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# Time trends in subarachnoid haemorrhage mortality across the BRICS (Brazil, Russian Federation, India, China and South Africa): an age-period-cohort analysis for the GBD 2021

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## ABSTRACT

**Objectives** Subarachnoid haemorrhage (SAH) is the third most prevalent subtype of stroke, representing a critical and potentially life-threatening cerebrovascular emergency. Given their large populations and diverse healthcare infrastructures, the BRICS (Brazil, Russian Federation, India, China and South Africa) nations play a pivotal role in the global SAH landscape. This investigation assesses the mortality trends of SAH in BRICS countries from 1982 to 2021.

**Design and participants** This study uses data from the Global Burden of Disease (GBD) 2021 public dataset to investigate the temporal trends in SAH mortality over four decades globally and within BRICS countries. The age-period-cohort (APC) model was employed to estimate net drift, local drift, age-specific curves and period (cohort) relative risks.

**Primary outcome measures** Mortality.

**Results** From 1982 to 2021, there was a 3.85% increase in global SAH deaths and a 59.46% decrease in age-standardised mortality rates. SAH mortality rates are increasing across various age groups in BRICS countries, except in China and the Russian Federation, where most age groups show increasing trends. The annual net drift in SAH mortality varied from a decrease of 5.62% in China to an increase of 0.31% in the Russian Federation. Countries demonstrated similar age-effect patterns, with risk decreasing as age increased. However, period and cohort effects varied, suggesting different control measures and temporal mortality trends.

**Conclusions** Changing patterns of mortality from SAH in the BRICS countries over the last four decades vary. We suggest using local resources to step up SAH prevention. Healthcare for all ages, especially the vulnerable, should improve to prevent and treat SAH better.

### STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study marks the inaugural application of the age-period-cohort (APC) model in analysing subarachnoid haemorrhage (SAH) mortality, granting us the ability to gain comparative perspectives on the global arena and the BRICS (Brazil, Russian Federation, India, China and South Africa) nations.
⇒ In stark contrast to prior Global Burden of Disease 2019 reports, our research provides a deeper understanding of the disease's progression by leveraging the interplay of APC effects. This allows us to identify distinct mortality risk factors both globally and within the specific context of BRICS countries.
⇒ A significant proportion of SAH patients may die before reaching the hospital and remain undiagnosed, which may lead to an underestimation of the burden of disease.
⇒ The cross-sectional study lacks sufficient strength of causal correlation evidence and detailed analysis of subnational variations.

## INTRODUCTION

Subarachnoid haemorrhage (SAH) is a critical and potentially life-threatening cerebrovascular emergency that occurs when bleeding happens within the subarachnoid space, the delicate membrane-lined cavity surrounding the brain. This catastrophic event is characterised as bleeding into the subarachnoid space (the space between the arachnoid membrane and the pia mater of the brain or spinal cord) resulting in a clinical stroke.[1] While SAH comprises only 10% of all stroke cases,[2] it carries an alarmingly disproportionate high mortality rate, with half of all cases resulting in death within the initial 2 weeks.[3 4] Furthermore, a notable fraction of those who survive are left with long-lasting disabilities, significantly impacting their daily lives.[4] Despite remarkable progress in medical and surgical treatments, SAH continues to pose a significant public health challenge, emphasising the pressing need for exhaustive epidemiological studies to unravel its full burden and risk factors.

The BRICS (Brazil, Russian Federation, India, China and South Africa) nations form a multifaceted group characterised by diverse healthcare systems, socioeconomic profiles and varying degrees of disease prevalence. The significance of studying SAH within these countries stems from their sizeable populations and the potential for this condition to impose a substantial health burden.[5–7] Given these factors, investigating SAH in the BRICS countries is of utmost importance to gain insights into its epidemiology, risk factors and potential strategies for prevention and management, particularly in light of significant disparities in access to care and treatment outcomes. The recent update from the Global Burden of Disease (GBD) 2021 database provides a valuable opportunity to assess the temporal trends and spatial heterogeneity of the burden of SAH among BRICS countries. Additionally, the age-period-cohort (APC) model is a powerful analytical tool that can be used to dissect the complex effects of APC on SAH. Consequently, this research aids in shaping effective public health interventions, which aim to enhance healthcare outcomes related to SAH.

The core purpose of this research endeavour is to harness the GBD 2021 database as a tool to dissect mortality patterns of SAH across BRICS nations. Furthermore, it aims to employ the APC model to delve into the intricate interplay among age, period and birth cohort factors influencing these mortality rates. The significance of this study lies in its potential to highlight the unique challenges and opportunities for intervention in the BRICS countries, thereby supporting efforts to reduce the mortality associated with SAH. Ultimately, the insights gained from this research will contribute to the global knowledge base on SAH and align with the broader goals of enhancing global health.

## MATERIALS AND METHODS

### Data sources

The data used in this research stemmed from the publicly accessible GBD 2021 dataset, which can be retrieved via the Global Health Data Exchange's GBD Results tool (https://ghdx.healthdata.org/gbd-2021).[8] This dataset offers multilayered insights into the disease burden of 371 illnesses and injuries across 204 countries and territories worldwide. It encapsulates the most comprehensive assessment of disease burden, risks, mortality and disability, making it a crucial resource for global health understanding.[1 9] Notably, GBD 2021 incorporates several significant updates, including 19 189 new disability-adjusted life-year data sources, 12 fresh causes and various methodological advancements. Moreover, it takes into account the impact of the COVID-19 pandemic on the global disease burden.[1] In this study, SAH was defined as a non-traumatic, primary event identified by brain imaging. All estimations were presented within 95% uncertainty intervals (UIs), undergoing 1000 iterations of repeated sampling. The upper and lower limits of these intervals were determined by the 2.5th and 97.5th percentiles of the uncertainty distribution.[10]

### Patient and public involvement

Patients and/or the public were not involved in this study.

### Statistical analysis

#### APC analysis

In this study, the APC model was employed for data analysis, incorporating age, period and cohort as the primary independent variables. The model designated the mortality of the observed event or phenomenon within the study population as the dependent variable, under the assumption of a specific probability distribution. Through the application of APC models, this research aims to extend beyond traditional epidemiological analysis to elucidate the intricate influence of diverse factors on disease trends.[11] Specifically, within the APC model, the age effect encapsulates the varying risk of distinct outcomes across different age groups. The period effect captures the temporal variations in outcomes, affecting all age groups simultaneously. Finally, the cohort effect represents the shifts in outcomes among individuals belonging to the same birth cohort.[12]

#### Data arrangement

The death estimates for SAH, alongside the population data from each country, were used as inputs for the APC model that implemented the intrinsic estimator (IE) method. In this study, the IE method was applied to resolve the problem of parameter indeterminacy generated by the APC model's age, period and cohort effects.[13] Further methodological details are available in the prior literature.[13 14] In the context of the APC model, it is imperative that the age group data and the period group data adhere to a standardised structure. To keep the number of parameters manageable while ensuring a smooth depiction of time-effects, age-specific mortality rates in this study were divided into 5-year groups at equal intervals (15–19, 20–24, 25–29, …, 90–94 years). The period group was segmented into eight consecutive 5-year intervals, spanning from 1982–1986 (median year, 1984) to 2017–2021 (median year, 2019). As birth cohorts are defined by the age of the subjects and the dates of event occurrence, that is, cohort = period - age, the corresponding birth cohorts ranged from 1892–1896 (median year, 1894) to 1998–2002 (median year, 2000).

In this study, our primary attention is directed towards the following estimable functions. The net drift metric encapsulates the comprehensive annual percentage alteration in mortality rates across time. Furthermore, local drifts elucidate the annual percentage variations within distinct periods and cohorts for each age bracket. The longitudinal age curve portrays the fitted age-specific mortality rates over time within the reference cohort, taking into account deviations across periods. Additionally, the period (or cohort) rate ratio (RR) function represents the comparative ratio of age-specific mortality rates in each period (or cohort) relative to the reference period (or cohort). Specifically, an RR value >1 indicates an elevated risk of SAH mortality, whereas a value <1 suggests a diminished risk. The statistical significance of the estimated parameters and functions was rigorously evaluated using the Wald $\chi^2$ test, with all statistical assessments executed in a two-tailed manner. The APC analysis was conducted using the APC Web Tool, a comprehensive resource provided by the National Cancer Institute (http://analysistools.nci.nih.gov/apc/). By default, the web tool uses the median age and period ranges as reference points for calculations.[14] Additionally, all graphical representations were precisely crafted using the R statistical programme, specifically V.4.0.3.

## RESULT

### Globally and in BRICS countries, trends in SAH mortality, 1982–2021

Table 1 shows the population, total number of deaths, all-age mortality rate, age-standardised mortality rate and net drift of mortality. Over the past four decades, the number of SAH deaths increased from 339 741 (95% UI 252 196 to 455 867) in 1982 to 352 811 (95% UI 309 016 to 401 474) in 2021, representing a 3.85% increase. The age-standardised mortality rate decreased from 10.31 (95% UI 7.55 to 14.02) per 100 000 population in 1982 to 4.18 (95% UI 3.66 to 4.76) per 100 000 population in 2021, indicating a 59.46% decrease. The APC model estimated a net drift of −2.62% (95% CI −2.70 to −2.55) in SAH mortality from 1982 to 2021 globally (table 1).

In the BRICS countries, the Russian Federation and China witnessed a declining proportion of global SAH mortality from 1982 to 2021, while India observed an increasing proportion. Brazil and South Africa remained an unchanged proportion in 2021. The all-age mortality rate for SAH ranged from 1.19 (95% UI 0.97 to 1.38) per 100 000 population in South Africa to 9.31 (95% UI 8.57 to 10.03) per 100 000 population in the Russian Federation. Meanwhile, the age-standardised mortality rate in 2021 was highest in the Russian Federation at 5.99 (95% UI 5.51 to 6.44) per 100 000 population and lowest in South Africa at 1.46 (95% UI 1.20 to 1.68) per 100 000 population. In the Russian Federation, there has been an upward trend in the age-standardised mortality rate of SAH from 1982 to 2021, reaching 11.55%. Conversely, the other BRICS countries have shown a declining trend. Among these nations, China exhibited the most significant decrease with a rate of −84.73%, while South Africa had the least significant decrease, with a rate of −10.43%. According to the APC model estimates, the annual net drift in SAH mortality ranged from −5.62% (95% CI −5.70 to −5.53) in China to 0.31% (95% UI −0.05 to 0.68) in the Russian Federation within the BRICS countries (table 1).

### Time trends in SAH mortality across different age groups

Figure 1A depicts the annual percentage change in SAH mortality rates across different age groups globally. All age groups exhibit local drift values below 0, signifying an overall decrease in SAH mortality rates. It is noteworthy that male populations generally have higher local drift values compared with female populations, indicating a relatively slower decline in mortality rates among male populations. Among the BRICS nations, China and India are particularly prominent, showing a decline in SAH mortality rates across nearly all age groups. In contrast, Brazil exhibits local drift values primarily below 0 for most age groups, except for the older cohort aged 70–90 years, suggesting a potential increase in SAH mortality in this age group. An interesting trend emerges in the Russian Federation, where positive local drift values are observed in both the older (75–90 years) and younger (20–40 years) age groups, while the middle-aged cohort (40–75 years) experiences negative drift. South Africa displays divergent trends, with younger age groups (20–55 years) showing negative local drift and older age groups (55–90 years) demonstrating positive drift, indicating a potential rise in SAH mortality among the elderly. In terms of gender differences, China consistently shows higher local drift values for male populations across all age groups. India and South Africa exhibit a more complex gender divide, with male populations having higher local drift in younger age groups and female populations showing higher values in older age groups. However, in Brazil and the Russian Federation, gender disparities in local drift are not easily distinguishable.

Figure 1B depicts the temporal evolution in the age distribution of fatalities, highlighting a significant shift in mortality patterns over the extended period from 1982 to 2021. Specifically, the data reveal that the global proportion of deaths attributed to SAH among the older age cohort (60–94 years) has shown a discernible upward trajectory. A similar pattern, characterised by an increasing SAH mortality rate among the elderly population (60–94 years), was observed in all BRICS nations. Furthermore, in Brazil, a noteworthy shift was observed in the distribution of SAH-related deaths, moving from the younger age group (15–59 years) to the older age bracket (60–94 years).

### APC effects on SAH mortality

Figure 2 presents the APC effects estimates derived from the APC model for both global and BRICS countries. Overall, a similar age effect pattern is observed in all countries, with risk increasing as age increases. This suggests that older individuals are more susceptible to the life-threatening effects of SAH, and mortality risks accumulate with the ageing process. Gender differences in age effects are seen in all BRICS countries, with male populations having higher risks than female populations (figure 2A).

Globally, the period effects have maintained a downward trend over the past four decades, indicating effective control of SAH mortality risk over time. Similar patterns were observed in Brazil, China and India. In the Russian Federation, the period effects display an inverted V-shape, with risk initially increasing and then decreasing. In South Africa, the period effects demonstrate a pattern

**Table 1** Trends in subarachnoid haemorrhage mortality across BRICS, 1982–2021

| | Global | | Brazil | | Russian Federation | | India | | China | | South Africa | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1982 | 2021 | 1982 | 2021 | 1982 | 2021 | 1982 | 2021 | 1982 | 2021 | 1982 | 2021 |
| Population | | | | | | | | | | | | |
| Number*, n x 1 000 000 | 4634 (4542, 4371) | 7891 (7668, 8131) | 129 (118, 140) | 220 (188, 251) | 143 (131, 155) | 145 (125, 164) | 728 (673, 787) | 1415 (1240, 1602) | 1006 (938, 1073) | 1423 (1319, 1530) | 31 (26, 35) | 57 (50, 64) |
| Percentage of global, % | 100 | 100 | 2.8 | 2.8 | 3.1 | 1.8 | 15.7 | 17.9 | 21.7 | 18 | 0.7 | 0.7 |
| Deaths | | | | | | | | | | | | |
| Number*, n | 3 39 741 (2 52 196, 4 55 867) | 3 52 811 (3 09 016, 4 01 474) | 7027 (6741, 7324) | 13 701 (12 896, 14 273) | 8234 (7788, 8623) | 13 481 (12 417, 14 528) | 25 846 (15 755, 43 045) | 48 285 (33 672, 66 532) | 169 161 (85 056, 2 44 810) | 91 803 (66 672, 1 16 216) | 299 (241, 360) | 678 (554, 785) |
| Percentage of global, % | 100 | 100 | 2.1 | 3.9 | 2.4 | 3.8 | 7.6 | 13.7 | 49.8 | 26 | 0.1 | 0.2 |
| Percent change of deaths 1982–2021, % | 3.85 | | 94.98 | | 63.72 | | 86.82 | | –45.73 | | 133.44 | |
| All-age mortality rate | | | | | | | | | | | | |
| Rate per 100 000* | 7.33 (5.44, 9.84) | 4.47 (3.92, 5.09) | 5.46 (5.24, 5.69) | 6.22 (5.85, 6.48) | 5.76 (5.45, 6.03) | 9.31 (8.57, 10.03) | 3.55 (2.17, 5.92) | 3.41 (2.38, 4.70) | 16.81 (8.45, 24.33) | 6.45 (4.69, 8.17) | 0.97 (0.78, 1.17) | 1.19 (0.97, 1.38) |
| Percent change of rate 1982–2021, % | –39.01 | | 13.92 | | 61.63 | | –3.94 | | –61.63 | | 22.69 | |
| Age-standardised mortality rate | | | | | | | | | | | | |
| Rate per 100 000* | 10.31 (7.55, 14.02) | 4.18 (3.66, 4.76) | 8.14 (7.81, 8.54) | 5.45 (5.12, 5.68) | 5.37 (5.07, 5.63) | 5.99 (5.51, 6.44) | 6.36 (3.66, 7.77) | 3.95 (2.73, 5.50) | 30.92 (15.25, 45.75) | 4.72 (3.45, 5.95) | 1.63 (1.33, 1.96) | 1.46 (1.20, 1.68) |
| Percent change of rate 1982–2021, % | –59.46 | | –33.05 | | 11.55 | | –37.89 | | –84.73 | | –10.43 | |
| APC model estimates | | | | | | | | | | | | |
| Net drift of mortality rate†, % per year | –2.62 (2.70, –2.55) | | –1.14 (-1.22, –1.06) | | 0.31 (-0.05, 0.68) | | –1.26 (-1.36, –1.15) | | –5.62 (-5.70, –5.53) | | –0.17 (-0.51, –0.16) | |

All-age mortality rate = crude mortality rate.
Age-standardised mortality rate is computed by direct standardisation with global standard population in GBD 2021.
Net drifts are estimates derived from the age-period-cohort model and denote overall annual percentage change in mortality, which captures the contribution of the effects from calendar time and successive birth cohorts. Parentheses for all GBD health estimates indicate 95% uncertainty intervals.
*Parentheses for all GBD health estimates indicate 95% uncertainty intervals due to the inherent characteristics of model selection, parameter estimation and the quality and availability of data inputs for GBD 2021.
†Parentheses for net drift indicate 95% confidence intervals.
APC, age-period-cohort; BRICS, Brazil, Russian Federation, India, China and South Africa; GBD, Global Burden of Disease.

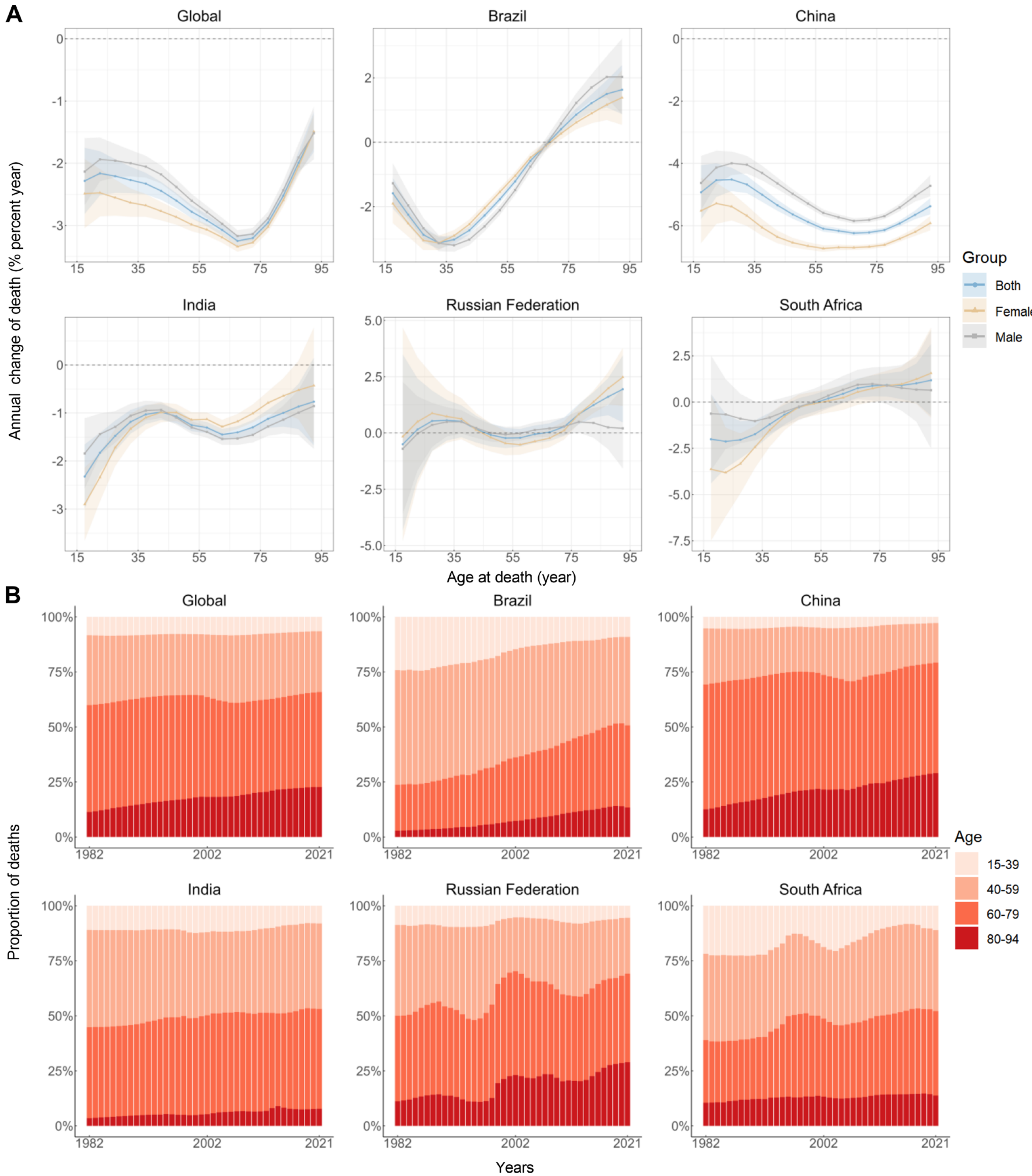


**Figure 1** Local drifts of mortality rate and age distribution of deaths in global and Brazil, Russian Federation, India, China and South Africa, 1982–2021. (A) Local drifts of subarachnoid haemorrhage mortality rate (estimates from age-period-cohort models) for 16 age groups (15–19 to 90–94 years), 1982–2021. The dots and shaded areas indicate the annual percentage change of mortality rate (% per year) and the corresponding 95% CIs. (B) Temporal change in the relative proportion of subarachnoid haemorrhage deaths across age groups, 1982–2021.

of initial decrease, followed by an increase, and then another decrease (figure 2B).

Globally, the cohort effects exhibit a continuously decreasing trend in the successive birth cohort. Similar patterns were observed in India and China. In the Russian Federation and South Africa, cohort effects remain relatively stable, with a slight decline. In Brazil, cohort effects display a trend of initially rising, then falling and finally levelling off (figure 2C).

## DISCUSSION

Over the period spanning from 1982 to 2021, the total number of SAH deaths exhibited a slight increase, which

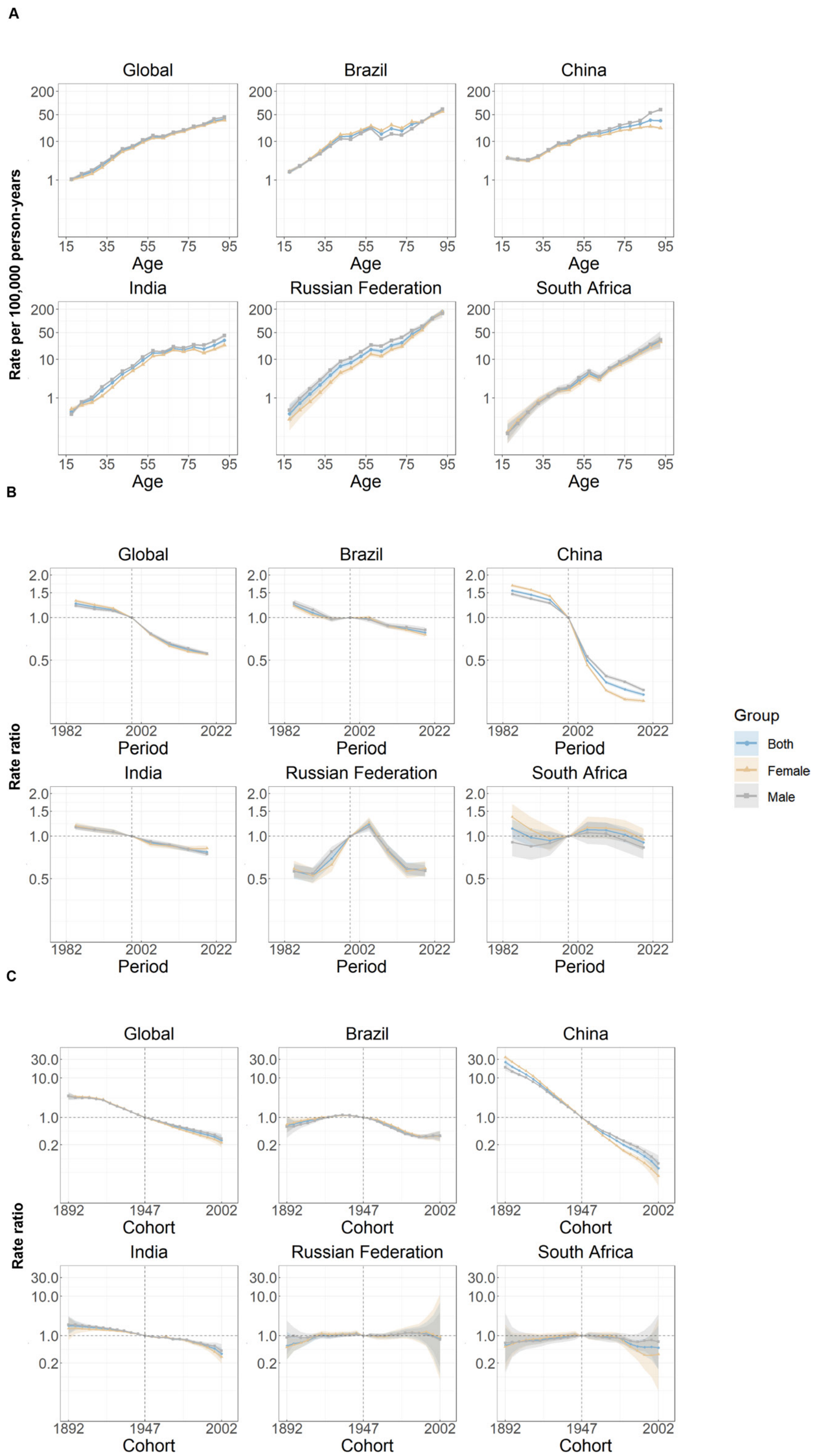


**Figure 2** Age, period and cohort effects on subarachnoid haemorrhage mortality in global and BRICS. (A) Age effects are shown by the fitted longitudinal age curves of mortality rate (per 100 000 person-years) adjusted for period deviations. (B) Period effects are shown by the relative risk of mortality rate (mortality rate ratio) and computed as the ratio of age-specific rates from 1982–1986 to 2017–2021, with the referent cohort set at 1997–2001. (C) Cohort effects are shown by the relative risk of mortality rate and computed as the ratio of age-specific rates from the 1892 cohort to the 2002 cohort, with the referent cohort set at 1947. The rate ratio is estimated using maximum likelihood of the age-period-cohort (APC) model Poisson with log (Y) based on natural-spline function, and it indicates the value of a particular period or cohort compared with the reference value. When the rate ratio is more than 1, it suggests that the factor increases the risk of subarachnoid haemorrhage mortality. When the rate ratio is less than 1, it suggests that the factor decreases the risk of subarachnoid haemorrhage mortality. The dots and shaded areas denote mortality rates or rate ratios and their corresponding 95% CIs. Note: The web tool of APC analysis uses the median age and period ranges as reference points for calculations.

can be partly attributed to the burgeoning population globally. There is a pronounced variation in the mortality rates and long-term trends of SAH among the BRICS nations. Within the BRICS nations, specific patterns of mortality variations emerged, with Brazil, the Russian Federation and South Africa all registering varying degrees of increase in SAH deaths, while China and India showed a decrease during this time frame. However, after adjusting for fluctuations in age demographics, the trend of standardised mortality rates for SAH has declined in BRICS nations other than the Russian Federation, suggesting that beyond the influence of population migration, there are underlying factors that have significantly contributed to the observed changes in SAH mortality over the past four decades. This might be linked to improved surgical and medical management, such as the strategy of admitting patients early and the early occlusion of the aneurysm.[15 16] We also found that, except in India, the proportion of deaths among elderly patients in other countries showed an upward trend, which may be related to the international ageing of the population.[16 17]

China and India exhibit significant similarities in terms of age, period and cohort. Similar to global observations, SAH risk exhibits a clear correlation with increasing age in China and India, reflective of an ageing population combined with pressure on healthcare systems to address SAH risks.[18] The decline in mortality in China and India was an important contributor to the slight reduction in mortality risk over the global period and cohort. These advances in China could be attributed to the robust healthcare policies and initiatives undertaken by the Chinese government during the study period. Programmes such as the Stroke Screening and Intervention Program for High-risk Population and the 'Healthy China 2030' blueprint (2016), which emphasise reduction in smoking, physical inactivity, air pollution and cardiovascular risks, have improved access to medical services for SAH patients and align well with the observed reduction in SAH mortality risk.[19–22] Cohort effects, through their constantly declining trend, further emphasise China's transition toward addressing preventive healthcare. Broader implications of enhanced public health campaigns since the 1990s—including smoking reduction and stricter control on dietary salt—continue to benefit across generational levels, particularly among the younger cohort populations.[23] In India, expanded public health progress, achieved primarily through government health initiatives such as the National Health Mission, improved access to primary healthcare in rural areas and strength in combating risk factors like hypertension.[24] Cohort trends in India also reveal a continuously decreasing risk trajectory, likely due to improved literacy rates alongside reduced exposure to critical lifestyle and environmental risks in younger birth cohorts.

South Africa and the Russian Federation also share similarities in terms of age, period and cohort effects. South Africa shows distinctly fluctuating patterns in period and cohort effects, correlating with persistent socioeconomic challenges and unequal access to healthcare. During the earlier periods studied, initially decreasing period effects indicate some successes in managing cerebrovascular health through improved postapartheid healthcare reforms aimed at equitable access, such as policies adopted by South Africa's National Department of Health.[25] However, the subsequent periods experienced temporary increases in mortality, and this upward trend persisted until 2014. This increase can possibly be attributed to the peak of the AIDS epidemic in South Africa during that period, which overwhelmed medical resources, led to difficulties in accessing healthcare and further resulted in an elevated mortality rate for acute conditions such as SAH. [26 27]The Russian Federation presents a unique pattern regarding both period and cohort effects that differ from the rest of the BRICS countries. The inverted V-shaped trend in period effects likely reflects the tumultuous socioeconomic changes that accompanied the post-Soviet transition in the 1990s. During that period, economic instability and disruptions in the healthcare system, combined with reduced availability of disease prevention and treatment measures, as well as consecutive changes in health policies resulting in the lack of effective public health interventions, may have all contributed to the rising mortality rate from SAH.[28–30] In recent years, both South Africa and the Russian Federation have experienced a downward trend in mortality rates. In South Africa, the recent reintroduction of a downward trajectory may reflect gradual improvements in hypertension control, measures against substance abuse, and neonatal healthcare advances. In the Russian Federation, following economic stabilisation and reorganisation of the healthcare system in the early 2000s, a decline in SAH mortality was observed, suggesting improved medical technologies and access to comprehensive hypertension management and smoking cessation programmes. The cohort effect in both South Africa and the Russian Federation has remained relatively stable. This may be due to advancements in medical technology and corresponding policy improvements in both countries, which have had a positive impact on all birth cohorts. This universal improvement may have offset individual differences between cohorts, resulting in a stable cohort effect. In Brazil, a significant decline was observed in period effects, and this decrease may result from the improvement of health services[31] and the control of other risk factors for cardiovascular diseases, such as smoking.[32] The initial rise followed by a fall in cohort effects could be attributed to Brazil's socioeconomic development since the late 20th century, where increased industrialisation and urbanisation initially escalated health inequities and lifestyle-related risks such as hypertension and smoking. However, the health reforms initiated in the 1980s and the establishment of Brazil's Unified Health System (SUS) in 1988 have demonstrated significant steps toward improving healthcare access and combating major risk factors like tobacco use and alcohol consumption.[33] These healthcare reforms and economic investments likely influenced the stabilisation of cohort effects in more recent years.

To our knowledge, this study marks the inaugural application of the APC model in analysing SAH mortality, granting us the ability to gain comparative perspectives spanning both the global arena and the BRICS nations. In stark contrast to prior GBD 2019 reports, our research provides a deeper understanding of the disease's progression by leveraging the interplay of age, period and cohort effects, allowing us to identify distinct mortality risk factors both globally and within the specific context of BRICS countries. Additionally, our study quantifies localised variations in mortality age distributions and the age of onset from 1982 to 2021, both universally and within the BRICS nations. This approach facilitates the unravelling of temporal mortality patterns within distinct age cohorts while accounting for period- and cohort-specific dynamics. Our APC model-based analysis offers policymakers and healthcare practitioners invaluable insights by thoroughly examining SAH mortality trends and assessing the efficacy of corresponding healthcare services. Admittedly, several limitations need to be acknowledged. First, the GBD database is limited by the quality of disease registries in each country or region. A significant proportion of SAH patients may die before reaching the hospital and remain undiagnosed, which may lead to an underestimation of the burden of disease. Future research endeavours may benefit significantly from integrating high-quality forensic and diagnostic data to address gaps in documenting out-of-hospital deaths. Second, the study lacks a detailed analysis of subnational variations, given the disparities in health issues and access to healthcare services at that level. Third, the investigation of period and cohort effects was conducted using cross-sectional data from the most recent GBD 2021 estimates, covering the years 1982–2021. Therefore, further international cohort studies are essential to evaluate location- and time-specific relative risks and to assess varying risks among susceptible populations.

## CONCLUSION

The BRICS countries have achieved varying degrees of progress in reducing SAH mortality. Recognising the diverse environmental contexts within these countries, we recommend a gradual advancement of SAH prevention efforts that are tailored to specific circumstances, effectively leveraging available policy-driven, human and financial resources. To further enhance the prevention and treatment of SAH, healthcare services should be expanded to cover all age groups, with special attention given to vulnerable populations.

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**Contributors** SG prepared the first draft. YW and LF accessed and acquired the raw data, performed the primary analysis and prepared tables and figures. SG contributed to the interpretation of the data. YW critically reviewed results and provided important comments on the manuscript. TW and LC substantially edited and critically reviewed the manuscript. SG and YW were responsible for general supervision and had final responsibility for the decision to submit for publication. All authors reviewed and approved the final manuscript and are accountable for all aspects of the work, including accuracy and integrity. LC is the guarantor.

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**Competing interests** None declared.

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

**Patient consent for publication** Not applicable.

**Ethics approval** Not applicable.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data are available in a public, open access repository. The datasets generated during and/or analysed during the current study are available in the GBD Data Tool repository (http://ghdx.healthdata.org/gbd-results-tool). This public link to the database of GBD study is open, and the use of data does not require additional consent from IHME.



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