of five joinpoints.
c) Stratified Trends and Correlation Analysis: We analyzed trends stratified by age, gender, and SDI. We also conducted a correlational trend analysis of incidence, prevalence, DALYs, and mortality rates with the SDI using ASR stratification. During this phase, point estimates were identified for 204 countries. Linear models were fitted, Pearson correlation coefficients were calculated, and correlational plots were generated.
d) Regional and National Trends: We employed AAPC to examine trends at both regional and national levels, using the same approach as the AAPC model described earlier. Our results elucidated and offered interpretations for the statistical test outcomes, including effect sizes, CIs, UIs, and p-values [20, 21].

All statistical analyses were meticulously executed via R software (version 4.2.0) and the Joinpoint Regression Program [19] (version 4.9.0.0). Any derived p-value < 0.05 was deemed indicative of statistically significant differentiation.

Results

Global trends

Globally, among adolescents and young adults (AYAs), the incidence rate of ischemic stroke showed a decrease during 1990–1999 (AAPC: -0.6; 95% CI: -0.6 to -0.5), followed by a further decline from 2000 to 2009 (AAPC: -0.3; 95% CI: -0.3 to -0.2). However, it exhibited an increase from 2010 to 2019 (AAPC: 1.1; 95% CI: 0.9 to 1.2). Over the entire period from 1990 to 2019, there was no statistically significant difference in the AAPC p-value. Joinpoint regression identified four significant shifts in incidence rates in 2000, 2010, 2014, and 2017. The prevalence of ischemic stroke notably increased only during 2010–2019 (AAPC: 0.8; 95% CI: 0.1 to 1.4), while the overall prevalence AAPC p-value did not show any significant variation. Mortality rates for ischemic stroke followed a declining trend from 2000 to 2019 and overall from 1990 to 2019 (AAPC: -0.61; 95% CI: -0.92 to -0.29). Concerning DALYs, a decrease was observed exclusively from 2000 to 2009 (AAPC: -0.5; 95% CI: -0.9 to -0.2), but the overall trend was downward from 1990 to 2019. Joinpoint analyses identified five intersections for DALYs and prevalence, three of which coincided in 2000, 2010, and 2014, all exhibiting similar upward trends. Details are in Fig. 1; Table 1, and Supplementary Material Tables 1 and 2.

For intracerebral hemorrhage, global incidence rates among AYAs decreased between 1990 and 2000 (AAPC:

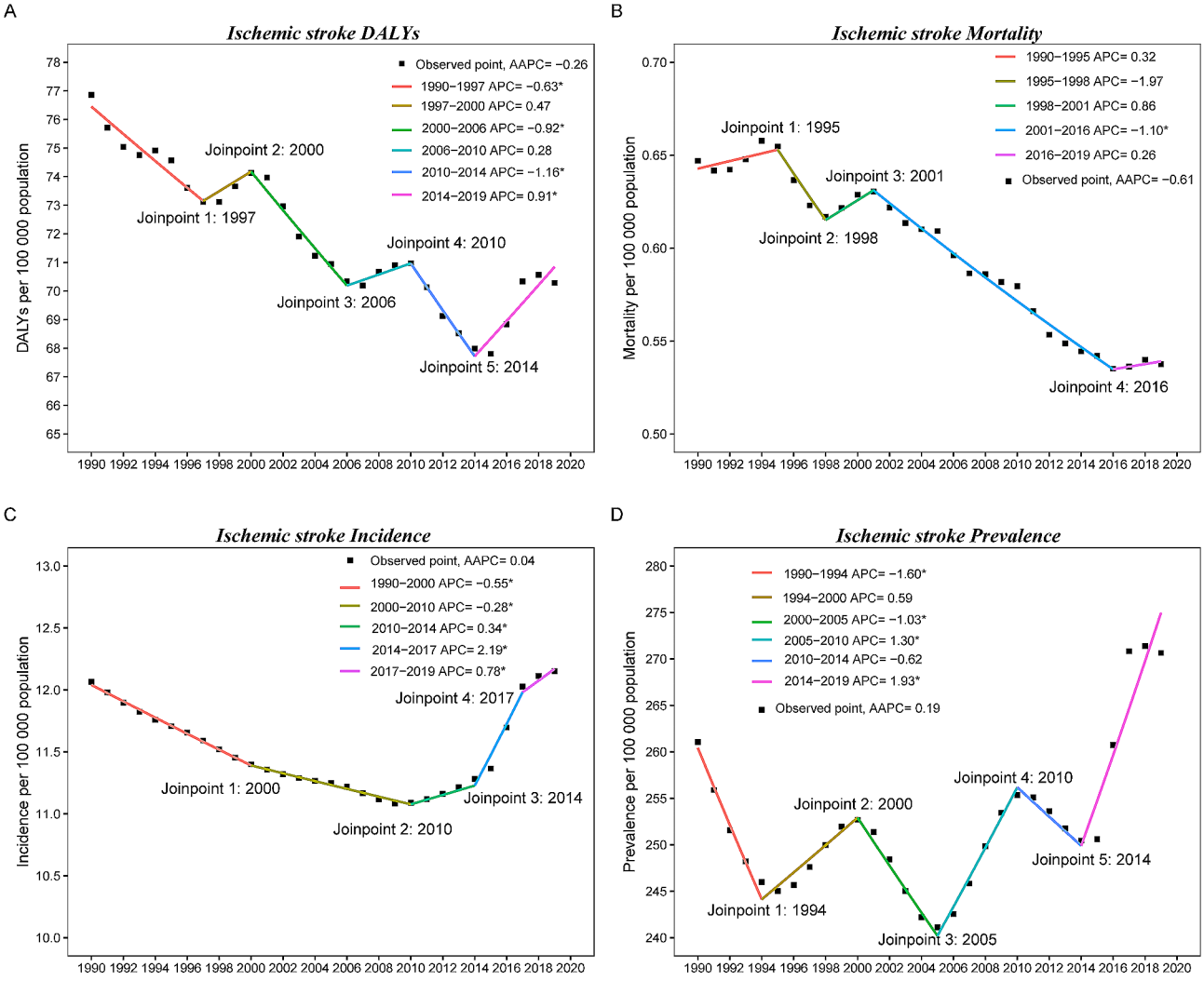

Fig. 1 Joinpoint regression analysis for global DALYs of Ischemic stroke **(A)**, Mortality of Ischemic stroke **(B)**, Incidence of Ischemic stroke **(C)** and Prevalence of Ischemic stroke **(D)** in adolescents and young adults aged 15–39 years from 1990 to 2019

-0.4; 95% CI: -0.5 to -0.3), declined more steeply from 2000 to 2009 (AAPC: -1.4; 95% CI: -1.4 to -1.4), and continued to fall from 2010 to 2019 (AAPC: -0.2; 95% CI: -0.3 to -0.2). Joinpoint regression identified five significant transition points in 1993, 1996, 2005, 2010, and 2016. Over these periods and overall, prevalence due to intracerebral hemorrhage did not display any statistically significant increases or decreases. DALYs and mortality rates both exhibited downward trends across the decades, with joinpoint analysis revealing shared transition points in 1997, 2001, 2006, 2010, and 2013. Details are in Fig. 2; Table 1, and Supplementary Material Tables 1 and 2.

Regarding subarachnoid hemorrhage among AYAs globally, incidence rates fell from 1990 to 1999 (AAPC: -0.9; 95% CI: -1.1 to -0.8), declined further from 2000 to 2009 (AAPC: -1.5; 95% CI: -1.5 to -1.4), but then increased from 2010 to 2019 (AAPC: 0.4; 95% CI: 0.3 to 0.5). Five significant transitions were detected through joinpoint regression in the years 1993, 1996, 2001, 2009, and 2014. Prevalence rates for subarachnoid hemorrhage fell from 1990 to 2009, exhibiting an overall downward trajectory. Both DALYs and mortality rates showed rapid declines followed by slower reductions. Integrated point analysis confirmed that DALYs and mortality rates displayed significant shifts at the same five points in 1995, 2000, 2004, and 2015. Details are in Fig. 3; Table 1, and Supplementary Material Tables 1 and 2.

Global trends by sex

The incidence of ischemic stroke has increased in both males and females, but the rate of increase is more pronounced in males (AAPC: 0.35; 95%CI: 0.31 to 0.38) compared to females (AAPC: 0.07; 95%CI: 0.03 to 0.38). Nonetheless, both the number and incidence rates of stroke in females exceed those of males. By 2019, the

Table 1 Global AAPCs in prevalence, incidence, mortality, and DALYs of ischemic stroke, intracerebral hemorrhage and subarachnoid hemorrhage

	Incidence		Prevalence		DALYs		Mortality	
	AAPC (95CI%)	*P* value	AAPC (95CI%)	*P* value	AAPC (95CI%)	*P* value	AAPC (95CI%)	*P* value
Ischemic stroke								
1990–1999	-0.6 (-0.6 to -0.5)	< 0.001	-0.4 (-0.9 to 0.1)	0.105	-0.4 (-0.8 to 0.0)	0.054	-0.4 (-1.1 to 0.4)	0.304
2000–2009	-0.3 (-0.3 to -0.2)	< 0.001	0.0 (-0.6 to 0.6)	0.998	-0.5 (-0.9 to -0.2)	0.004	-0.9 (-1.1 to -0.7)	< 0.001
2010–2019	1.1 (0.9 to 1.2)	< 0.001	0.8 (0.1 to 1.4)	0.016	0.0 (-0.4 to 0.4)	0.929	-0.6 (-1.0 to -0.3)	0.001
1990–2019	0.04 (-0.01 to 0.09)	0.161	0.19 (-0.13 to 0.51)	0.247	-0.26 (-0.52 to -0.01)	0.043	-0.61 (-0.92 to -0.29)	< 0.001
Intracerebral hemorrhage								
1990–1999	-0.4 (-0.5 to -0.3)	< 0.001	-0.2 (-0.5 to 0.1)	0.207	-0.4 (-0.6 to -0.2)	0.001	-0.4 (-0.7 to -0.2)	0.001
2000–2009	-1.4 (-1.4 to -1.4)	< 0.001	-0.3 (-0.7 to 0.1)	0.127	-1.6 (-2.0 to -1.3)	< 0.001	-1.7 (-2.1 to -1.3)	< 0.001
2010–2019	-0.2 (-0.3 to -0.2)	< 0.001	0.3 (-0.1 to 0.7)	0.181	-1.7 (-2.3 to -1.2)	< 0.001	-1.9 (-2.5 to -1.4)	< 0.001
1990–2019	-0.74 (-0.78 to -0.69)	< 0.001	-0.03 (-0.24 to 0.19)	0.805	-1.2 (-1.44 to -0.96)	< 0.001	-1.29 (-1.54 to -1.04)	< 0.001
Subarachnoid hemorrhage								
1990–1999	-0.9 (-1.1 to -0.8)	< 0.001	-0.6 (-1.0 to -0.3)	< 0.001	-1.6 (-1.8 to -1.3)	< 0.001	-1.7 (-1.9 to -1.4)	< 0.001
2000–2009	-1.5 (-1.5 to -1.4)	< 0.001	-0.7 (-1.1 to -0.3)	< 0.001	-2.6 (-2.9 to -2.2)	< 0.001	-2.8 (-3.1 to -2.4)	< 0.001
2010–2019	0.4 (0.3 to 0.5)	< 0.001	0.1 (-0.3 to 0.6)	0.583	-1.1 (-1.2 to -0.9)	< 0.001	-1.2 (-1.4 to -1.0)	< 0.001
1990–2019	-0.72 (-0.79 to -0.65)	< 0.001	-0.36 (-0.58 to -0.15)	0.001	-1.74 (-1.89 to -1.59)	< 0.001	-1.88 (-2.03 to -1.73)	< 0.001

AAPC = average annual percentage change. DALYs = disability-adjusted life-years

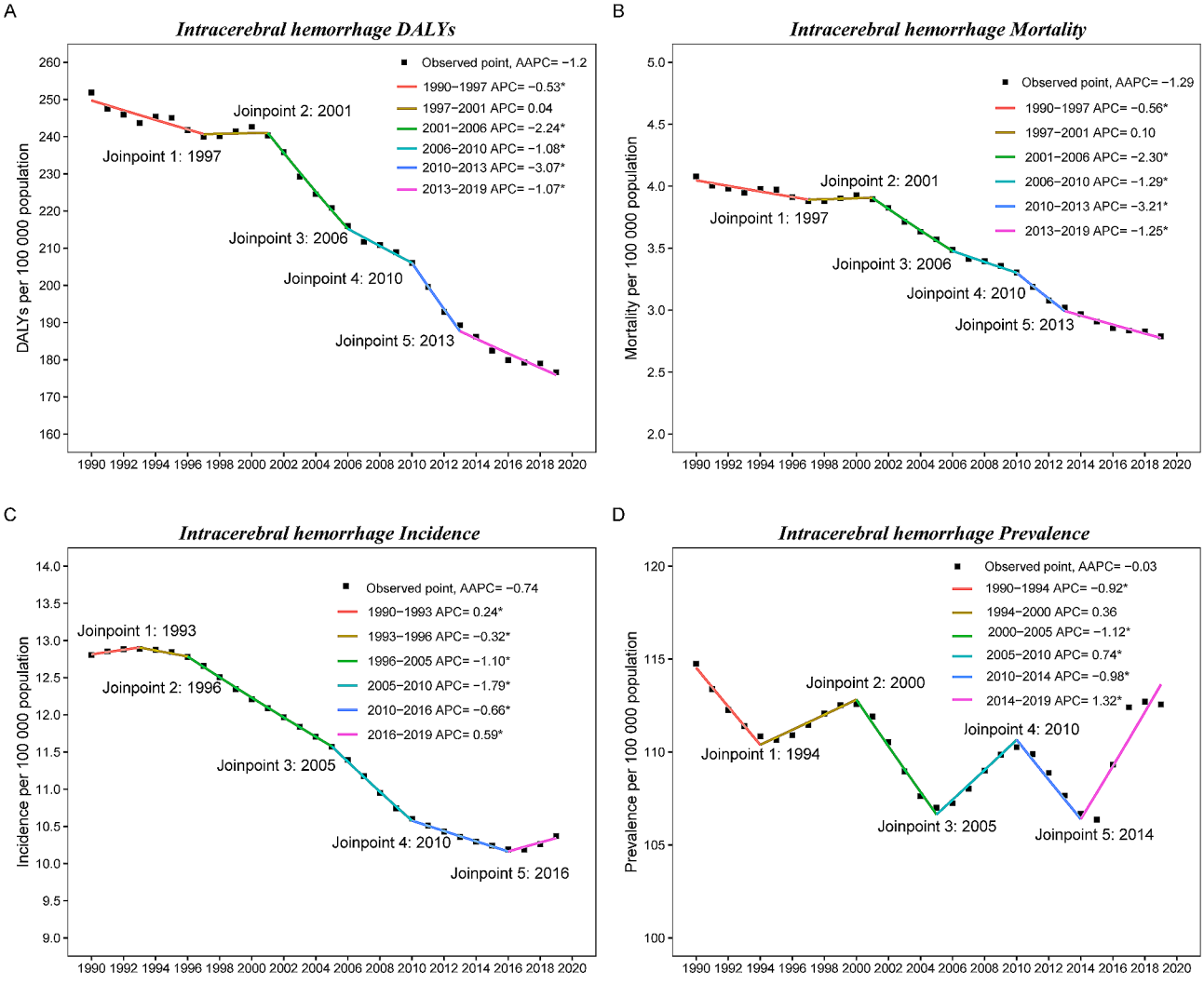

Fig. 2 Joinpoint regression analysis for global DALYs of Intracerebral hemorrhage **(A)**, Mortality of Intracerebral hemorrhage **(B)**, Incidence of Intracerebral hemorrhage **(C)** and Prevalence of Intracerebral hemorrhage **(D)** in adolescents and young adults aged 15–39 years from 1990 to 2019

incidence rate in females had decreased to 13.3 per 100,000 (95%UI: 7.1 to 22.6) from its 1990 value, yet the number of cases (196,917; 95%UI: 106,412 to 334,626) had risen. In contrast, both the number of cases and the incidence rate in males surpassed their 1990 values. Regarding disability-adjusted life years (DALYs), females exhibited a declining trend (AAPC: -0.26; 95%CI: -0.5 to -0.02), while male changes were not statistically significant. In terms of prevalence, males displayed an increase (AAPC: 0.35; 95%CI: -0.01 to 0.68), and while the AAPC for females was greater than zero, it was not statistically significant. The mortality rate for females decreased (AAPC: -0.83; 95%CI: -0.99 to -0.68). Although the AAPC for males was not statistically significant, both their mortality rate and number of deaths were higher than those of females. Detailed data are provided in Supplemental Material Tables 1 and 2.

For intracerebral hemorrhage, the incidence, DALYs, and mortality rates all declined across both genders. However, females experienced a sharper drop in incidence rate (AAPC: -0.77; 95%CI: -0.82 to -0.72) compared to their male counterparts (AAPC: -0.38; 95%CI: -0.43 to -0.32). Even though males registered a greater count in both cases and deaths, females had a larger number of affected individuals, tallying 1,808,467 cases (95%UI: 1,234,182 to 2,240,340) in contrast to males who had 1,569,538 cases (95%UI: 1,236,106 to 1,958,800). Detailed data are provided in Supplemental Material Tables 1 and 2.

Similarly, patterns observed in subarachnoid hemorrhage closely resembled those of intracerebral hemorrhage. While incidence rates, DALYs, and mortality all declined, females once again exhibited a swifter decline in incidence (AAPC: -0.61; 95%CI: -0.68 to -0.55) compared to males (AAPC: -0.38; 95%CI: -0.43 to -0.34).

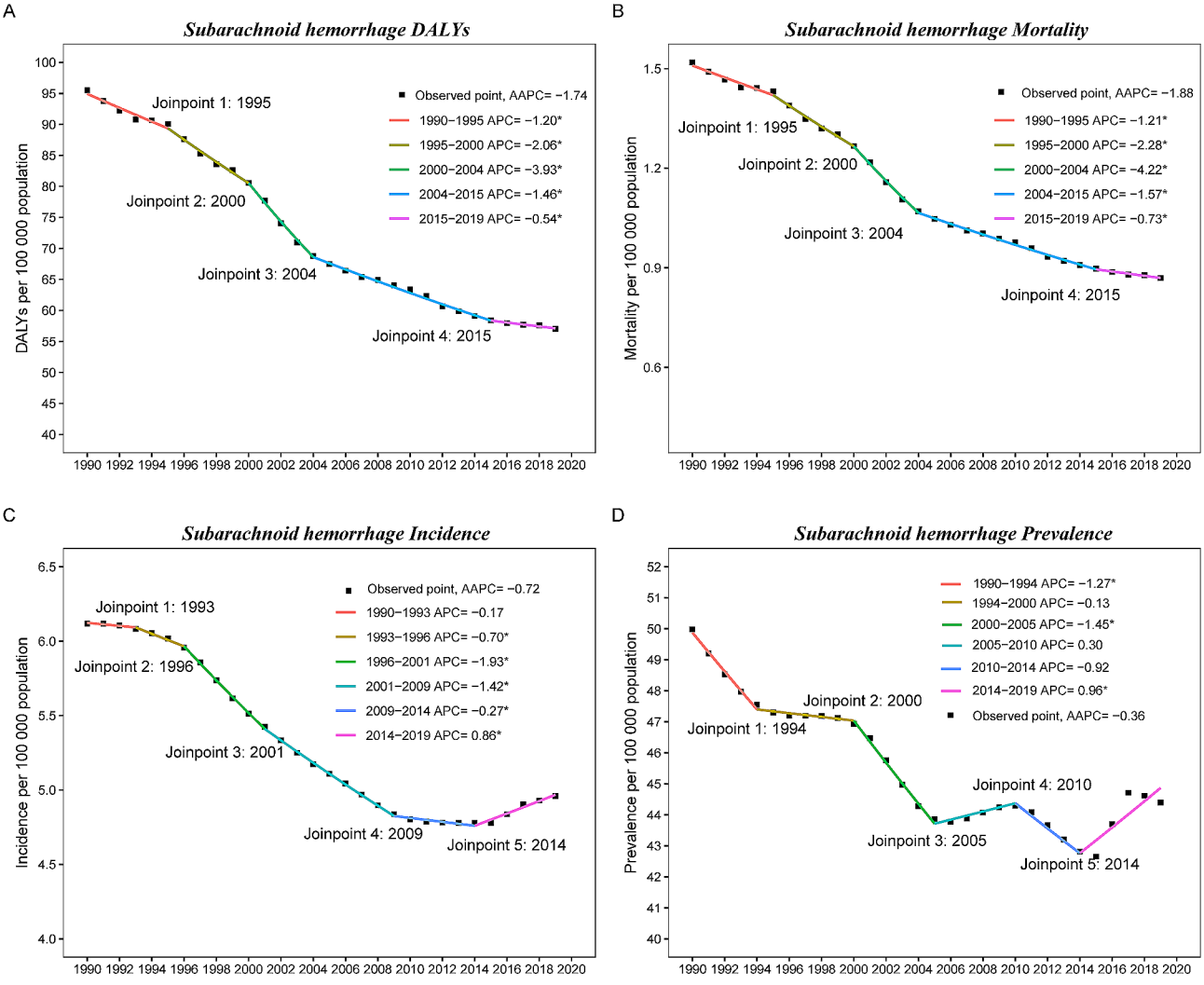

Fig. 3 Joinpoint regression analysis for global DALYs of Subarachnoid hemorrhage **(A)**, Mortality of Subarachnoid hemorrhage **(B)**, Incidence of Subarachnoid hemorrhage **(C)** and Prevalence of Subarachnoid hemorrhage **(D)** in adolescents and young adults aged 15–39 years from 1990 to 2019

The tally for affected females, reaching 685,097 cases (95%UI: 521,367 to 880,845), outstripped that of males, who recorded 651,566 cases (95%UI: 495,222 to 838,896). Detailed data are provided in Supplemental Material Tables 1 and 2.

Global trends by age group

From 1990 to 2019, the incidence rate of ischemic stroke in the 35–39 age group experienced a slight increase (AAPC: 0.1; 95%CI: 0.05 to 0.15), rising from 22.1 per 100,000 in 1990 (95%UI: 13.8 to 34.4) to 22.7 per 100,000 in 2019 (95%UI: 14.1 to 35.6). Other age groups, however, did not show significant changes in their incidence rates over the same period. In terms of DALYs, only the age groups 15–19 (AAPC: -0.24; 95%CI: -0.45 to -0.04) and 35–39 (AAPC: -0.32; 95%CI: -0.53 to -0.12) exhibited a significant decrease. Specifically, DALYs for the 15–19 age group declined from 40.4 per 100,000 in 1990 (95%UI: 30.9 to 52.6) to 37.2 per 100,000 in 2019 (95%UI: 27.8 to 48.8). Likewise, for the 35–39 age group, DALYs decreased from 138.8 per 100,000 in 1990 (95%UI: 117.0 to 164.8) to 124.7 per 100,000 in 2019 (95%UI: 103.5 to 148.8). While the AAPC for ischemic stroke did not display significant changes across the five age groups during this period, the number of cases followed an upward trajectory. As for mortality, the steepest decline was observed in the 15–19 age group (AAPC: -0.84; 95%CI: -1.08 to -0.59), followed by the 35–39 age group (AAPC: -0.63; 95%CI: -0.85 to -0.41). The age group 20–24 had the slowest decline (AAPC: -0.38; 95%CI: -0.58 to -0.18). Meanwhile, there were no significant changes in mortality rates for the age groups 25–29 and 30–34. Detailed data are provided in Supplemental Material Tables 1 and 2.

Between 1990 and 2019, incidence, DALYs, and mortality rates for intracerebral hemorrhage, all exhibited

declining trends across all age groups. The 30–34 age group experienced the most rapid decrease in incidence (AAPC: -0.86; 95%CI: -0.91 to -0.81). The DALYs (AAPC: -1.52; 95%CI: -1.76 to -1.28) and mortality (AAPC: -1.73; 95%CI: -1.86 to -1.6) rates showed the sharpest declines for the 15–19 age group. Interestingly, only the 15–19 age group had a significant increase in the prevalence of intracerebral hemorrhage (AAPC: 0.34; 95%CI: 0.08 to 0.61), while the other age groups remained relatively stable. Detailed data are provided in Supplemental Material Tables 1 and 2.

Likewise, between 1990 and 2019, all age groups observed a decrease in incidence, DALYs, and mortality rates for subarachnoid hemorrhage. The 30–34 age group recorded the fastest decline in incidence (AAPC: -0.79; 95%CI: -0.85 to -0.74). Like intracerebral hemorrhage, the 15–19 age group experienced the most substantial reductions in DALYs and mortality. Additionally, only the age groups 25–29, 30–34, and 35–39 displayed a decreasing trend in prevalence for subarachnoid hemorrhage, with the 35–39 group showing the most rapid decline (AAPC: -0.46; 95%CI: -0.58 to -0.34). Detailed data are provided in Supplemental Material Tables 1 and 2.

Global trends by SDI and correlation

Between 1990 and 2019, among the global population aged 15–39, the incidence of ischemic stroke decreased in high-SDI individuals (AAPC: -0.39; 95%CI: -0.48 to -0.31). Although the change in incidence was not significant in the middle-SDI cohort, the number of cases in this group did increase from 92,375 (95%UI: 50,554 to 155,324) to 126,854 (95%UI: 69,720 to 213,674). Conversely, the high, low, and lower-middle SDI cohorts displayed an upward trend in incidence, with the lower-middle SDI group having the steepest increase (AAPC: 0.34; 95%CI: 0.28 to 0.41), followed by the high-SDI group (AAPC: 0.3; 95%CI: 0.23 to 0.38). Regarding DALYs, the upper-middle and middle SDI regions showed a decreasing trend, with the most pronounced decline occurring in the upper-middle SDI regions (AAPC: -0.79; 95%CI: -0.99 to -0.6). However, DALYs were increased in low SDI regions (AAPC: 0.2; 95%CI: 0.09 to 0.32). Regarding prevalence, only the upper-middle SDI regions experienced a decline (AAPC: -0.17; 95%CI: -0.31 to -0.02). As for mortality rates, an increase was noted solely in the low-SDI regions (AAPC: 0.16; 95%CI: 0.05 to 0.26). The lower-middle SDI and the remaining regions showed a downward trend in mortality. Detailed data are provided in Supplemental Material Tables 1 and 2.

From 1990 to 2019, the incidence, DALYs rate, and mortality of cerebral hemorrhage globally decreased among the 15–39 age bracket across all SDI cohorts. High-SDI regions experienced the most rapid decline in DALYs (AAPC: -1.88; 95%CI: -2.17 to -1.59) and mortality (AAPC: -2.3; 95%CI: -2.6 to -1.99), while upper-middle SDI regions saw the fastest drop in incidence (AAPC: -1.27; 95%CI: -1.33 to -1.2). The highest incidence occurred in low-SDI regions, with 13.4 cases per 100,000 (95%UI: 9.6 to 18.3), which also had the highest DALYs rate, at 231.5 cases per 100,000 (95%UI: 231.5 to 277.5), and mortality, at 3.8 cases per 100,000 (95%UI: 3.0 to 4.5). Regarding prevalence, declines were observed only in upper-middle SDI regions (AAPC: -0.17; 95%CI: -0.25 to -0.09) and low-SDI regions (AAPC: -0.49; 95%CI: -0.61 to -0.37), with the highest prevalence in middle-SDI regions (122.8 cases per 100,000; 95%UI: 96.2 to 153.3). Detailed data are provided in Supplemental Material Tables 1 and 2.

From 1990 to 2019, all SDI regions exhibited a decline in the incidence, DALYs rate, and subarachnoid hemorrhage mortality for the global population aged 15–39. Upper-middle SDI regions experienced the sharpest decline in incidence (AAPC: -0.88; 95%CI: -0.97 to -0.8), but the highest incidence was recorded in lower-middle SDI regions with 5.4 cases per 100,000 (95%UI: 3.5 to 8.0). High-SDI regions demonstrated the most rapid reductions in both DALYs rate (AAPC: -2.21; 95%CI: -2.41 to -2) and mortality (AAPC: -2.22; 95%CI: -2.35 to -2.08). Notably, the DALYs rate was at its peak in the lower-middle SDI regions, reaching 74.9 cases per 100,000 (95%UI: 55.4 to 102.0), and the same region also posted the highest mortality rate of 1.2 cases per 100,000 (95%UI: 0.9 to 1.7). As for prevalence, a decreasing trend was evident predominantly in upper-middle SDI, low SDI, lower-middle SDI, and middle SDI regions, with the upper-middle SDI regions registering the most pronounced drop (AAPC: -0.34; 95%CI: -0.45 to -0.23). The greatest prevalence was observed in the high SDI regions, amounting to 50.9 cases per 100,000 (95%UI: 38.7 to 65.5).

Globally, the relationship between SDI levels and the incidence of ischemic strokes, cerebral hemorrhages, and subarachnoid hemorrhages among individuals aged 15–39 is varied. Regression analysis revealed that ischemic stroke incidence initially rose with increasing SDI, peaked rapidly at SDI=0.50, and then plateaued between SDI=0.6–0.75 before declining sharply beyond SDI=0.75. In contrast, the incidence of cerebral hemorrhage remained stable as SDI increased up to approximately SDI=0.6, after which it declined significantly. Notably, the incidence of subarachnoid hemorrhage followed a pattern of initial increase with rising SDI, peaking at SDI=0.6, and subsequently decreasing. Notably, the Supplementary material Fig. 3 provides evidence that upper-middle SDI and high-SDI regions recorded higher incidence rates than low-SDI regions. Detailed data are shown in Supplementary Material Fig. 1 to 3.

Regional trends

Between 1990 and 2019, the incidence rates of ischemic stroke among individuals aged 15–39 showed regional disparities. South Asia experienced the most marked increase, with an AAPC of 0.29 (95%CI: 0.33 to 0.45), whereas Central Latin America observed a significant decline, with an AAPC of -0.83 (95%CI: -0.88 to -0.78). By 2019, North Africa and the Middle East had the highest incidence rate, at 20.3 cases per 100,000 (95%UI: 13.0 to 30.7), while Western Europe reported the lowest rate, at 7 cases per 100,000 (95%UI: 3.1 to 13.4), consistent with 1990 data. North Africa and the Middle East also registered the highest DALYs rate, at 137.1 cases per 100,000 (95%UI: 110.0 to 168.5), and the highest mortality rate, at 1.6 cases per 100,000 (95%UI: 1.2 to 2.0). The region's growth rates for DALYs (AAPC: 0.19; 95%CI: 0.07 to 0.32) and mortality (AAPC: 0.21; 95%CI: 0.07 to 0.35) were the fastest worldwide. In Eastern Europe, prevalence increased most rapidly, with an AAPC of 0.31 (95%CI: 0.26 to 0.36), whereas Oceania recorded the highest incidence and Australasia the lowest. Detailed data are provided in Supplemental Material Tables 1 and 2.

The incidence of intracerebral hemorrhage among individuals aged 15–39 varied by region. Oceania experienced a slight increase in incidence, with an AAPC of 0.09 (95%CI: 0.05 to 0.12), while Tropical Latin America saw a significant decline, with an AAPC of -2.57 (95%CI: -2.63 to -2.52). Oceania had the highest incidence, at 44.5 cases per 100,000 (95%UI: 36.1 to 55.1), whereas Australasia reported the lowest, at 2.8 cases per 100,000 (95%UI: 1.3 to 5.0). Oceania also had the highest DALYs rate, at 582.9 cases per 100,000 (95%UI: 401.7 to 828.7), and the highest mortality rate, at 9.3 cases per 100,000 (95%UI: 6.2 to 13.6). Conversely, the High-income Asia Pacific region recorded the steepest decline in DALYs and mortality rates. Australasia consistently had the lowest incidence, DALYs, and mortality rates, while Oceania had the highest rates in all three categories. Detailed data are provided in Supplemental Material Tables 1 and 2.

For subarachnoid hemorrhage, East Asia showed the most rapid decline in incidence, with an AAPC of -1.33 (95%CI: -1.54 to -1.12). Most regions exhibited decreasing trends except for Eastern Europe, the High-income Asia Pacific, and Sub-Saharan Africa. Oceania had the highest incidence, at 12.6 cases per 100,000 (95%UI: 9.3 to 16.8) and the highest DALYs rate, at 169.9 cases per 100,000. Oceania also had the highest prevalence, at 83.8 cases per 100,000 (95%UI: 69.2 to 101.1), and the highest mortality, at 2.6 cases per 100,000 (95%UI: 1.3 to 4.7). Tropical Latin America experienced the most significant decrease in prevalence, with an AAPC of -0.87 (95%UI: -0.93 to -0.82), and most regions showed declining trends. Central Sub-Saharan Africa had the highest prevalence. In terms of mortality rates, Eastern Europe had the fastest increase, with an AAPC of 0.87 (95%CI: 0.21 to 1.54), while East Asia had the greatest reduction, with an AAPC of -3.68 (95%CI: -4.24 to -3.13). Western Sub-Saharan Africa had the lowest mortality rate, while Oceania had the highest. Detailed data are provided in Supplemental Material Tables 1 and 2.

National trends

In 2019, for ischemic stroke among individuals aged 15–39 globally, Saudi Arabia experienced the most significant increase in incidence rate, with an AAPC of 1.44 (95%CI: 1.36 to 1.53), while Portugal demonstrated the most pronounced decline, with an AAPC of -1.64 (95%CI: -1.75 to -1.54). This year, Sudan recorded the highest incidence rate at 27.4 cases per 100,000 (95%UI: 18.6 to 39.6), while Switzerland reported the lowest at 5.4 cases per 100,000 (95%UI: 2.0 to 11.1). Additionally, Sweden had the highest prevalence at 467.6 cases per 100,000 (95%UI: 352.6 to 593.6), whereas Argentina had the lowest at 143.1 cases per 100,000 (95%UI: 112 to 176.4). Notably, Switzerland posted the lowest DALYs rate, while Nauru led in both DALYs and mortality rates. Singapore recorded the world's lowest mortality rate, at 0.03 cases per 100,000 (95%UI: 0.02 to 0.05). For more detailed information, please consult in Fig. 4.

Concerning cerebral hemorrhage research in 2019, Lesotho showed the swiftest increase in incidence (AAPC: 2.23; 95%UI: 2.02 to 2.45), whereas Rwanda decreased the fastest (AAPC: -5.21; 95%UI: -5.43 to -4.98). In terms of incidence data, Kiribati ranked first (80.1 cases per 100,000; 95%UI: 66.9 to 95.6), and Israel last (2.3 cases per 100,000; 95%UI: 1 to 4.1). Kiribati also topped the prevalence chart (414.7 cases per 100,000; 95%UI: 356.6 to 470.3), distinctly contrasting with Switzerland's prevalence (47.8 cases per 100,000; 95%UI: 37.3 to 59.6). Significantly, Kiribati led the globe in DALYs and mortality rates for cerebral hemorrhage, while Switzerland consistently remained the lowest. Detailed figures are available in Fig. 5.

In 2019, concerning cerebral hemorrhage research, Lesotho experienced the swiftest increase in incidence, with an AAPC of 2.23 (95%UI: 2.02 to 2.45), while Rwanda saw the most rapid decrease, with an AAPC of -5.21 (95%UI: -5.43 to -4.98). Regarding incidence data, Kiribati had the highest rate at 80.1 cases per 100,000 (95%UI: 66.9 to 95.6), whereas Israel recorded the lowest at 2.3 cases per 100,000 (95%UI: 1 to 4.1). Kiribati also ranked first in prevalence, with a rate of 414.7 cases per 100,000 (95%UI: 356.6 to 470.3), contrasting markedly with Switzerland's prevalence rate of 47.8 cases per 100,000 (95%UI: 37.3 to 59.6). Notably, Kiribati had the highest global DALYs and mortality rates for cerebral

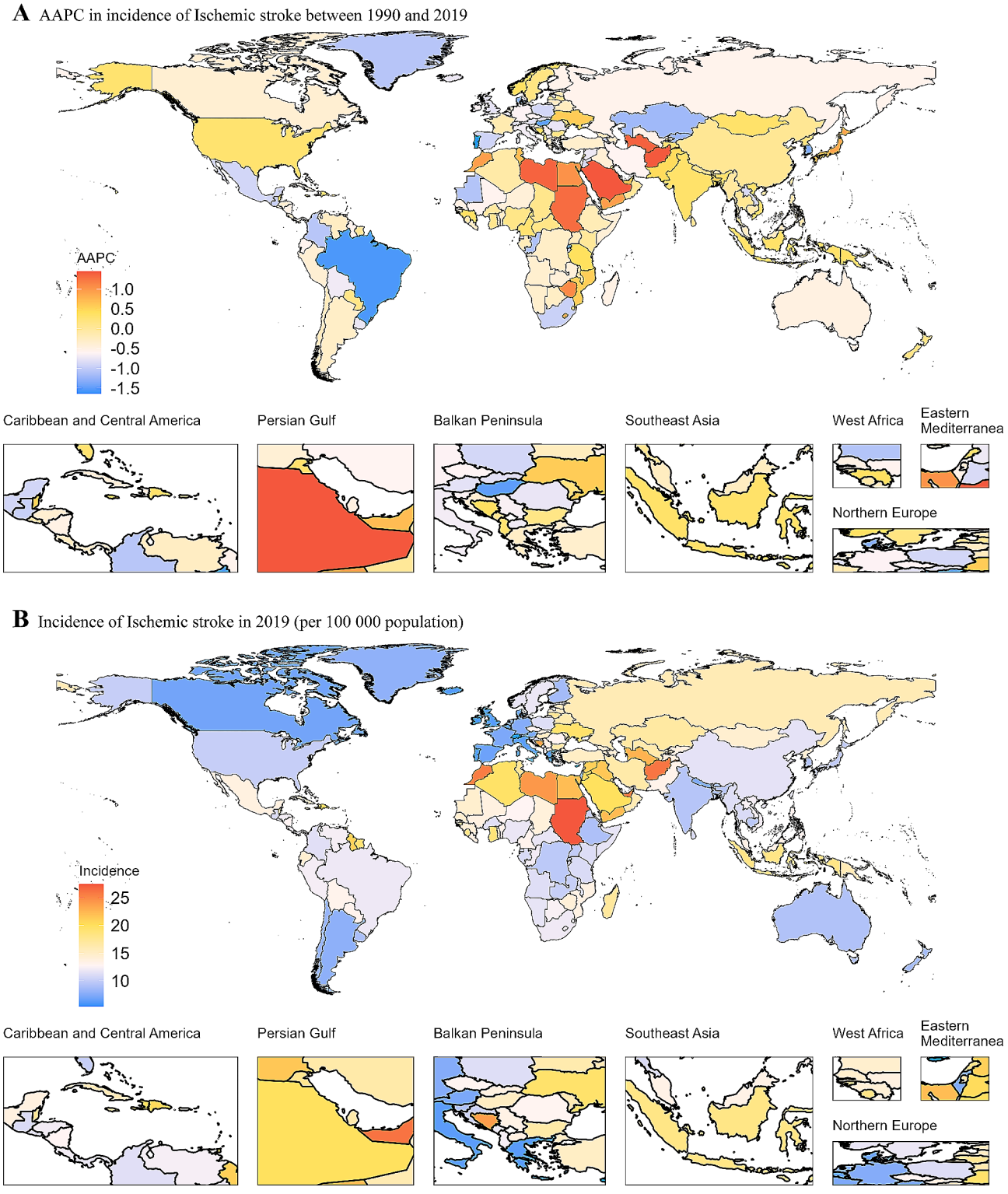

Fig. 4 Global map of average annual percentage changes in incidence of Ischemic stroke **(A)** from 1990 to 2019 and 2019 incidence of Ischemic stroke **(B)**

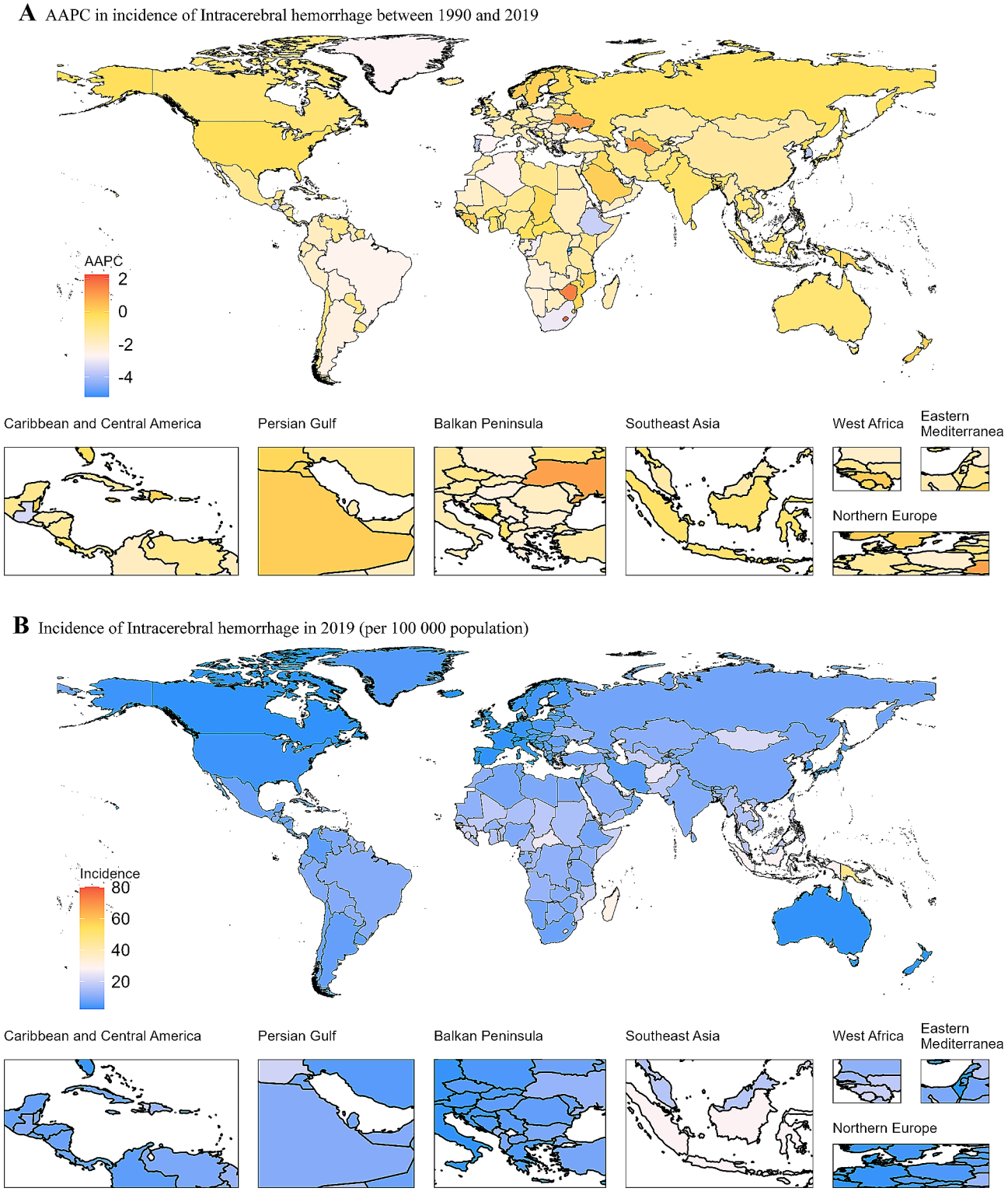

Fig. 5 Global map of average annual percentage changes in incidence of Intracerebral hemorrhage **(A)** from 1990 to 2019 and 2019 incidence of Intracerebral hemorrhage **(B)**

hemorrhage, while Switzerland consistently posted the lowest rates. Detailed data are available in Fig. 6.

Discussion

To the best of our knowledge, this is the first study to detail trends in the incidence and DALY rates of ischemic stroke, intracerebral hemorrhage, and subarachnoid hemorrhage among adolescents and young adults aged 15–39 years across 204 countries globally, regionally, and nationally from 1990 to 2019. Our findings indicate that, globally, the incidence of ischemic stroke in this age group has not shown significant changes, but the number of incidents and prevalent cases has increased. The incidence rates, DALY rates, and mortality rates of intracerebral hemorrhage and subarachnoid hemorrhage have all declined, while their prevalence rates remain unchanged. Notably, the upward trend in ischemic stroke is most pronounced in males, older age groups (35–39 years), and regions with high, low, and middle SDI. Regionally, a more rapid increase in burden is observed in high-income North America, Oceania, North Africa and the Middle East, and South Asia. Countries like Saudi Arabia, Afghanistan, Turkmenistan, Libya, and Sudan have witnessed a more rapid rise in ischemic stroke burden, while countries such as Portugal, Brazil, and Hungary have seen a significant decrease. The patterns for intracerebral hemorrhage and subarachnoid hemorrhage were similar, showing a decline across all age groups, with more significant reductions among females and in the age group of 30–34 and regions with high and middle SDI. Regionally, East Asia and tropical Latin America have experienced a faster decline in burden. On a national scale, countries such as Rwanda, Brazil, and Portugal have exhibited a rapid reduction in burden.

The continually rising global burden of ischemic stroke in adolescents and young adults underscores the urgent need for preventive and control measures in this demographic. This resurgence may be attributed to an increase in both traditional risk factors, such as hypertension, diabetes, tobacco use, lipid anomalies, high BMI, and decreased physical activity [22–24], as well as modern risk factors, including illicit and recreational drug use, academic and work pressures, and increasing psychological stress. Notably, the increasing BMI among contemporary children and adolescents increases the stroke risk burden [25–27]. While females exhibit a higher incidence of stroke than males, data indicates a much more rapid increase in males, emphasizing the need for interventions targeted at both genders. The correlation between oral contraceptive use and increased incidence in young females is noteworthy [28]. In young stroke patients, cryptogenic strokes show a higher incidence, with some etiologies remaining unidentified [12, 29]. Some may even be associated with other conditions, such as migraines [14, 30], which warrants further exploration.

Examining regional data, the rapid escalation of ischemic stroke in high-income North America, North Africa and the Middle East, and South Asia may reflect swift societal transitions in these areas, contributing to the development of ischemic stroke. Possible contributing factors include: (i) changes in lifestyle and dietary habits, where the excessive intake of sugar, calories, and salt can increase risks of obesity, hypertension, and diabetes, subsequently raising stroke risks [31]; (ii) air pollution, where prolonged exposure to harmful particulates may raise stroke risks [32, 33]; (iii) increased screening and diagnostic measures in developed regions, enhancing detection rates in young individuals; (iv) mental health issues, which may elevate stroke risks regardless of the SDI of the region; and (v) inadequacies in primary stroke prevention, particularly in lower SDI regions [34]. It is imperative for regions still experiencing rising trends to address deficiencies in health sector practices. Areas exhibiting declining trends must remain vigilant and offer insights into globally effective control measures for ischemic stroke.

Our study has several limitations. First, our research is limited by the variable quality and missing data of the GBD, and before 2019, there was no distinct separation between subarachnoid hemorrhage and intracerebral hemorrhage in the dataset. Second, the study only includes data on ischemic stroke, intracerebral hemorrhage, and subarachnoid hemorrhage, excluding comprehensive stroke data. Third, these metrics are modeled on a national scale and do not account for sub-national variations, leading to variations in reported stroke incidences due to differences in diagnostic standards. To reduce errors, standardization is essential when comparing data across countries and regions. Fourth, this research relies solely on the GBD database, excluding other potential datasets like the WHO's Global Health Estimates. Despite these limitations, this study provides the most recent and comprehensive assessment of stroke burden trends among adolescents and young adults globally. The results highlight the potential key populations for global stroke burden reduction and preventive strategy implementation.

Conclusion

In conclusion, our study provides insights into the global patterns of incidence, prevalence, DALY rates, and mortality rates of ischemic stroke, intracerebral hemorrhage, and subarachnoid hemorrhage among adolescents and young adults from 1990 to 2019. The absence of tailored guidelines for managing strokes in this demographic highlights the need for targeted strategies to lessen the stroke burden and improve socioeconomic advancement,

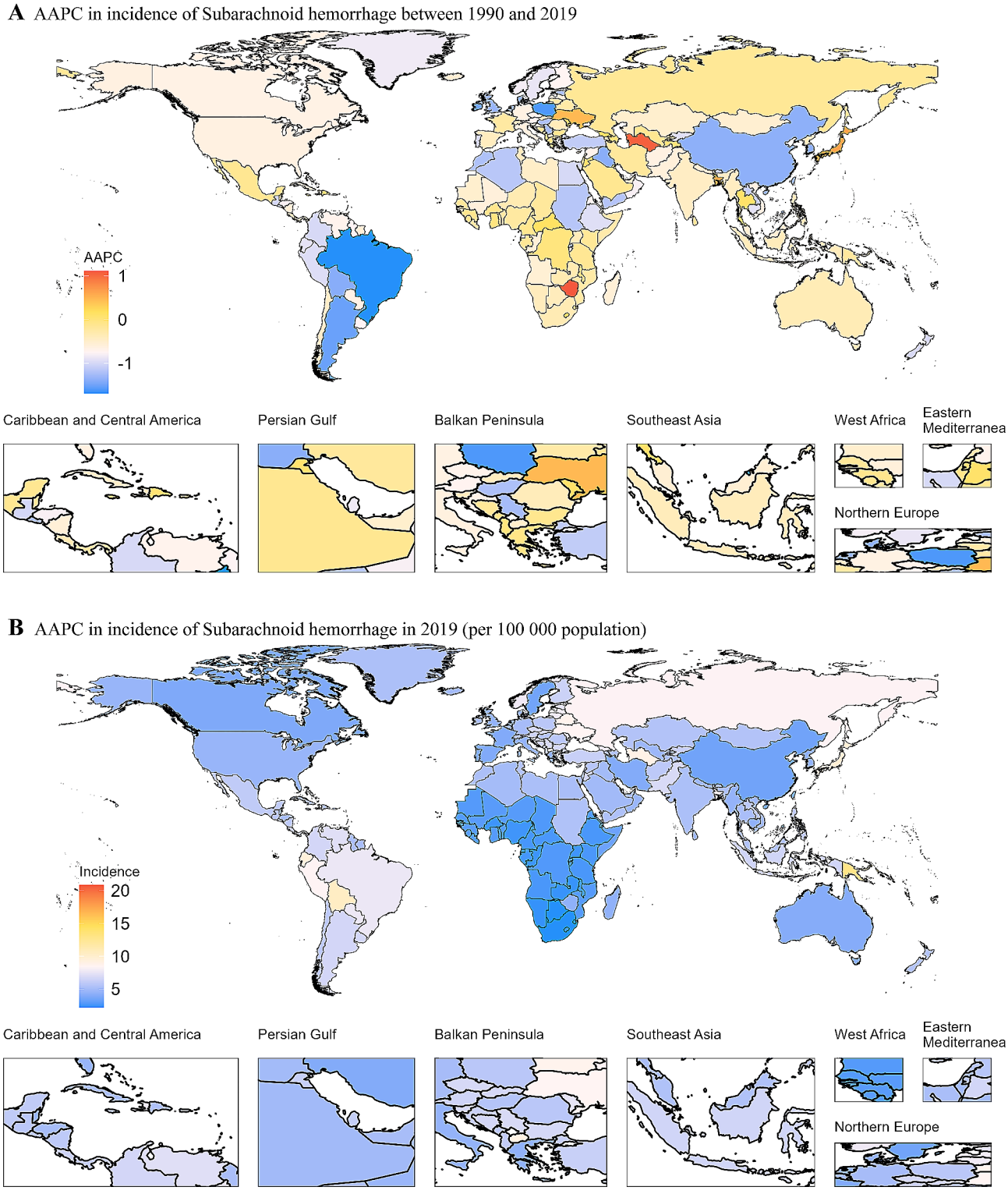

Fig. 6 Global map of average annual percentage changes in incidence of Subarachnoid hemorrhage **(A)** from 1990 to 2019 and 2019 incidence of Subarachnoid hemorrhage **(B)**

reduce familial pressures, and bolster health and educational achievements.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-19551-1.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Acknowledgements
Thank you to all members of GBD Database Collaboration Group and Xiaoming Study Room.

Author contributions
Conceptualization: Zixuan Ma, Yuanxin Zhou, Wenkai He, Mingyan Li; Methodology: Zixuan Ma, Yuanxin Zhou, Li Mai; Formal analysis and investigation: Zixuan Ma, Yuanxin Zhou, Lifeng Xu; Writing - original draft preparation: Zixuan Ma, Yuanxin Zhou, Mingyan Li, Wenkai He; Writing - review and editing: Zixuan Ma, Yuanxin Zhou, Can Li, Lifeng Xu, Mai Li, Wenkai He, Mingyan Li. All authors have read and agreed to the published version of the manuscript.

Funding
Not applicable.

Data availability
All data used from GHDx platform (https://vizhub.healthdata.org/gbd-results/).

Declarations

Ethics approval and consent to participate
The Institutional Review Board of the Second Affiliated Hospital of Guangzhou Medical University determined that approval for this research was not necessary, as it uses publicly available data. This study conforms to the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) for cross-sectional studies.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 28 August 2023 / Accepted: 22 July 2024
Published online: 30 July 2024

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