
GBD 2019 Stroke Collaborators*

Summary

Background Regularly updated data on stroke and its pathological types, including data on their incidence, prevalence, mortality, disability, risk factors, and epidemiological trends, are important for evidence-based stroke care planning and resource allocation. The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) aims to provide a standardised and comprehensive measurement of these metrics at global, regional, and national levels.

Methods We applied GBD 2019 analytical tools to calculate stroke incidence, prevalence, mortality, disability-adjusted life-years (DALYs), and the population attributable fraction (PAF) of DALYs (with corresponding 95% uncertainty intervals [UIs]) associated with 19 risk factors, for 204 countries and territories from 1990 to 2019. These estimates were provided for ischaemic stroke, intracerebral haemorrhage, subarachnoid haemorrhage, and all strokes combined, and stratified by sex, age group, and World Bank country income level.

Findings In 2019, there were 12·2 million (95% UI 11·0–13·6) incident cases of stroke, 101 million (93·2–111) prevalent cases of stroke, 143 million (133–153) DALYs due to stroke, and 6·55 million (6·00–7·02) deaths from stroke. Globally, stroke remained the second-leading cause of death (11·6% [10·8–12·2] of total deaths) and the third-leading cause of death and disability combined (5·7% [5·1–6·2] of total DALYs) in 2019. From 1990 to 2019, the absolute number of incident strokes increased by 70·0% (67·0–73·0), prevalent strokes increased by 85·0% (83·0–88·0), deaths from stroke increased by 43·0% (31·0–55·0), and DALYs due to stroke increased by 32·0% (22·0–42·0). During the same period, age-standardised rates of stroke incidence decreased by 17·0% (15·0–18·0), mortality decreased by 36·0% (31·0–42·0), prevalence decreased by 6·0% (5·0–7·0), and DALYs decreased by 36·0% (31·0–42·0). However, among people younger than 70 years, prevalence rates increased by 22·0% (21·0–24·0) and incidence rates increased by 15·0% (12·0–18·0). In 2019, the age-standardised stroke-related mortality rate was 3·6 (3·5–3·8) times higher in the World Bank low-income group than in the World Bank high-income group, and the age-standardised stroke-related DALY rate was 3·7 (3·5–3·9) times higher in the low-income group than the high-income group. Ischaemic stroke constituted 62·4% of all incident strokes in 2019 (7·63 million [6·57–8·96]), while intracerebral haemorrhage constituted 27·9% (3·41 million [2·97–3·91]) and subarachnoid haemorrhage constituted 9·7% (1·18 million [1·01–1·39]). In 2019, the five leading risk factors for stroke were high systolic blood pressure (contributing to 79·6 million [67·7–90·8] DALYs or 55·5% [48·2–62·0]) of total stroke DALYs), high body-mass index (34·9 million [22·3–48·6] DALYs or 24·3% [15·7–33·2]), high fasting plasma glucose (28·7 million [19·8–41·5] DALYs or 20·2% [13·8–29·1]), ambient particulate matter pollution (28·7 million [23·4–33·4] DALYs or 20·1% [16·6–23·0]), and smoking (25·3 million [22·6–28·2] DALYs or 17·6% [16·4–19·0]).

Interpretation The annual number of strokes and deaths due to stroke increased substantially from 1990 to 2019, despite substantial reductions in age-standardised rates, particularly among people older than 70 years. The highest age-standardised stroke-related mortality and DALY rates were in the World Bank low-income group. The fastest-growing risk factor for stroke between 1990 and 2019 was high body-mass index. Without urgent implementation of effective primary prevention strategies, the stroke burden will probably continue to grow across the world, particularly in low-income countries.

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Introduction Disease and population distribution patterns, life expectancy, mortality, causes of death, and socio-demographic factors continue to change across the world, including ageing of populations and changes in the prevalence of risk factors for non-communicable disorders. Timely estimates of the burden of stroke and its pathological types, the burden attributable to risk factors, and trends in the burden over time are necessary at the global, regional, and national levels to guide
The second-leading cause of death in the world in 2017 was measured by disability-adjusted life-years (DALYs) and the third-leading cause of death and disability combined (as evidence-based health-care policy, planning, and resource allocation for stroke.

The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2017 showed that stroke was the third-leading cause of death and disability combined (as measured by disability-adjusted life-years [DALYs]) and the second-leading cause of death in the world in 2017. A GBD 2017 stroke analysis found that, although age-standardised incidence rates from 1990 to 2016 were minimal, the burden of stroke was likely to remain high well into the future.

Research in context

Evidence before this study
The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) produces the most comprehensive estimates of the global, regional, and country-specific burden of stroke. Population-level estimates for stroke incidence or mortality have been published by WHO and independent research groups, but those of GBD include more extensive estimates by age, sex, location, and year. To evaluate the availability of evidence, we did a structured review of the published scientific literature in Medline, Scopus, Google Scholar, and PubMed for relevant reports published in any language up to June 30, 2021, using search terms that included “stroke”, “cerebral infarction”, “isch(a)emic stroke”, “intracerebral h(a)emorrhage”, “h(a)emorrhagic stroke”, or “subarachnoid h(a)emorrhage”, AND “incidence”, “prevalence”, “mortality”, or “epidemiology” or “population attributable fraction (PAF)”, “risk factor(s)”, or “disability-adjusted life-year(s) (DALYs)”. GBD 2017 included stroke in its analysis, but the most recent paper by the GBD Collaborator Network on the topic of stroke was from GBD 2016. The report concluded that because the decrease in global age-standardised incidence rates from 1990 to 2016 was sharp, the decrease in age-standardised incidence was much less steep, suggesting that prevention efforts have been less successful than treatment efforts. The results from GBD 2016 showed that 87.9% of ischaemic stroke DALYs and 89.5% of haemorrhagic stroke DALYs were due to potentially modifiable risk factors measured in GBD, demonstrating the enormous potential to reduce the burden of stroke through reductions in risk factor exposure. According to WHO, effective stroke prevention strategies include reducing the risk associated with hypertension (high systolic blood pressure), elevated lipids, diabetes (high fasting plasma glucose), smoking, low physical activity, unhealthy diet, and abdominal obesity (high body-mass index [BMI]), which is similar to the findings from GBD 2016 and GBD 2017.

Implications of all the available evidence
The findings from this study can help guide evidence-based health-care planning, prevention, and resource allocation for stroke and its pathological types, including country-specific prioritisation of these measures. By evaluating the risk-attributable burden of different stroke types in different geographical locations, this study can be used to develop location-specific strategies for reducing the burden of stroke. Based on the available evidence, public health and research priorities should include: expanding evidence-based prevention strategies that reduce exposure to risk factors; reducing the gaps in acute and chronic stroke prevention, screening, and treatment services between high-income and low-income to middle-income countries; and further epidemiological research on stroke risk and outcomes across different countries and populations.

Methods
Overview and case definition
Details of the GBD 2019 eligibility criteria, the literature search strategy, and data extraction are described in detail elsewhere (appendix sections 1.1–4.3). In brief, stroke was defined by WHO clinical criteria as rapidly neurological dysfunction due to focal cerebral, spinal,
or retinal infarction. Intracerebral haemorrhage was defined as stroke with a focal collection of blood in the brain not due to trauma. Subarachnoid haemorrhage was defined as non-traumatic stroke due to bleeding into the subarachnoid space of the brain. The GBD classifies causes into four levels, from the broadest (Level 1; eg, non-communicable diseases), to the most specific (Level 4; eg, intracerebral haemorrhage). Stroke is a Level 3 cause, within the Level 2 category of cardiovascular diseases, while its subtypes are Level 4 causes.

**Fatal disease modelling**

We used vital registration and verbal autopsy data as inputs into the Cause of Death Ensemble modelling (CODEm) framework to estimate deaths due to overall stroke and stroke subtypes. CODEm is a flexible modelling tool that utilises geospatial relationships and information from covariates to produce estimates of death for all locations across the time series (1990–2019). Deaths from vital registration systems coded to impossible or intermediate causes of death or unspecified stroke were reassigned by use of statistical methods (appendix sections 1.4, 1.7, 1.8).10

**Non-fatal disease modelling**

Estimates of the incidence and prevalence of stroke were generated with the DisMod-MR 2.1 (disease-model-Bayesian meta-regression) modelling tool.3 DisMod-MR is a Bayesian geospatial disease modelling software that uses data on various disease parameters, the epidemiological relationships between these parameters, and geospatial relationships to produce estimates of prevalence and incidence (appendix section 3). All available high-quality data on incidence, prevalence, and mortality were used to estimate non-fatal stroke burden. We modelled first-ever ischaemic stroke, intracerebral haemorrhage, and subarachnoid haemorrhage from the day of incidence through 28 days and separately modelled survival beyond 28 days.

**Risk factor estimation**

To analyse the attributable burden of stroke due to 19 risk factors currently available for such analysis in GBD 2019, we calculated population attributable fractions (PAFs) of DALYs (appendix section 2). This work was done within the comparative risk assessments framework of GBD by use of four datasets: the burden estimates for stroke and stroke subtypes; the epidemiological relationships between these parameters, and geospatial relationships to produce estimates of prevalence and incidence (appendix section 3). All available high-quality data on incidence, prevalence, and mortality were used to estimate non-fatal stroke burden. We modelled first-ever ischaemic stroke, intracerebral haemorrhage, and subarachnoid haemorrhage from the day of incidence through 28 days and separately modelled survival beyond 28 days.

**Data sources and presentation**

For GBD 2019, we used data from 3686 vital registration sources, 147 verbal autopsy sources, 368 incidence sources, 117 prevalence sources, 229 excess mortality sources, 7753 risk factor exposure sources, and 2733 risk factor relative risk sources. Further details of the data sources used in this analysis are available on the Global Health Data Exchange website.

Estimates in this Article are presented in absolute numbers and as age-standardised rates per 100,000 population (with 95% uncertainty intervals [UIs]) and are stratified by age, sex, 21 GBD regions, seven GBD super-regions (appendix figure 6.1), and four income levels (as determined by the World Bank).11 Count data are presented in tables to two decimal places (and rounded to one decimal place in the text), and percentage data (including percentage change) are presented to one decimal place.

**Role of the funding source**

The funder had no role in study design, data collection, data analysis, interpretation of the study results, writing
of the report, or the decision to submit the manuscript for publication.

**Results**

**Overall stroke burden**

In 2019, there were 12·2 million (95% UI 11·0–13·6) incident strokes and 101 million (93·2–111) prevalent strokes, 143 million (133–153) DALYs due to stroke, and 6·55 million (6·00–7·02) deaths from stroke (table 1).

Globally, stroke was the second-leading Level 3 cause of death (11·6% [10·8–12·2] of total deaths) after ischaemic heart disease (16·2% [15·0–16·9]). Stroke was also the third-leading Level 3 cause of death and disability combined in 2019 (5·7% [5·1–6·2] of total DALYs), after neonatal disorders (7·3% [6·4–8·4]) and ischaemic heart disease (7·2% [6·5–8·0]; appendix section 4.1 and figure S2). In 2019, the World Bank low-income group of countries had an age-standardised stroke-related mortality rate 3·6 (3·5–3·8) times higher and an age-standardised stroke-related DALY rate 3·7 (3·5–3·9) times higher than those of high-income countries (see appendix tables S1, S3, and S5 and figures S2–7 for more detailed results by country and World Bank income group). In 2019, 86·0% (85·9–86·9) of all stroke-related deaths and 89·0% (88·9–89·3) of stroke-related DALYs occurred in lower-income, lower-middle-income, and upper-middle-income countries (appendix table S1). There were substantial between-country variations (figure 1A) in age-standardised stroke incidence rates and regional variations (figure 2) in age-standardised incidence, prevalence, mortality, and DALY rates. The absolute number of incident strokes globally increased by 70·0% (67·0–73·0) from 1990 to 2019, whereas prevalent strokes increased by 85·0% (83·0–88·0), deaths from stroke increased by 43·0% (31·0–55·0), and DALYs due to stroke increased by 32·0% (22·0–42·0; table 1, appendix figure S3). Although absolute numbers increased over the study period, age-standardised rates all decreased between 1990 and 2019: by 17·0% (15·0–18·0) for incidence; by 6·0% (5·0–7·0) for prevalence; by 36·0% (31·0–42·0) for mortality; and by 36·0% (31·0–42·0) for DALYs (table 1). However, among those younger than 70 years, age-specific stroke prevalence and incidence rates increased substantially over the study period (22·0% [21·0–24·0] increase in prevalence and 15·0% [12·0–18·0] increase in incidence; incidence data are shown in appendix figure 7, prevalence data are available on the Global Health Data Exchange). Although the absolute number of DALYs due to stroke in males (76·9 million [95% UI 70·2–83·5]) exceeded that in females (66·4 million [60·5–72·3]) at the global level in 2019, the point estimates of incident and prevalent strokes were higher in females (64·4 million [58·1–71·7] incident strokes and 56·4 million [52·0–61·5] prevalent strokes) than in males (57·9 million [52·4–64·5] incident strokes and 45·0 million [41·1–49·3] prevalent strokes, 143 million (133–153) DALYs due to stroke, and 6·55 million (6·00–7·02) deaths from stroke (table 1).

<table>
<thead>
<tr>
<th>Incidence (95% UI)</th>
<th>Deaths (95% UI)</th>
<th>Prevalence (95% UI)</th>
<th>DALYs (95% UI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Incidence</strong></td>
<td><strong>Deaths</strong></td>
<td><strong>Prevalence</strong></td>
<td><strong>DALYs</strong></td>
</tr>
<tr>
<td><strong>2019</strong></td>
<td><strong>2019</strong></td>
<td><strong>2019</strong></td>
<td><strong>2019</strong></td>
</tr>
<tr>
<td><strong>Percentage</strong></td>
<td><strong>Percentage</strong></td>
<td><strong>Percentage</strong></td>
<td><strong>Percentage</strong></td>
</tr>
<tr>
<td><strong>Ischaemic stroke</strong></td>
<td><strong>Ischaemic stroke</strong></td>
<td><strong>Ischaemic stroke</strong></td>
<td><strong>Ischaemic stroke</strong></td>
</tr>
<tr>
<td>Absolute number, millions</td>
<td>7·63</td>
<td>88·0% (6·57 to 8·96)</td>
<td>3·29</td>
</tr>
<tr>
<td>Age-standardised rate, per 100 000 people</td>
<td>94·51</td>
<td>10·0% (81·9 to 110·76)</td>
<td>43·50</td>
</tr>
<tr>
<td><strong>Intracerebral haemorrhage</strong></td>
<td><strong>Intracerebral haemorrhage</strong></td>
<td><strong>Intracerebral haemorrhage</strong></td>
<td><strong>Intracerebral haemorrhage</strong></td>
</tr>
<tr>
<td>Absolute number, millions</td>
<td>3·41</td>
<td>43·0% (2·97 to 3·91)</td>
<td>2·89</td>
</tr>
<tr>
<td>Age-standardised rate, per 100 000 people</td>
<td>41·81</td>
<td>29·0% (36·52 to 47·88)</td>
<td>36·04</td>
</tr>
<tr>
<td><strong>Subarachnoid haemorrhage</strong></td>
<td><strong>Subarachnoid haemorrhage</strong></td>
<td><strong>Subarachnoid haemorrhage</strong></td>
<td><strong>Subarachnoid haemorrhage</strong></td>
</tr>
<tr>
<td>Absolute number, millions</td>
<td>1·18</td>
<td>61·0% (1·01 to 1·39)</td>
<td>0·37</td>
</tr>
<tr>
<td>Age-standardised rate, per 100 000 people</td>
<td>14·46</td>
<td>17·0% (12·33 to 16·94)</td>
<td>4·66</td>
</tr>
<tr>
<td><strong>Total stroke</strong></td>
<td><strong>Total stroke</strong></td>
<td><strong>Total stroke</strong></td>
<td><strong>Total stroke</strong></td>
</tr>
<tr>
<td>Absolute number, millions</td>
<td>12·22</td>
<td>70·0% (11·04 to 13·59)</td>
<td>6·55</td>
</tr>
<tr>
<td>Age-standardised rate, per 100 000 people</td>
<td>150·8</td>
<td>17·0% (135·65 to 167·5)</td>
<td>84·2</td>
</tr>
</tbody>
</table>

Table 1: Absolute number and age-standardised rates per 100 000 people are presented to two decimal places and percentage change is shown to one decimal place. UI=uncertainty interval. DALY=disability-adjusted life-year.
A All strokes

Incidence rates per 100 000 people

- <64·0
- 64·0 to <85·5
- 85·5 to <100·5
- 100·5 to <124·3
- 124·3 to <141·7
- ≥141·7

Caribbean and central America
Persian Gulf
Balkan Peninsula
Southeast Asia
Northern Europe

B Ischaemic strokes

Incidence rates per 100 000 people

- <41·3
- 41·3 to <50·9
- 50·9 to <60·1
- 60·1 to <70·5
- 70·5 to <81·7
- ≥81·7

Caribbean and central America
Persian Gulf
Balkan Peninsula
Southeast Asia
Northern Europe

(Figure 1 continues on next page)
Figure 1: Age-standardised stroke incidence rates per 100 000 people by stroke type and country, for both sexes, 2019 (A) All strokes. (B) Ischaemic stroke. (C) Intracerebral haemorrhage. (D) Subarachnoid haemorrhage.
strokes), and there were no noticeable sex differences in the number of stroke-related deaths (appendix table S2). Although age-standardised incidence rates did not differ significantly between males and females, age-standardised death rates were greater in males than in females (96.4 [87.6–104.2] per 100 000 vs 73.5 [65.2–80.7] per 100 000) as were DALY rates (204.3 [185.2–219.5] per 100 000 vs 153.1 [139.7–166.7] per 100 000; see appendix section 4.1 for details of age-specific trends by country).

**Burden of pathological types of stroke**

Ischaemic stroke constituted 62.4% of all new strokes in 2019 (7.63 million [95% UI 6.57–8.96] strokes), intracerebral haemorrhage constituted 27.9% (3.41 million [2.97–3.91]), and subarachnoid haemorrhage constituted 9.7% (1.18 million [1.01–1.39]; table 1). Intracerebral haemorrhage and subarachnoid haemorrhage showed larger reductions in age-standardised rates from 1990 to 2019 than ischaemic stroke (table 1; appendix section 4.2, tables S3–5, and figure S8). There were substantial between-country variations in the age-standardised incidence (figures 1B–D), prevalence, mortality, and DALY rates (appendix figures S8–11) of these three pathological types of stroke by GBD regions, country income level, and sex (appendix section 4.2), with an almost two-fold greater proportion of intracerebral haemorrhage in World Bank low-income to upper-middle-income countries compared with high-income countries (29.5% [28.4–30.3] vs 15.8% [15.5–16.2]), but a lower proportion of subarachnoid haemorrhage in low-income to upper-middle-income countries compared with high-income countries (7.9% [7.5–8.3] vs 19.7% [18.4–21.0]).

**Stroke-related DALYs attributable to risk factors**

GBD stroke estimates for 1990–2019 are available to download from the GBD Results Tool. In 2019, 87.0% (95% UI 84.2–89.8) of total stroke DALYs were attributable to the 19 risk factors modelled in GBD 2019. The PAF of DALYs attributable to all risk factors combined was similar for ischaemic stroke (85.7% [81.2–90.3]), intracerebral haemorrhage (88.7% [85.2–91.0]), and subarachnoid haemorrhage (84.6% [81.3–87.6]; appendix section 4.3 and tables S6–8). From 1990 to 2019, the total number of stroke-related DALYs due to risk factors increased from 91.5 million (85.8–98.3) to 125 million (115–134), with a decrease in the high-income group (from 16.4 million [15.4–17.4] in 1990 to 13.1 million [11.8–14.4] in 2019) and an increase in the low-income to upper-middle-income groups (from 75.1 million [68.5–82.3] DALYs in all three income groups combined in 1990 to 111 million [100.3–122.5] DALYs in 2019). From 1990 to 2019, the largest increase in the age-standardised stroke PAF globally was for high BMI, increasing from 15.4% (8.2–24.2) to 24.3% (15.7–33.2), a 57.8% increase. In other words, if high BMI exposure were reduced to its TMREL, there would be a 24.3% reduction in stroke in 2019, compared to just a 15.4% reduction in 1990. Other risk factors with an increasing age-standardised stroke PAF from 1990 to 2019 included high systolic blood pressure (from 1.5% [1.2–1.9] to 3.2% [2.8–3.6]), a 113.3% increase.
pressure (from 52.0% [44.6–58.6] to 55.5% [48.2–62.0], a 6.7% increase) and high fasting plasma glucose (from 14.4% [9.9–20.8] to 20.2% [13.8–29.1], a 40.3% increase). By contrast, from 1990 to 2019, the stroke PAF of ambient particulate matter with a diameter of <2.5 μm (known as PM<sub>2.5</sub>) pollution decreased from 32.5% [29.6–35.6] to 20.1% (16.6–23.0); a 38.2% decrease, and that of dietary risks decreased from 32.6% [24.7–41.5] to 30.6% (22.6–39.8; a 6.1% decrease).

In 2019, there were moderate between-country (1–3 times), regional (as measured by 21 GBD regions), and country economic development level (as measured by the World Bank income groups) variations in the proportion of stroke-related DALYs and its DALYs related to stroke pathological types that were attributable to risk factors. Between-country variations were more pronounced for subarachnoid haemorrhage (figure 3; appendix tables S6–12 and figures S12–14), and the highest

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### Environmental risks

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>World Bank high-income countries</th>
<th>World Bank upper-middle-income countries</th>
<th>World Bank lower-middle-income countries</th>
<th>World Bank low-income countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient PM&lt;sub&gt;2.5&lt;/sub&gt; pollution</td>
<td>28 (27.4–33.3)</td>
<td>16 (12.7–21.8)</td>
<td>13 (9.3–18.3)</td>
<td>10 (6.5–16.8)</td>
</tr>
<tr>
<td>Household air pollution from solid fuels</td>
<td>11 (10–12)</td>
<td>9 (0.01–0.07)</td>
<td>6 (0.26–4.6)</td>
<td>5 (0.25–2.9)</td>
</tr>
<tr>
<td>Low ambient temperature</td>
<td>8.3 (6.9–9.9)</td>
<td>6 (0.01–0.06)</td>
<td>4 (0.01–0.04)</td>
<td>3 (0.00–0.03)</td>
</tr>
<tr>
<td>High ambient temperature</td>
<td>0.9 (0.3–2.8)</td>
<td>1 (0.01–0.06)</td>
<td>1 (0.01–0.04)</td>
<td>1 (0.00–0.05)</td>
</tr>
<tr>
<td>Lead exposure</td>
<td>6.7 (4.7–9.8)</td>
<td>5.4 (0.25–4.2)</td>
<td>4 (0.8–3.4)</td>
<td>3 (0.2–0.5)</td>
</tr>
</tbody>
</table>

### Dietary risks

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Low physical activity</th>
<th>Tobacco smoking</th>
<th>Physiological factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diet high in sodium</td>
<td>17 (7.5–34.9)</td>
<td>12 (4.1–24.3)</td>
<td>1.7 (0.3–4.5)</td>
</tr>
<tr>
<td>Diet high in red meat</td>
<td>10 (5.7–13.5)</td>
<td>7 (4.5–9.3)</td>
<td>1.45 (0.98–1.85)</td>
</tr>
<tr>
<td>Diet low in fruits</td>
<td>10 (5.7–13.5)</td>
<td>7 (4.5–9.3)</td>
<td>0.81 (0.41–1.30)</td>
</tr>
<tr>
<td>Diet low in vegetables</td>
<td>4.1 (5.5–24.3)</td>
<td>2.9 (0.3–4.1)</td>
<td>0.40 (0.01–0.04)</td>
</tr>
<tr>
<td>Diet low in whole grains</td>
<td>3.2 (1.2–6.4)</td>
<td>2.2 (1.3–5.0)</td>
<td>0.31 (0.02–0.03)</td>
</tr>
<tr>
<td>Alcohol consumption</td>
<td>8.5 (4.3–7.6)</td>
<td>6.0 (0.6–3.4)</td>
<td>1.00 (0.06–4.3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical activity</th>
<th>Percentage</th>
<th>Percentage</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low physical activity</td>
<td>2.4 (0.1–0.0)</td>
<td>1.7 (0.3–4.5)</td>
<td>0.26 (0.01–0.04)</td>
</tr>
<tr>
<td>Tobacco smoking</td>
<td>20 (16.4–21.9)</td>
<td>2.4 (2.4–2.9)</td>
<td>0.00 (0.00–0.02)</td>
</tr>
<tr>
<td>Physiological factors</td>
<td>3.2 (1.2–5.1)</td>
<td>0.31 (0.02–0.03)</td>
<td>0.15 (0.00–0.01)</td>
</tr>
</tbody>
</table>

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(Table 2 continues on the next page)
proportion of stroke-related DALYs was observed in the 
World Bank low-income to upper-middle-income groups 
(ranging from 85·9% [95% UI 83·2–88·6] in the World 
Bank low-income group to 87·3% [84·4–89·9] in the 
World Bank upper-middle-income group). From 1990 to 2019, 
there was an increase in the total number of stroke-related 
DALYs due to high BMI, high fasting plasma glucose, high 
LDL cholesterol, kidney dysfunction, a diet high in red 
meat, alcohol consumption, and second-hand smoking, 
but a decrease in DALYs due to smoking and a diet low in 
fruits and vegetables (appendix figure S15). There were 
also moderate variations in the ranking of risk factors by 
pathological types of stroke (figure 4; appendix figures 
S16–S18). In 2019, the five leading specific risk factors 
contributing to stroke death and disability combined 
(DALYs) were high systolic blood pressure (79·6 million 
[67·7–90·8] attributable DALYs; 55·5% [48·2–62·0] of all 
stroke DALYs), high BMI (34·9 million [22·3–48·6]; 
24·3% [15·7–33·2]), high fasting plasma glucose (28·9 
million [19·8–41·5]; 20·2% [13·8–29·1]), ambient 
particulate matter pollution (28·7 million [23·4–33·4; 
20·1% [16·6–23·0]), and smoking (25·3 million 
[22·6–28·2]; 17·6% [4·6–19·0]; table 2, figure 5). For risk 
factors by pathological type of stroke and changes in risk 
factor rankings from 1990 to 2019 by GBD regions, see the 
appendix (section 4.3 and figures S19–26).

### Discussion

In 2019, stroke remained the second-leading Level 3 
cause of death and the third-leading Level 3 cause of 
death and disability combined in the world, and its 
burden (in terms of the absolute number of cases) 
increased substantially from 1990 to 2019. Our findings 
indicate that the bulk of the global stroke burden (86·0% 
[95% UI 85·9–86·9] of deaths and 89·0% [88·9–89·3] of 
DALYs) is in lower-income and middle-income 
countries. Globally, over the past three decades, the total 
number of stroke-related DALYs due to risk factors 
increased substantially (by 33·5 million, from 91·5 million 
in 1990 to 125 million in 2019), with diverging trends in 
World Bank high-income countries and low-income to 
upper-middle-income countries: a relatively small decrease 
in the high-income group and large increases in the 
low-income to upper-middle-income groups. The large 
increase in the global burden of stroke was probably not 
only due to population growth and ageing but also because 
of the substantial increase in exposure to several important 
risk factors such as high BMI, ambient particulate matter 
pollution, high fasting plasma glucose, high systolic blood 
pressure, alcohol consumption, low physical activity, 
kidney dysfunction, and high temperature (appendix 
figure S26). This study is also the first systematic analysis 
to determine the effect of non-optimal temperature on

<table>
<thead>
<tr>
<th>Cluster of risk factors</th>
<th>Globally</th>
<th>World Bank high-income countries</th>
<th>World Bank upper-middle-income countries</th>
<th>World Bank lower-middle-income countries</th>
<th>World Bank low-income countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute number (millions)</td>
<td>Percentage</td>
<td>Absolute number (millions)</td>
<td>Percentage</td>
<td>Absolute number (millions)</td>
<td>Percentage</td>
</tr>
<tr>
<td>Combined risk factors</td>
<td>125·00</td>
<td>87·0%</td>
<td>(115·00–134·00)</td>
<td>84·2–89·8</td>
<td>13·10</td>
</tr>
</tbody>
</table>

Data in parentheses are 95% uncertainty intervals. Count data in millions are presented to two decimal places and percentage data are presented to one decimal place. Percentages and number of DALYs are not mutually exclusive: the sum of percentages and number of DALYs in the columns exceeds the totals for all risk factors combined because of overlap between various risk factors. The crude sum of population attributable fraction (PAF) of the risk factors might exceed 100% because the effects of many of these risk factors are mediated partly or wholly through another risk factor or risk factors. DALY=disability-adjusted life-year. PM₂·₅=particulate matter with a diameter of <2·5 μm. *Air pollution cluster includes ambient PM₂·₅ pollution and household air pollution from solid fuels. †Tobacco smoke cluster includes smoking (including second-hand smoking), dietary risks (diet high in sodium, diet low in fruits, diet low in vegetables, diet high in red meat, diet low in whole grains, and alcohol consumption), and low physical activity. ‡Dietary risks cluster includes diet high in sodium, diet low in fruits, diet low in vegetables, diet high in red meat, diet low in whole grains, and alcohol consumption. §Environmental risks cluster includes air pollution cluster, low ambient temperature, high ambient temperature, and lead exposure. ¶Occupational risks cluster includes occupational risks. ||Metabolic risks cluster includes hypercholesterolaemia, hypertension, obesity, and diabetes. |
A  All stroke

DALYs per 100 000 people

<table>
<thead>
<tr>
<th>Category</th>
<th>DALYs per 100 000 people</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;448.7</td>
<td>1221.1 to &lt;1587.4</td>
</tr>
<tr>
<td>448.7 to &lt;536.1</td>
<td>1587.4 to &lt;1915.6</td>
</tr>
<tr>
<td>536.1 to &lt;642.1</td>
<td>1915.6 to &lt;2221.4</td>
</tr>
<tr>
<td>642.1 to &lt;964.0</td>
<td>2221.4 to &lt;2710.4</td>
</tr>
<tr>
<td>964.0 to &lt;1221.1</td>
<td>≥2710.4</td>
</tr>
</tbody>
</table>

B  Ischaemic stroke

DALYs per 100 000 people

<table>
<thead>
<tr>
<th>Category</th>
<th>DALYs per 100 000 people</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;231.9</td>
<td>533.4 to &lt;637.0</td>
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<tr>
<td>231.9 to &lt;266.1</td>
<td>617.0 to &lt;734.9</td>
</tr>
<tr>
<td>266.1 to &lt;315.1</td>
<td>734.9 to &lt;926.1</td>
</tr>
<tr>
<td>315.1 to &lt;433.4</td>
<td>926.1 to &lt;1390.0</td>
</tr>
<tr>
<td>433.4 to &lt;533.4</td>
<td>≥1390.0</td>
</tr>
</tbody>
</table>

(Figure 3 continues on next page)
Figure 3: Age-standardised stroke-related DALYs attributable to all risk factors combined, for both sexes, 2019
(A) All strokes. (B) Ischaemic stroke. (C) Intracerebral haemorrhage. (D) Subarachnoid haemorrhage. DALY = disability-adjusted life-year.
stroke burden. The greater age-standardised burden of stroke in World Bank low-income to upper-middle-income countries than in the high-income countries might also relate to poorer acute health care for stroke,9 poorer stroke awareness,28 and greater prevalence or effect of some risk factors (eg, tobacco use, poor diet, diabetes, hypertension, cardiovascular disease, rheumatic heart disease, dyslipidaemia, and obesity) in low-income countries than in upper-middle-income countries,28 which highlights the inadequacy of primary prevention efforts in these settings.

For the first time, we have presented the global, regional, and national burden of stroke and its risk factors by its major pathological types. Although ischaemic
stroke continues to constitute the largest proportion of all new strokes (comprising 62.4% of all incident strokes in 2019), followed by intracerebral haemorrhage (27.9%), and subarachnoid haemorrhage (9.7%), the relative proportions of each pathological type varied substantially by income group. For example, a new stroke case was nearly twice as likely to be intracerebral haemorrhage in the World Bank low-income to upper-middle-income groups combined (19.7% vs 7.9%). The increased risk of intracerebral haemorrhage in low-income and upper-middle-income countries might be related to the high relative clinical significance and population-attributable risk of hypertension in these countries.29 Our finding that a greater proportion of incident strokes in low-income to upper-middle-income countries are intracerebral haemorrhages in males than in females (appendix figure F6.9) are in line with previous observations,20,30 and might be explained by lower levels of awareness and control of hypertension in low-income

<table>
<thead>
<tr>
<th>C Intracerebral haemorrhage</th>
<th>D Subarachnoid haemorrhage</th>
</tr>
</thead>
<tbody>
<tr>
<td>High systolic blood pressure</td>
<td>High systolic blood pressure</td>
</tr>
<tr>
<td>High body-mass index</td>
<td>High body-mass index</td>
</tr>
<tr>
<td>Ambient particulate matter pollution</td>
<td>Ambient particulate matter pollution</td>
</tr>
<tr>
<td>High fasting plasma glucose</td>
<td>High fasting plasma glucose</td>
</tr>
<tr>
<td>Smoking</td>
<td>Smoking</td>
</tr>
<tr>
<td>Diet high in sodium</td>
<td>Diet high in sodium</td>
</tr>
<tr>
<td>Household air pollution from solid fuels</td>
<td>Household air pollution from solid fuels</td>
</tr>
<tr>
<td>Alcohol use</td>
<td>Alcohol use</td>
</tr>
<tr>
<td>Diet low in fruits</td>
<td>Diet low in fruits</td>
</tr>
<tr>
<td>Kidney dysfunction</td>
<td>Kidney dysfunction</td>
</tr>
<tr>
<td>Diet high in red meat</td>
<td>Diet high in red meat</td>
</tr>
<tr>
<td>Low temperature</td>
<td>Low temperature</td>
</tr>
<tr>
<td>Lead exposure</td>
<td>Lead exposure</td>
</tr>
<tr>
<td>Second-hand smoke</td>
<td>Second-hand smoke</td>
</tr>
<tr>
<td>Diet low in vegetables</td>
<td>Diet low in vegetables</td>
</tr>
<tr>
<td>High temperature</td>
<td>High temperature</td>
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</tbody>
</table>

Figure 4: Age-standardised stroke-related DALYs attributable to risk factors by 21 GBD regions, for both sexes, 2019

(A) All strokes. (B) Ischaemic stroke. (C) Intracerebral haemorrhage. (D) Subarachnoid haemorrhage. Numbers show the ranking level (1=highest, 15=lowest) by the number of DALYs attributable to the corresponding risk factors. Red shows 1st ranking; light brown, 2nd and 3rd ranking; very light yellow, 4–7 ranking; very light blue, 8–13 ranking; and dark blue, 14–15 ranking. Diet low in whole grains, low physical activity, and high LDL cholesterol were not assessed for intracerebral haemorrhage. Diet low in whole grains, alcohol use, low physical activity, high LDL cholesterol, and kidney dysfunction were not assessed for subarachnoid haemorrhage. DALY=disability-adjusted life-year. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

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The proportion of DALYs attributable to GBD-modelled risk factors was also particularly high in low-income to upper-middle-income countries. Second, the pace of the global decline in age-standardised stroke incidence, death, and DALY rates was noticeably slower over the past decade (2010–19) than in the previous decade (2000–09), and global age-standardised prevalence significantly increased from 2010 to 2019 (appendix figure 6.8). There was a significant increase in stroke prevalence and incidence rates in people younger than 70 years between 1990 and 2019 with even faster increases from 2010 to 2019 (appendix figure 6.7). A trend towards plateauing or increasing stroke incidence or mortality rates, or both, was recently observed in middle-aged people in the USA, European countries, Brazil, and China. This trend might be a reflection of the increased exposure to some risk factors for stroke, such as elevated blood pressure, high BMI, and high fasting plasma glucose, across most countries. In the USA, a worrisome trend observed in recent years (2017–18) is that awareness of hypertension in the population whose blood pressure is controlled is declining.

Figure 5: Proportion of DALYs attributable to risk factors by pathological type of stroke for both sexes combined, 2019
Proportion of DALYs attributable to household air pollution from solid fuels are not shown in this figure. DALY=disability-adjusted life-year.

Despite the overall declines in age-standardised stroke incidence, prevalence, death, and DALY rates, three concerning trends have emerged. First, the greatest share of the global burden of stroke continues to be borne by low-income to upper-middle-income countries.
population growth and ageing, resulting in overall increases in the number of incident, prevalent, fatal, and disabling strokes over time. A linear interpolation shows that if current trends continue, by 2050 there will be more than 200 million stroke survivors and almost 300 million DALYs, 25 million new strokes, and 13 million deaths from stroke annually.

This study was, to our knowledge, the first systematic analysis to provide estimates of the burden of stroke and its subtypes associated with non-optimal temperature (daily temperatures below or above the TMREL). Although previous studies have made ecological observations of the effects of ambient temperature on the risk of stroke, this study was the first to show the sizeable global effect of non-optimal temperature (primarily low temperature, at 8·36 million [95% UI 6·19–10·80] DALYs or a PAF of 5·8% [4·4–7·5]) on the burden of stroke and its pathological types (appendix tables T10b, T11b, and T12b). These findings were in line with a recent systematic review on ambient temperature and stroke occurrence. Our estimates of geographical variations in the burden of stroke and its pathological types associated with non-optimal temperature and other risk factors suggest that country-specific and stroke type-specific priorities and strategies should be developed and implemented for reducing the burden of stroke in different geographical locations.

Our findings of the high proportion (87·0%) of age-standardised stroke-related DALYs associated with GBD risk factors are in line with previous observations and highlight the potential to greatly reduce the stroke burden by addressing risk factor exposure. The increased contribution of certain metabolic risk factors in 2019 compared with 1990 (eg, an increase in the proportional contribution to stroke-related DALYs of 57·8% by high BMI and 40·3% by high fasting plasma glucose) and a decreasing contribution of certain environmental and occupational and behavioural risk factors to the stroke-related DALY burden over the same period (eg, a 38·2% decrease for household air pollution from solid fuels and a 6·1% decrease for a diet low in vegetables) might be related to a growing proportion of the global population reaching the final stages of the epidemiological transition, in which the risk burden has shifted towards metabolic risk factors and an increased proportion of the disease burden comes from stroke and other non-communicable diseases. This observation also means that guidance on reducing the risk of stroke by targeting certain risk factors will need to change to reflect changes in the risk-attributable profile.

Our estimates of the global, regional, and national burden of stroke and its pathological types and risk factors are important for evidence-based health-care planning, priority setting, and resource allocation for stroke care, primary prevention, and research. The high and increasing stroke burden alongside stagnant or even increasing mortality rates from cardiovascular disease in some countries, and increasing rates of exposure to many important stroke risk factors from 1990 to 2019, suggest that current primary stroke prevention strategies and measures are not sufficient, and that efforts to implement population-wide primary prevention strategies more widely must be reinforced worldwide. For every US$1 spent on prevention of stroke and cardiovascular disease, there is an estimated $10·9 return on investment. Population-wide interventions for primary prevention of stroke and cardiovascular disease should include measures to reduce exposure to metabolic risk factors (eg, screening for and proper management of systolic blood pressure and weight), behavioural risk factors (eg, smoking cessation programmes and programmes to increase the accessibility and affordability of nutrient-rich foods), and environmental and occupational risk factors (eg, measures to reduce air pollution and lead exposure). The development and implementation of such population-level interventions, alongside efforts to reduce poverty and racial and socioeconomic inequities, through legislation, taxation, and other measures at the government level, must be the mainstream approach for reducing the risk of stroke, cardiovascular disease, and other non-communicable diseases, but the importance of primary prevention measures at the individual level should not be overlooked. In this respect, the emphasis should be on strategies that are appropriate for most people at risk of stroke and cardiovascular disease regardless of their level of risk exposure, such as digital technologies for affordable identification of people at increased risk of stroke and cardiovascular disease, universal health coverage, cheap and effective multidrug regimens (eg, polypills) for people at increased risk of cardiovascular disease, and involvement of health-care volunteers in primary prevention activities. For example, the World Stroke Organization recommends that all adults know their individual risk of having a stroke, their personal risk factors for stroke, and how to control these risk factors using the validated, internationally endorsed, and free Stroke Riskometer app, which is currently available in 19 languages for more than 70% of the global population. A recent Cochrane systematic review showed the feasibility and potential effectiveness of several health promotion interventions targeting risk factors to achieve behavioural changes for primary prevention of cardiovascular disease in low-income to upper-middle-income countries. Although knowledge of personal risk and management of behavioural risk factor activities is primarily the prerogative of individuals, health professionals have a responsibility to identify risk factors that require pharmacological and non-pharmacological treatment to reduce the chance of stroke occurrence (eg, elevated blood pressure, atrial fibrillation, diabetes, dyslipidaemia, or symptomatic carotid artery stenosis). Simple, inexpensive screening for cardiovascular disease risks (eg, elevated blood pressure, atrial fibrillation, diabetes, dyslipidaemia, or symptomatic carotid artery stenosis).
pressure, smoking, and overweight) by health professionals in low-income and middle-income settings or more accurate screening for high cardiovascular disease risks (including blood lipid tests) by health professionals in higher-income locations can help to identify people who might require prophylactic drug therapy, in conjunction with behavioural interventions.46 However, health professionals often do not have enough time to conduct detailed assessments of behavioural risk factors or to develop individually tailored recommendations for primary prevention of stroke and cardiovascular disease. To ameliorate this problem, data on stroke risk and risk factors from individuals should be integrated with the electronic patient management systems of health service providers. A study in Finland suggests that the quality of stroke prevention by primary health-care professionals could be improved by developing digital clinical decision-making tools and by implementing inter-professional teamwork47 (eg, the PreventS web app currently being developed in New Zealand). All of these measures should be facilitated by ongoing, culturally appropriate health education campaigns (including coordinated activities of non-governmental organisations) and inclusion of such health education information into standardised educational curricula at all levels.

In addition to primary stroke prevention efforts, appropriate secondary prevention efforts and adequate acute treatment and rehabilitation are essential to improve stroke outcomes. Our findings of large geographical variations in stroke prevalence, mortality, and disability are a reflection not only of geographical differences in stroke incidence but also of major inequities in acute stroke care and rehabilitation across countries.48 Even in European countries, only 7–3% of all patients with acute ischaemic stroke receive intravenous thrombolysis, and only 1–9% receive endovascular treatment, with the highest country-level rates being 20–6% for intravenous thrombolysis (in the Netherlands) and 5–6% for endovascular treatment (in Malta),49 and one in three patients discontinues using one or more secondary stroke prevention drugs about 1 year after stroke.50 Treatment rates are even lower in many low-income and middle-income countries.51 To reduce inequalities in stroke care, a roadmap for delivering quality stroke care and various action plans46,47 have been suggested, with emphasis on the importance of applying culturally appropriate and context-appropriate strategies. There is a pressing need to implement evidence-based guidelines for stroke management and to reduce the gap in stroke care between high-income countries and low-income and middle-income countries. Recent evidence suggests that delivering an adequate level of stroke care52 and preventive interventions53 in low-income and middle-income countries are feasible. Attention should be paid to developing the workforce for stroke care and setting up affordable and accessible rehabilitation facilities. Promising results54 suggest that self-management could be used as an adjunct strategy for ongoing rehabilitation at home or in other settings. The importance of country-based ongoing stroke registries and stroke risk factors surveys, which are profoundly lacking in low-income and middle-income countries, should also be emphasised.

Although this study was, to our knowledge, the first and most comprehensive review of the global, regional, and national burden of stroke and its 19 specific risk factors by all three pathological types, it was not free from limitations common to all previous GBD estimates of stroke risk and risk factors,2,3,11,36 particularly the absence of original, good-quality stroke epidemiological studies for most countries. We therefore were not able to include some important potential risk factors (eg, atrial fibrillation and substance abuse), or include different patterns in risk factor exposure (eg, different doses and types of alcohol consumption, pack-years of smoking) and doses of exposure, analyse stroke burden by ischaemic stroke subtypes, or do a decomposition analysis to attribute changes in stroke burden to changes in the population growth, ageing, and risk factors separately. Additionally, evidence for the selection of TMRELs for some risk factors was uncertain and based on non-experimental studies, although all TMRELs were discussed and approved by a team of risk epidemiologists and stroke experts. Despite these limitations, our results are broadly consistent with previous estimates from population-based and analytical epidemiological studies, thus supporting the validity of our results.

In summary, although strokes are largely preventable, as indicated by declining incidence rates globally, stroke remained the second-leading cause of death and third-leading cause of death and disability combined worldwide in 2019. Without wider implementation of population-wide primary stroke and cardiovascular disease prevention strategies, the burden of stroke is likely to continue growing, disproportionally affecting low-income and middle-income countries. As the 19 analysed risk factors for stroke are common for other major non-communicable diseases, appropriate control of these risk factors will also reduce the burden of coronary heart disease, vascular dementia, type 2 diabetes, and even some types of cancer. Further research on the frequency, outcomes, and determinants of stroke and its pathological types in different locations and over time is warranted. Such research could include identifying populations at highest risk as well as further investigating differences in stroke pathological types and their geographical patterns, all of which would be useful for more targeted prevention and treatment efforts. Closing the gaps between high-income countries and low-income and middle-income countries in the adaptation and implementation of internationally recognised guidelines and recommendations for reducing stroke morbidity and mortality, with an emphasis on primary prevention strategies, is crucial to addressing the global stroke burden.
Contributors
Please see the appendix (pp 7–30) for more detailed information about individual author contributions to the research, divided into the following categories: managing the estimation or publication process; writing the first draft of the manuscript; primary responsibility for seeking, cataloguing, extracting, or cleaning data; designing or coding figures and tables; providing data or critical feedback on data sources; development of methods or computational machinery; providing critical feedback on methods or results; drafting the manuscript or revising it critically for important intellectual content; extracting, cleaning, or cataloguing data; designing or coding figures and tables; and managing the overall research enterprise. V L Feigin and G A R Roth had primary responsibility for seeking, cataloguing, extracting, or cleaning data; designing or coding figures and tables; providing data or critical feedback on data sources; development of methods or computational machinery; providing critical feedback on methods or results; drafting the manuscript or revising it critically for important intellectual content; extracting, cleaning, or cataloguing data; designing or coding figures and tables; and managing the overall research enterprise. V L Feigin had final responsibility for the decision to submit for publication.

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Declaration of interests

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Data sharing

All data presented in the manuscript can be found on the Institute for Health Metrics and Evaluation GBD Compare and Viz Hub website at https://vizhub.healthdata.org/gbd-compare/.

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