

# Global, regional, and national burden of stroke and its risk factors, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019



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 (28.9 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

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\*Collaborators are listed at the end of the Article

Correspondence to:  
Prof Valery L Feigin, National Institute for Stroke and Applied Neurosciences, Faculty of Health and Environmental Sciences, Auckland University of Technology, Northcote, Auckland 0627, New Zealand  
[valery.feigin@aut.ac.nz](mailto:valery.feigin@aut.ac.nz)

### 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 minimal, the burden of stroke was likely to remain high well into the future.

#### Added value of this study

As part of GBD 2019, this study provides updated estimates of the burden of overall stroke, ischaemic stroke, intracerebral haemorrhage, and subarachnoid haemorrhage for 204 countries and territories in 21 GBD regions from 1990 to 2019, by age, sex, and country income level (by the World

Bank classification). Stroke burden was measured by incidence, prevalence, mortality, and DALYs as well as the PAF of stroke-related DALYs associated with potentially modifiable behavioural, environmental and occupational, and metabolic risk factors or risk factor clusters. Until GBD 2017, intracerebral haemorrhage and subarachnoid haemorrhage were not estimated separately, so this is the first report by the GBD Collaborator Network to present the global, regional, and national burden of haemorrhagic strokes by intracerebral haemorrhage and subarachnoid haemorrhage separately. This study is also the first systematic analysis to determine the effect of non-optimal temperature on stroke burden.

#### 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 stroke 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.

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.<sup>1,2</sup> A GBD 2017 stroke analysis found that, although age-standardised mortality rates for stroke decreased sharply from 1990 to 2017,<sup>2</sup> 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<sup>3</sup> 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]),<sup>4</sup> which is similar to the findings from GBD 2016<sup>3</sup> and GBD 2017.<sup>5</sup>

In this study, we estimated the global, regional, and national burden of overall stroke, ischaemic stroke, intracerebral haemorrhage, and subarachnoid haemorrhage in terms of their incidence, prevalence, mortality, and DALYs, as well as stroke-related DALYs associated with 19 potentially modifiable behavioural, environmental and occupational, and metabolic risk factors or groups of risk factors. We present data for 204 countries and territories, 21 GBD regions, and four World Bank income level groups from 1990 to 2019, by age group and sex. This manuscript was produced as part of the GBD Collaborator Network and in accordance with the GBD Protocol.

## Methods

### Overview and case definition

Details of the GBD 2019 eligibility criteria, the literature search strategy, and data extraction are described in detail elsewhere<sup>6,7</sup> (appendix sections 1.1–4.3). In brief, stroke was defined by WHO clinical criteria<sup>8</sup> as rapidly developing clinical signs of (usually focal) disturbance of cerebral function lasting more than 24 h or leading to death. Ischaemic stroke was defined as an episode of neurological dysfunction due to focal cerebral, spinal,

See Online for appendix

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 methods for assigning cause of death to stroke and stroke subtypes in regions where neuroimaging was not available have been previously described.<sup>9</sup> 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).<sup>10</sup>

### 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.<sup>3</sup> 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).<sup>7</sup> This work was done within the comparative risk assessments framework of GBD by use of four datasets: the burden estimates for stroke and its three pathological types; the exposure level for each risk factor; the relative risk of stroke as an outcome of exposure to the risk factor; and the theoretical minimum risk exposure level (TMREL), which is the level of exposure that minimises risk for each individual in the population.<sup>11</sup> The relative risks included in this analysis were generated from meta-analyses of epidemiological

studies reporting associations between the risk factors of interest and stroke; these analyses are not stroke-type specific. The PAF (estimated independently for each risk factor) is the proportion of the cause that would be decreased if the exposure to the risk factor in the past had been reduced to the counterfactual level of the TMREL.

Risks included in the analysis were ambient particulate matter pollution; household air pollution from solid fuels; non-optimal temperature—ie, low temperature (daily temperatures below the TMREL) and high temperature (daily temperatures above the TMREL); lead exposure; diet high in sodium; diet high in red meat; diet low in fruits; diet low in vegetables; diet low in whole grains; alcohol consumption (any dosage); low physical activity (only for ischaemic stroke burden); smoking; secondhand smoke; high BMI; high fasting plasma glucose; high systolic blood pressure; high LDL cholesterol (only for ischaemic stroke burden); and kidney dysfunction, as measured by low glomerular filtration rate (GFR; not assessed for subarachnoid haemorrhage burden). As with causes, GBD organises risk factors into four levels, from the broadest (Level 1) to the most specific (Level 4). In addition to the specific risk factors above, we assessed the Level 1 groups of risks: behavioural, environmental and occupational, and metabolic. The PAFs of risk factor groups took into account interactions between risk factors included in the group, as explained elsewhere.<sup>12</sup> Percentages and number of DALYs are not mutually exclusive. The crude sum of the 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. Definitions of risk factors and risk groups and further details of risk factors are provided in the appendix (section 2.1).

### 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).<sup>13</sup> 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

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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

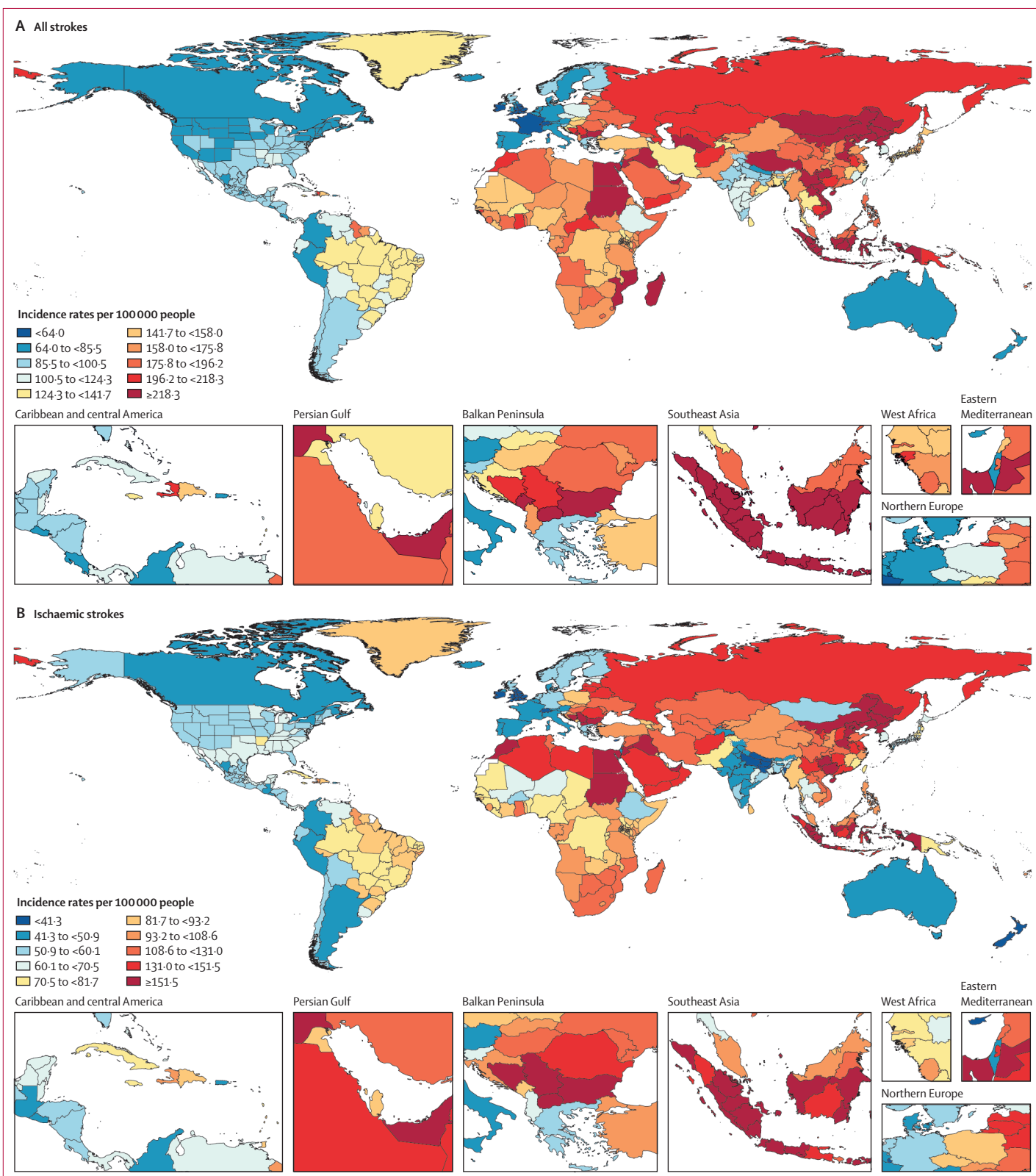
(figure 1A) in age-standardised stroke incidence rates and regional variations (figure 2) in age-standardised incidence, prevalence, mortality, and DALY rates. The absolute number of incident strokes globally increased by 70·0% (67·0–73·0) from 1990 to 2019, whereas prevalent strokes increased by 85·0% (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 (6·44 million [5·81–7·17] incident strokes and 56·4 million [52·0–61·5] prevalent strokes) than in males (5·79 million [5·24–6·45] incident strokes and 45·0 million [41·1–49·3] prevalent

	Incidence (95% UI)		Deaths (95% UI)		Prevalence (95% UI)		DALYs (95% UI)	
	2019	Percentage change, 1990–2019	2019	Percentage change, 1990–2019	2019	Percentage change, 1990–2019	2019	Percentage change, 1990–2019
<b>Ischaemic stroke</b>								
Absolute number, millions	7·63 (6·57 to 8·96)	88·0% (83·0 to 92·0)	3·29 (2·97 to 3·54)	61·0% (46·0 to 75·0)	77·19 (68·86 to 86·46)	95·0% (92·0 to 99·0)	63·48 (57·83 to 68·99)	57·0% (43·0 to 68·0)
Age-standardised rate, per 100 000 people	94·51 (81·9 to 110·76)	-10·0% (-12·0 to -8·0)	43·50 (39·08 to 46·77)	-34·0% (-39·0 to -28·0)	951·0 (849·2 to 1064·1)	-2·0% (-3·0 to 0·0)	798·8 (727·5 to 866·9)	-29·0% (-35·0 to -23·0)
<b>Intracerebral haemorrhage</b>								
Absolute number, millions	3·41 (2·97 to 3·91)	43·0% (41·0 to 45·0)	2·89 (2·64 to 3·10)	37·0% (22·0 to 51·0)	20·66 (18·02 to 23·42)	58·0% (56·0 to 60·0)	68·57 (63·27 to 73·68)	25·0% (12·0 to 36·0)
Age-standardised rate, per 100 000 people	41·81 (36·53 to 47·88)	-29·0% (-30·0 to -28·0)	36·04 (32·98 to 38·67)	-36·0% (-43·0 to -29·0)	248·8 (217·1 to 281·4)	-17·0% (-18·0 to -15·0)	823·8 (769·2 to 894·7)	-37·0% (-43·0 to -31·0)
<b>Subarachnoid haemorrhage</b>								
Absolute number, millions	1·18 (1·01 to 1·39)	61·0% (56·0 to 65·0)	0·37 (0·33 to 0·42)	-12·0% (-25·0 to 26·0)	8·40 (7·19 to 9·83)	65·0% (60·0 to 68·0)	11·18 (9·89 to 12·67)	-14% (-26·0 to 17·0)
Age-standardised rate, per 100 000 people	14·46 (12·33 to 16·94)	-17·0% (-19·0 to -15·0)	4·66 (4·13 to 5·17)	-57·0% (-64·0 to -39·0)	101·6 (87·1 to 118·5)	-37·0% (-43·0 to -31·0)	136·5 (120·8 to 154·7)	-54·0% (-61·0 to -37·0)
<b>Total stroke</b>								
Absolute number, millions	12·22 (11·04 to 13·59)	70·0% (67·0 to 73·0)	6·55 (6·00 to 7·02)	43·0% (31·0 to 55·0)	101·47 (93·21 to 110·53)	85·0% (83·0 to 88·0)	143·23 (133·10 to 153·24)	32·0% (22·0 to 42·0)
Age-standardised rate, per 100 000 people	150·8 (136·5 to 167·5)	-17·0% (-18·0 to -15·0)	84·2 (76·8 to 90·2)	-36·0% (-42·0 to -31·0)	1240·3 (1139·7 to 1353·0)	-6·0% (-7·0 to -5·0)	1768·1 (1640·7 to 1889·4)	-36·0% (-42·0 to -31·0)

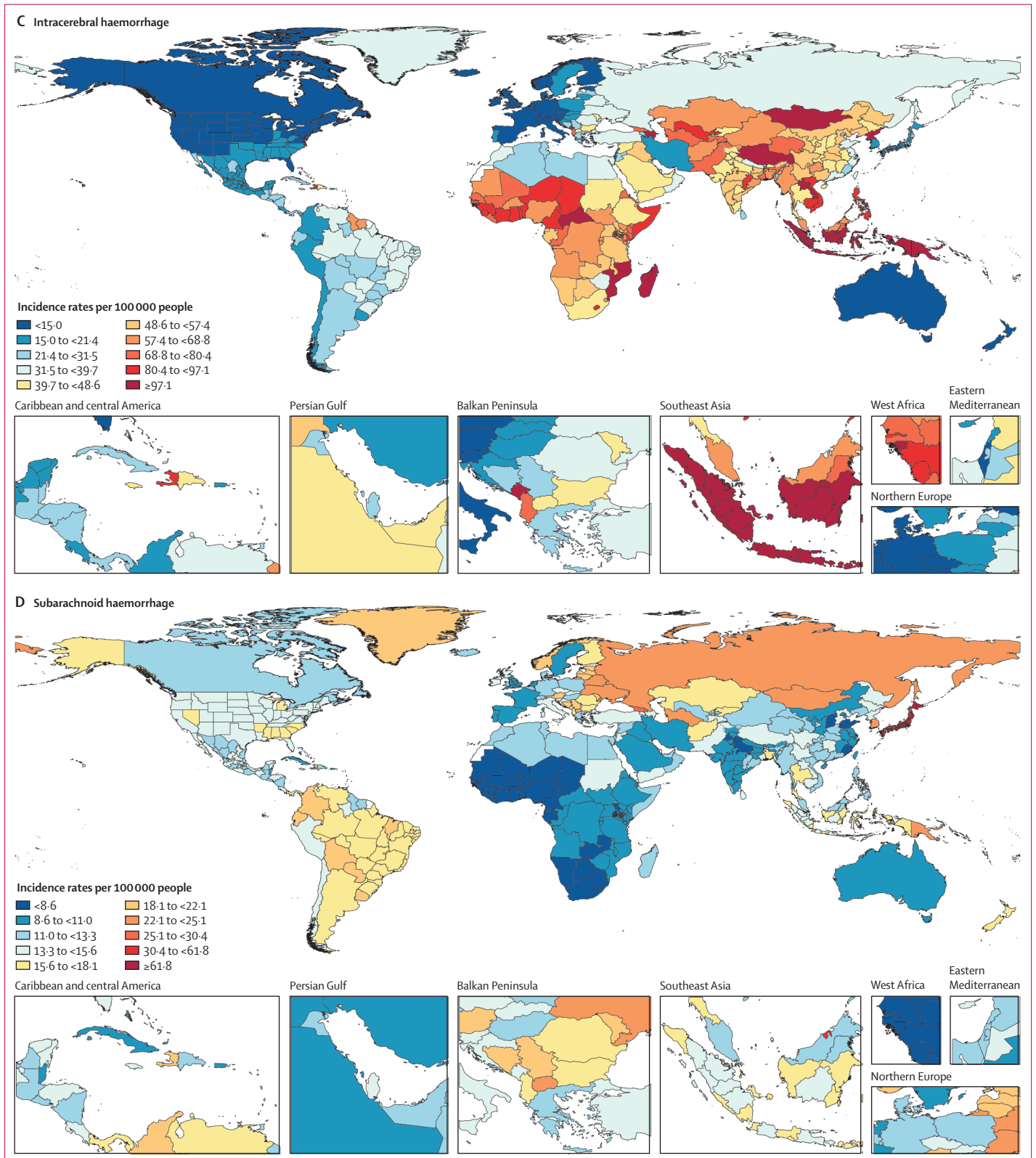
Absolute numbers in millions and age-standardised rates per 100 000 people are presented to two decimal places and percentage change is shown to one decimal place. UI=uncertainty interval. DALY=disability-adjusted life-year.

**Table 1: Absolute number and age-standardised rates per year of incident and prevalent strokes, deaths from stroke and DALYs due to stroke in 2019, and percentage change globally for 1990–2019, by pathological types of stroke**



(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.

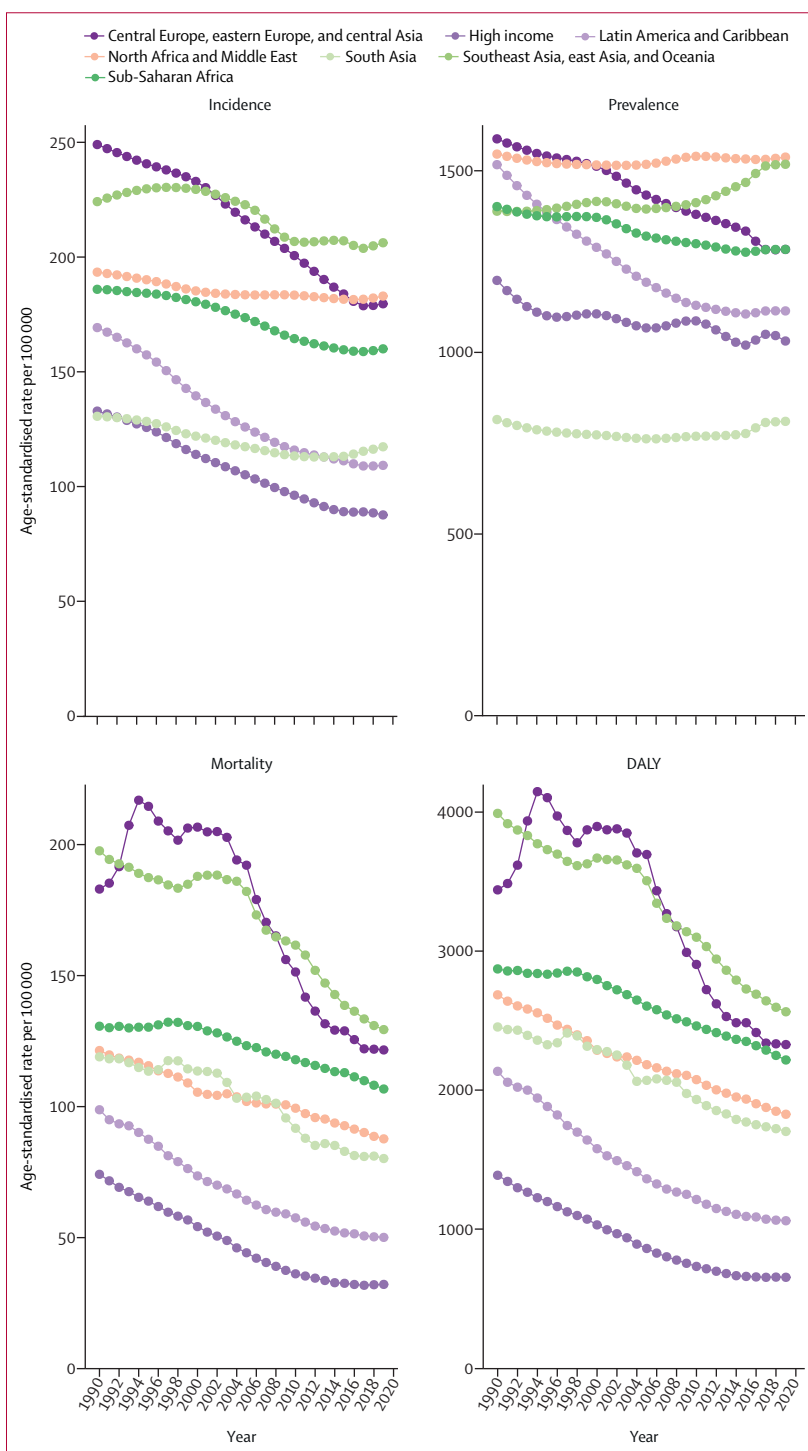
strokes), and there were no noticeable sex differences in the number of stroke-related deaths (appendix table S2). Although age-standardised incidence rates did not differ significantly between males and females, age-standardised death rates were greater in males than in females (96.4 [87.6–104.2] per 100 000 vs 73.5 [65.2–80.7] per 100 000) as were DALY rates (2024.3 [1852.4–2195.6] per 100 000 vs 1531.3 [1397.1–1667.6] 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



**Figure 2:** Age-standardised incidence, prevalence, mortality, and DALY rates (per 100 000 people per year) in seven GBD super regions, 1990–2019, for both sexes and all ages  
DALY=disability-adjusted life-year. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

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

For the GBD Results Tool see  
<http://ghdx.healthdata.org/gbd-results-tool>

	Globally		World Bank high-income countries		World Bank upper-middle-income countries		World Bank lower-middle-income countries		World Bank low-income countries	
	Absolute number (millions)	Percentage	Absolute number (millions)	Percentage	Absolute number (millions)	Percentage	Absolute number (millions)	Percentage	Absolute number (millions)	Percentage
<b>Environmental risks</b>										
Ambient PM <sub>2.5</sub> pollution	28.70 (23.40–33.40)	20.1% (16.6–23.0)	1.57 (1.20–1.95)	9.9% (7.8–12.3)	16.10 (13.20–18.90)	23.9% (20.5–26.7)	10.30 (8.04–12.60)	20.0% (15.7–24.1)	0.75 (0.42–1.16)	8.7% (5.0–13.4)
Household air pollution from solid fuels	14.70 (10.10–20.10)	10.3% (7.1–14.0)	0.03 (0.01–0.07)	0.2% (0.1–0.5)	3.64 (1.86–6.14)	5.4% (2.8–9.0)	8.09 (5.59–10.90)	15.7% (11.0–21.0)	2.96 (2.29–3.69)	34.4% (28.5–40.2)
Low ambient temperature	8.36 (6.19–10.80)	5.8% (4.4–7.5)	1.28 (0.96–1.64)	8.2% (6.1–10.5)	5.47 (4.07–7.29)	8.1% (6.2–10.7)	1.26 (0.45–2.03)	2.4% (0.9–3.9)	0.35 (0.22–0.50)	4.0% (2.6–5.6)
High ambient temperature	1.09 (0.11–2.38)	0.8% (0.1–1.6)	0.03 (0.01–0.06)	0.2% (0.1–0.4)	0.14 (0.00–0.39)	0.2% (0.0–0.6)	0.82 (0.06–1.72)	1.6% (0.1–3.4)	0.10 (0.02–0.28)	1.2% (0.3–3.1)
Lead exposure	6.74 (3.91–9.82)	4.7% (2.8–6.8)	0.25 (0.06–0.50)	1.6% (0.4–3.2)	3.13 (1.80–4.60)	4.7% (2.8–6.7)	2.94 (1.78–4.17)	5.7% (3.5–8.0)	0.42 (0.23–0.64)	4.9% (2.7–7.2)
<b>Dietary risks</b>										
Diet high in sodium	17.70 (5.75–34.90)	12.3% (4.1–24.3)	1.03 (0.15–2.59)	6.5% (0.9–16.4)	11.60 (4.77–20.20)	17.3% (7.3–29.6)	4.33 (0.56–10.50)	8.4% (1.1–20.3)	0.69 (0.09–1.88)	8.0% (1.0–21.6)
Diet high in red meat	10.10 (6.37–13.50)	7.1% (4.5–9.3)	1.45 (0.98–1.85)	9.2% (6.2–11.5)	6.73 (4.46–8.84)	10.0% (6.7–12.8)	1.63 (0.75–2.44)	3.2% (1.5–4.7)	0.29 (0.10–0.47)	3.4% (1.1–5.3)
Diet low in fruits	10.50 (6.24–16.00)	7.3% (4.4–11.2)	0.81 (0.41–1.30)	5.1% (2.6–8.2)	3.70 (1.92–5.97)	5.5% (2.9–8.8)	5.17 (3.23–7.74)	10.0% (6.2–14.9)	0.81 (0.47–1.27)	9.4% (5.6–14.4)
Diet low in vegetables	4.15 (1.54–6.84)	2.9% (1.1–4.8)	0.30 (0.10–0.54)	1.9% (0.6–3.4)	0.73 (0.31–1.19)	1.1% (0.5–1.8)	2.52 (0.80–4.30)	4.9% (1.5–8.2)	0.60 (0.24–0.95)	7.0% (2.8–11.1)
Diet low in whole grains	3.26 (0.98–4.76)	2.3% (0.7–3.3)	0.42 (0.12–0.62)	2.7% (0.8–3.9)	1.73 (0.48–2.57)	2.6% (0.7–3.7)	0.96 (0.31–1.43)	1.9% (0.6–2.8)	0.13 (0.04–0.20)	1.6% (0.5–2.3)
Alcohol consumption	8.54 (6.02–11.10)	6.0% (4.3–7.6)	1.00 (0.67–1.34)	6.3% (4.2–8.4)	4.99 (3.48–6.64)	7.4% (5.3–9.5)	2.13 (1.46–2.82)	4.1% (2.8–5.5)	0.42 (0.25–0.60)	4.9% (3.1–6.7)
<b>Physical activity</b>										
Low physical activity	2.41 (0.43–6.38)	1.7% (0.3–4.5)	0.46 (0.07–1.26)	2.9% (0.5–8.0)	1.23 (0.23–3.29)	1.8% (0.4–4.9)	0.65 (0.12–1.78)	1.3% (0.2–3.4)	0.07 (0.01–0.20)	0.8% (0.1–2.3)
<b>Tobacco smoking</b>										
Smoking	25.30 (22.60–28.20)	17.6% (16.4–19.0)	2.68 (2.44–2.94)	17.0% (15.8–18.3)	13.90 (11.90–16.10)	20.7% (19.0–22.4)	7.81 (6.94–8.74)	15.1% (13.9–16.4)	0.88 (0.72–1.06)	10.2% (9.1–11.3)
Second-hand smoking	5.09 (3.79–6.56)	3.5% (2.7–4.5)	0.31 (0.24–0.39)	2.0% (1.5–2.5)	2.62 (1.93–3.37)	3.9% (2.9–4.9)	1.93 (1.41–2.56)	3.7% (2.8–4.8)	0.22 (0.15–0.30)	2.6% (1.9–3.4)
<b>Physiological factors</b>										
High body-mass index	34.90 (22.30–48.60)	24.3% (15.7–33.2)	3.99 (2.73–5.36)	25.4% (17.2–34.2)	15.70 (9.39–22.80)	23.4% (14.1–33.0)	13.30 (8.65–18.30)	25.8% (17.0–34.7)	1.87 (1.04–2.84)	21.8% (12.9–31.6)
High fasting plasma glucose	28.90 (19.80–41.50)	20.2% (13.8–29.1)	3.88 (2.45–6.35)	24.7% (15.7–40.4)	12.30 (8.28–18.30)	18.3% (12.4–26.5)	11.30 (7.73–15.90)	21.9% (15.2–30.6)	1.37 (0.92–1.96)	15.9% (11.1–22.7)
High systolic blood pressure	79.60 (67.70–90.80)	55.5% (48.2–62.0)	7.71 (6.44–9.07)	48.9% (41.3–56.5)	37.20 (31.10–43.40)	55.4% (47.2–62.6)	30.00 (25.50–34.00)	58.1% (50.4–64.4)	4.57 (3.60–5.56)	53.2% (45.6–59.6)
High LDL cholesterol	13.70 (7.72–23.40)	9.6% (5.5–16.4)	2.02 (0.87–3.91)	12.8% (5.5–24.3)	7.34 (4.07–12.50)	10.9% (6.2–18.9)	3.84 (2.37–6.23)	7.4% (4.6–12.1)	0.50 (0.31–0.77)	5.8% (3.7–9.0)
Kidney dysfunction	11.90 (9.75–14.10)	8.3% (7.0–9.7)	1.07 (0.73–1.38)	6.8% (4.7–8.7)	5.62 (4.48–6.65)	8.4% (7.0–9.7)	4.70 (3.88–5.55)	9.1% (7.6–10.6)	0.56 (0.44–0.69)	6.5% (5.5–7.7)

(Table 2 continues on the next page)

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



	Globally		World Bank high-income countries		World Bank upper-middle-income countries		World Bank lower-middle-income countries		World Bank low-income countries	
	Absolute number (millions)	Percentage	Absolute number (millions)	Percentage	Absolute number (millions)	Percentage	Absolute number (millions)	Percentage	Absolute number (millions)	Percentage
(Continued from previous page)										
<b>Cluster of risk factors</b>										
Air pollution*	43.50 (38.40–48.70)	30.4% (27.7–33.1)	1.60 (1.23–2.00)	10.2% (8.0–12.6)	19.70 (16.70–22.80)	29.3% (26.5–32.2)	18.40 (16.20–20.70)	35.7% (32.7–38.8)	3.71 (3.08–4.38)	43.1% (40.1–46.3)
Tobacco smoke†	29.50 (26.30–32.70)	20.6% (19.2–22.0)	2.92 (2.65–3.20)	18.5% (17.3–19.8)	16.00 (13.80–18.50)	23.8% (22.1–25.6)	9.49 (8.44–10.60)	18.4% (16.8–19.8)	1.07 (0.89–1.30)	12.5% (11.2–13.8)
Dietary risks‡	43.80 (32.10–58.10)	30.6% (22.6–39.8)	4.01 (2.98–5.39)	25.5% (18.9–33.6)	22.40 (15.90–29.70)	33.3% (24.4–42.9)	15.00 (10.60–20.00)	29.0% (20.7–38.5)	2.42 (1.61–3.46)	28.2% (19.6–38.9)
Behavioural risks§	67.90 (58.20–79.30)	47.4% (41.3–54.4)	6.88 (5.90–7.99)	43.7% (38.0–49.8)	34.90 (29.10–41.20)	51.9% (45.3–58.6)	22.70 (19.00–27.00)	44.0% (37.7–51.5)	3.42 (2.59–4.43)	39.8% (32.8–48.8)
Environmental or occupational risks¶	54.20 (48.20–60.00)	37.8% (35.0–41.0)	2.98 (2.48–3.53)	18.9% (16.0–22.4)	25.60 (22.00–29.10)	38.1% (34.9–41.4)	21.40 (18.90–24.10)	41.5% (38.4–44.9)	4.17 (3.48–4.87)	48.6% (45.3–51.8)
Metabolic risks	102.00 (89.80–112.00)	71.0% (64.6–77.1)	10.90 (9.36–12.50)	69.1% (61.1–77.0)	47.50 (40.70–53.70)	70.7% (64.0–77.0)	37.60 (33.00–41.50)	72.8% (66.6–78.1)	5.63 (4.57–6.70)	65.5% (58.6–71.2)
<b>Combined risk factors</b>										
All factors	125.00 (115.00–134.00)	87.0% (84.2–89.8)	13.10 (11.80–14.40)	83.2% (78.6–88.2)	59.10 (53.00–65.10)	87.9% (84.9–90.7)	45.20 (41.30–49.00)	87.6% (85.2–89.9)	7.18 (6.08–8.41)	83.7% (81.0–86.1)

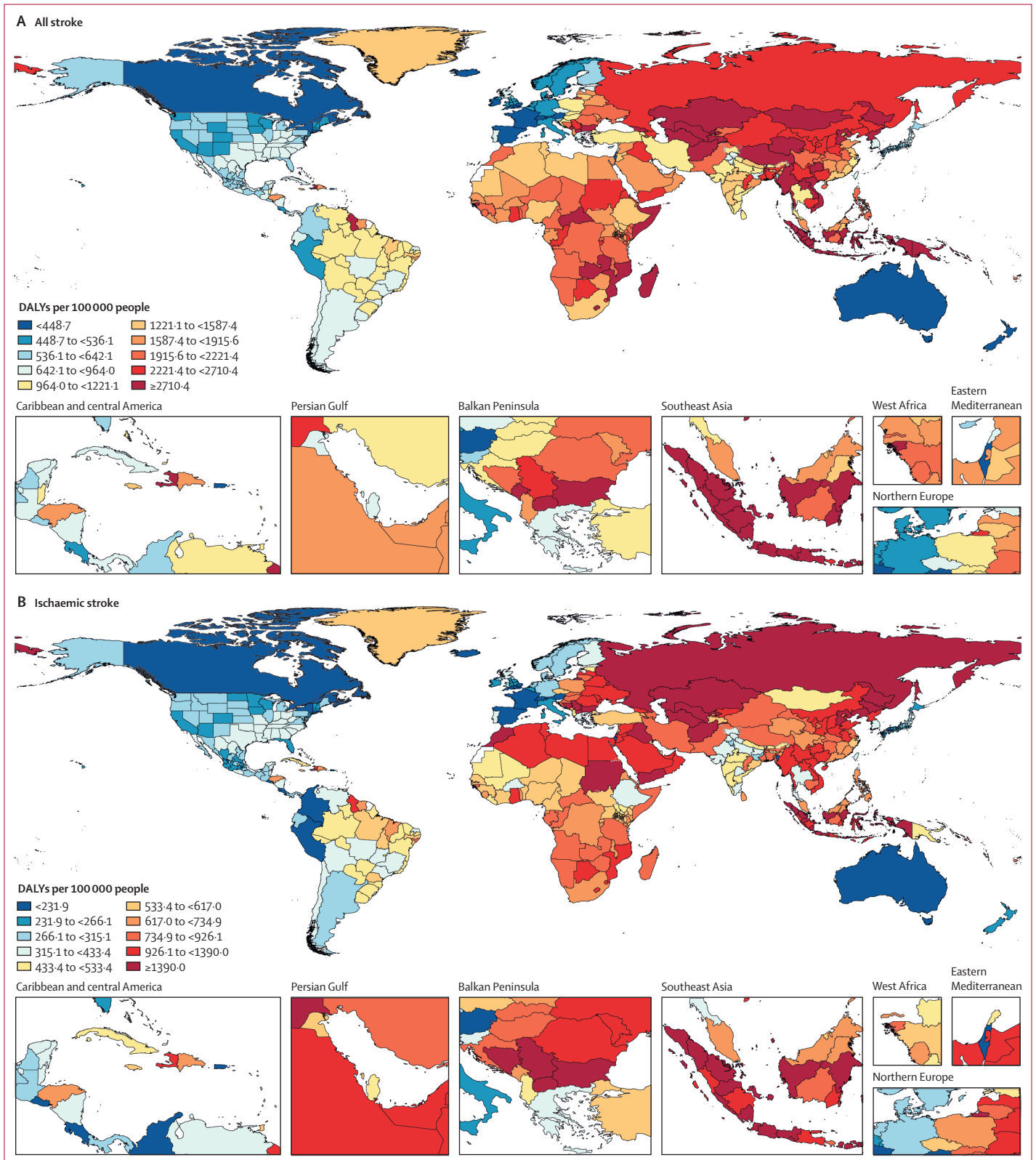
Data in parentheses are 95% uncertainty intervals. Count data in millions are presented to two decimal places and percentage data are presented to one decimal place. Percentages and number of DALYs are not mutually exclusive: the sum of percentages and number of DALYs in the columns exceeds the totals 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. PM<sub>2.5</sub>=particulate matter with a diameter of <2.5 µm. \*Air pollution cluster includes ambient PM<sub>2.5</sub> pollution and household air pollution from solid fuels. †Tobacco smoke cluster includes smoking and second-hand smoking. ‡Dietary risks cluster includes diet high in sodium, diet low in fruits, diet low in vegetables, diet high in red meat, and diet low in whole grains, and alcohol consumption. §Behavioural risks 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. ¶Environmental risks cluster includes air pollution cluster, low ambient temperature, high ambient temperature, and lead exposure. ||Metabolic risks cluster includes high body-mass index, high fasting plasma glucose, high LDL cholesterol, high systolic blood pressure, and kidney dysfunction.

**Table 2: Stroke-related DALYs (absolute numbers and percentages) associated with risk factors and their clusters in 2019, for all ages and both sexes**

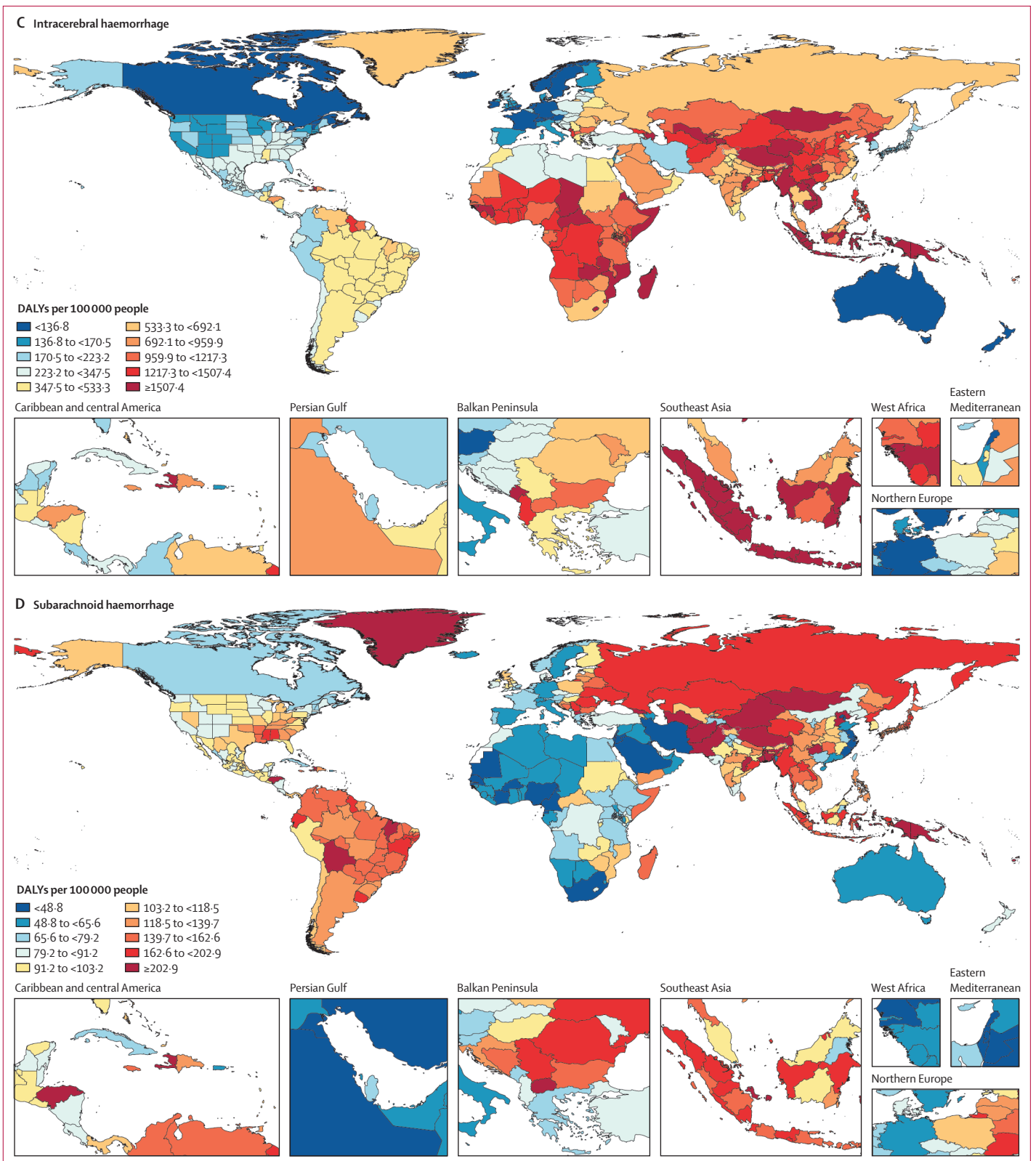
proportion of stroke-related DALYs was observed in the World Bank low-income to upper-middle-income groups (ranging from 85.9% [95% UI 83.2–88.6] in the World Bank low-income group to 87.3% [84.4–89.9] in the World Bank upper-middle-income group). From 1990 to 2019, there was an increase in the total 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 S16–18). 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% [16.4–19.0]; 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 lower-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).<sup>7,14</sup> This study is also the first systematic analysis to determine the effect of non-optimal temperature on



(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.

A All strokes		Global	Central Asia	Central Europe	Eastern Europe	High-income Asia Pacific	Australasia	High-income North America	Southern North America	Western Latin America	Andean Latin America	Caribbean	Central Latin America	Tropical Latin America	North Africa and Middle East	South Asia	East Asia	Oceania	Central sub-Saharan Africa	Eastern sub-Saharan Africa	Southern sub-Saharan Africa	Western sub-Saharan Africa	
High systolic blood pressure		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
High body-mass index		2	2	2	2	2	4	2	2	2	2	2	2	2	2	4	5	4	2	4	3	2	3
High fasting plasma glucose		3	3	3	5	3	3	3	3	3	4	3	3	3	3	2	6	2	3	3	4	3	4
Ambient particulate matter pollution		4	4	6	7	13	5	12	6	9	3	6	4	7	4	3	2	12	5	5	9	4	5
Smoking		5	5	4	3	6	2	4	4	4	8	4	6	4	6	6	3	5	4	8	7	5	9
Diet high in sodium		6	10	5	12	14	7	11	10	12	9	14	8	8	17	10	4	8	7	14	5	14	11
Household air pollution from solid fuels		7	14	16	19	20	19	20	19	19	11	5	10	15	14	5	12	3	6	2	2	8	2
High LDL cholesterol		8	8	7	4	5	6	6	9	5	5	7	7	6	5	11	8	11	9	10	12	7	8
Kidney dysfunction		9	9	11	8	8	11	8	11	10	7	8	5	9	7	9	11	7	8	9	10	9	7
Diet low in fruits		10	11	12	11	9	8	10	13	11	13	12	11	13	13	7	13	6	11	6	6	6	6
Diet high in red meat		11	7	9	9	4	10	5	5	6	6	13	9	5	15	19	7	10	14	15	14	11	14
Low temperature		12	6	8	6	10	9	7	8	7	10	19	15	19	8	17	9	15	20	16	15	12	20
Alcohol use		13	12	10	10	7	12	9	7	8	15	9	13	10	20	15	10	14	13	11	11	10	10
Lead exposure		14	17	18	18	16	17	18	17	18	16	11	12	16	10	8	14	17	16	12	13	15	13
Second-hand smoke		16	15	13	14	18	14	16	14	17	18	17	17	17	12	14	15	13	15	18	16	16	16
Diet low in vegetables		17	19	19	17	15	18	14	15	16	12	10	14	11	18	12	19	9	12	7	8	13	12
Diet low in whole grains		18	13	14	13	17	16	15	16	15	17	18	18	18	9	18	16	16	17	17	18	19	17
Low physical activity		19	18	17	16	12	15	17	18	14	19	16	19	12	11	20	18	18	18	19	20	17	18
High temperature		20	20	20	20	19	20	19	20	20	20	20	20	20	19	16	20	20	19	20	19	20	15
B Ischaemic stroke		Global	Central Asia	Central Europe	Eastern Europe	High-income Asia Pacific	Australasia	High-income North America	Southern North America	Western Latin America	Andean Latin America	Caribbean	Central Latin America	Tropical Latin America	North Africa and Middle East	South Asia	East Asia	Oceania	Central sub-Saharan Africa	Eastern sub-Saharan Africa	Southern sub-Saharan Africa	Western sub-Saharan Africa	
High systolic blood pressure		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
High fasting plasma glucose		2	2	2	5	4	3	2	2	2	3	2	2	2	2	2	6	2	2	3	3	2	3
High LDL cholesterol		3	4	4	3	2	2	4	3	3	4	3	3	3	5	4	3	4	3	4	4	4	4
Ambient particulate matter pollution		4	5	7	8	13	5	11	7	8	5	6	5	9	4	3	2	12	5	6	9	5	6
High body-mass index		5	3	3	2	3	6	3	4	4	2	4	4	4	3	6	7	5	6	5	5	3	5
Smoking		6	6	5	4	6	4	5	5	5	9	5	7	5	7	7	4	6	4	9	7	6	11
Diet high in sodium		7	11	6	11	16	7	10	10	13	7	13	8	10	17	11	5	8	8	15	6	15	10
Kidney dysfunction		8	8	9	7	7	8	7	9	9	6	7	6	8	6	8	9	7	9	7	8	7	7
Household air pollution from solid fuels		9	14	17	19	20	19	20	19	19	10	8	10	15	14	5	11	3	7	2	2	8	2
Diet high in red meat		10	10	10	9	5	10	6	6	6	11	12	9	6	13	19	8	11	16	16	15	10	15
Low temperature		11	7	8	6	9	9	8	8	7	8	19	14	18	10	18	10	16	19	17	14	11	20
Diet low in whole grains		12	9	11	10	10	13	9	11	11	12	10	12	11	8	12	13	10	12	10	11	13	8
Diet low in fruits		13	12	12	12	11	11	12	13	14	15	14	13	16	15	10	14	9	11	8	10	9	9
Lead exposure		14	17	18	18	14	17	17	18	17	17	11	11	13	11	9	12	17	17	13	12	16	12
Low physical activity		15	13	13	13	8	12	13	16	10	16	9	16	7	9	14	16	13	13	12	16	12	13
Second-hand smoke		16	15	15	16	19	16	18	15	18	18	17	18	17	12	16	15	15	14	18	18	17	17
Alcohol use		18	18	14	14	15	15	15	14	12	20	18	19	19	20	20	17	20	18	20	19	18	18
Diet low in vegetables		19	19	19	17	17	18	16	17	16	14	15	15	14	19	15	19	14	15	11	13	14	14
High temperature		20	20	20	20	18	20	19	20	20	19	20	20	20	18	17	20	19	20	19	20	20	16

(Figure 4 continues on next page)

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,<sup>15</sup> poorer stroke awareness,<sup>16</sup> 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,<sup>17,18</sup> 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

C Intracerebral haemorrhage																						
	Global	Central Asia	Central Europe	Eastern Europe	High-income Asia Pacific	Australasia	High-income North America	Southern Latin America	Western Latin America	Andean Latin America	Caribbean	Central Latin America	Tropical Latin America	North Africa and Middle East	South Asia	East Asia	Oceania	Central sub-Saharan Africa	Eastern sub-Saharan Africa	Southern sub-Saharan Africa	Western sub-Saharan Africa	
High systolic blood pressure	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	
High body-mass index	2	2	2	2	2	3	2	2	2	2	1	2	2	2	2	4	5	4	2	3	3	2
Ambient particulate matter pollution	3	4	7	6	11	6	11	7	8	3	6	4	7	3	3	2	12	5	6	10	4	5
High fasting plasma glucose	4	3	4	5	4	5	3	4	3	4	3	3	3	4	2	6	3	4	4	4	3	4
Smoking	5	5	3	3	5	2	4	3	4	8	5	6	4	5	7	3	5	3	8	7	5	8
Diet high in sodium	6	11	6	11	12	7	10	9	11	10	13	8	8	15	10	4	8	7	13	6	13	11
Household air pollution from solid fuels	7	12	14	16	17	16	17	16	16	13	4	11	13	10	5	11	2	6	2	2	8	3
Alcohol use	8	8	5	4	3	4	5	5	5	7	7	6	17	12	7	13	11	9	8	6	7	
Diet low in fruits	9	10	11	10	8	8	9	12	10	11	10	10	11	8	6	12	6	9	5	5	7	6
Kidney dysfunction	10	9	10	9	7	9	8	10	9	6	8	5	9	6	8	10	7	8	10	11	10	9
Diet high in red meat	11	7	8	8	6	11	6	6	6	7	12	9	5	12	17	8	10	13	14	13	9	13
Low temperature	12	6	9	7	9	10	7	8	7	12	16	14	16	7	15	9	14	16	15	14	12	17
Lead exposure	13	15	15	15	14	14	15	15	15	15	11	13	15	9	9	13	15	15	11	12	15	12
Second-hand smoke	15	13	12	12	15	13	14	13	14	16	15	16	14	11	14	14	11	14	16	15	14	15
Diet low in vegetables	16	16	16	14	13	15	13	14	13	9	9	12	10	13	11	16	9	12	7	9	11	10
High temperature	17	17	17	17	16	17	16	17	17	17	17	17	17	17	16	16	17	17	17	17	17	14

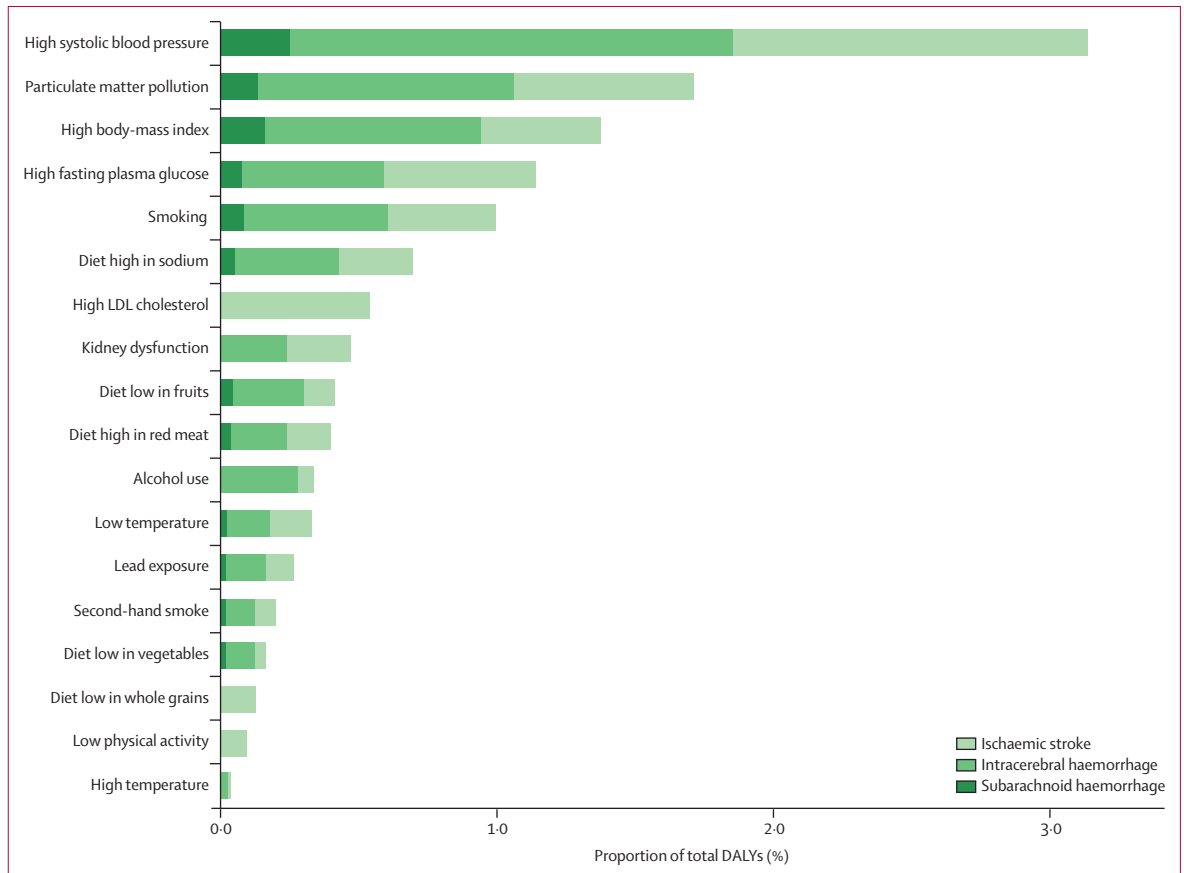
D Subarachnoid haemorrhage																						
High systolic blood pressure	1	1	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	
High body-mass index	2	2	2	2	2	2	1	2	2	1	2	2	2	2	2	3	2	2	3	3	2	2
Ambient particulate matter pollution	3	4	4	5	9	4	9	6	6	3	6	4	6	3	3	2	11	4	7	9	4	4
Smoking	4	5	3	3	3	3	3	3	3	9	5	5	3	5	7	5	5	3	8	7	7	7
High fasting plasma glucose	5	3	5	4	5	5	4	5	4	4	3	3	5	4	4	6	4	5	4	4	3	5
Diet high in sodium	6	9	6	9	10	6	8	8	9	11	12	7	8	14	9	4	9	7	11	8	10	9
Household air pollution from solid fuels	7	10	12	14	15	14	15	14	14	8	4	10	11	8	5	9	3	6	2	2	6	3
Diet low in fruits	8	8	9	7	6	7	6	9	8	7	7	8	9	7	6	10	6	8	5	5	5	6
Diet high in red meat	9	6	7	6	4	8	5	4	5	5	9	6	4	10	15	7	8	11	12	11	9	10
Low temperature	10	7	8	8	7	9	7	7	7	10	14	12	14	6	13	8	12	15	14	12	11	15
Lead exposure	12	13	13	13	13	13	13	13	13	13	10	11	13	9	8	11	13	13	9	10	13	11
Diet low in vegetables	13	14	14	12	11	12	11	12	12	6	8	9	7	12	10	14	7	10	6	6	8	8
Second-hand smoke	14	11	10	10	12	11	12	11	11	14	13	14	12	11	12	12	10	12	13	14	12	12
High temperature	15	15	15	15	14	15	14	15	15	15	15	15	15	15	14	15	15	14	15	15	15	13

**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.

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 than in the high-income group (29.5% of all incident strokes in 2019 vs 15.8%), whereas a new stroke case was more than twice as likely to be subarachnoid haemorrhage in the World Bank high-income

group than in the 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.<sup>18</sup> 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,<sup>19,20</sup> and might be explained by lower levels of awareness and control of hypertension in low-income





**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.

to upper-middle-income countries than in high-income countries,<sup>18,21</sup> as well as increased exposure to risk factors predisposing a higher proportion of males to intracerebral haemorrhage compared with females.<sup>20,22</sup> Our study also adds to the body of research on the incidence of subarachnoid haemorrhage; a previous systematic review of population-based studies of subarachnoid haemorrhage incidence by Etminan and colleagues<sup>23</sup> had similar findings to ours, as the authors used many of the same sources, but they only used crude incidence rates, which is perhaps why we found smaller between-country variations in the age-standardised incidence of subarachnoid haemorrhage (approximately a tenfold variation in our findings [appendix table s5] compared with a >20-fold variation in the systematic review).<sup>23</sup> The size of between-country variations we observed in age-standardised incidence, prevalence, and DALY rates of other pathological types of stroke and stroke overall were in line with previous observations.<sup>2,3,19,20,24</sup>

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.

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, in middle-aged people was recently observed in the USA, European countries, Brazil, and China.<sup>25–30</sup> 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.<sup>31–33</sup> 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.<sup>34</sup> Third, most countries have not achieved sufficient declines in stroke incidence rates to offset the demographic force of

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.<sup>35</sup> 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<sup>17,36</sup> 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.<sup>37</sup> 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,<sup>14</sup> and increasing rates of exposure to many important stroke risk factors from 1990 to 2019,<sup>7,14</sup> 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.<sup>38</sup> For every US\$1 spent on prevention of stroke and cardiovascular disease, there is an estimated \$10.9 return on investment.<sup>39</sup> 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,<sup>38</sup> such as digital health 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.<sup>40</sup> 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.<sup>41</sup> 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

For more on the **Stroke Riskometer & PreventS** app see <https://nisan.aut.ac.nz/Stroke-Riskometer/>

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.<sup>40</sup> 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 teamwork<sup>42</sup> (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.<sup>43</sup> 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),<sup>44</sup> and one in three patients discontinues using one or more secondary stroke prevention drugs about 1 year after stroke.<sup>45</sup> Treatment rates are even lower in many low-income and middle-income countries.<sup>21,43</sup> To reduce inequalities in stroke care, a roadmap for delivering quality stroke care and various action plans<sup>46,47</sup> 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 care<sup>48,49</sup> and preventive interventions<sup>49</sup> 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 results<sup>50</sup> 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,<sup>2,3,11,36</sup> 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 TMREs for some risk factors was uncertain and based on non-experimental studies, although all TMREs 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, disproportionately 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 7–10) 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 applying analytical methods to produce estimates; 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 Roth had access to and verified the data underlying this study. All authors had full access to all the data in the study, and V L Feigin had final responsibility for the decision to submit for publication.

**GBD 2019 Stroke Collaborators**

Valery L Feigin, Benjamin A Stark, Catherine Owens Johnson, Gregory A Roth, Catherine Bisignano, Gdiom Gebreheat Abady, Mitra Abbasifard, Mohsen Abbasi-Kangevari, Foad Abd-Allah, Vida Abedi, Ahmed Abualhasan, Niveen ME Abu-Rmeileh, Abdelrahman I Abushouk, Oladimeji M Adebayo, Gina Agarwal, Pradyumna Agasthi, Bright Opoku Ahinkorah, Sohail Ahmad, Sepideh Ahmadi, Yusra Ahmed Salih, Budi Aji, Samaneh Akbarpour, Rufus Olusola Akinyemi, Hanadi Al Hamad, Fares Alahdab, Sheikh Mohammad Alif, Wahid Alipour, Syed Mohamed Aljunid, Sami Almustanyir, Rajaa M Al-Raddadi, Rustam Al-Shahi Salman, Nelson Alvis-Guzman, Robert Ancuceanu, Deanna Anderlini, Jason A Anderson, Adnan Ansar, Ippazio Cosimo Antonazzo, Jalal Arabloo, Johan Ärnlöv, Kurnia Dwi Artanti, Zahra Aryan, Samaneh Asgari, Tahira Ashraf, Mohammad Athar, Alok Atreya, Marcel Ausloos, Atif Amin Baig, Ovidiu Constantin Baltatu, Maciej Banach, Miguel A Barboza, Suzanne Lyn Barker-Collo, Till Winfried Bärnighausen, Mark Thomaž Ugliara Barone, Sanjay Basu, Gholamreza Bazmandegan, Ettore Beghi, Mahya Beheshti, Yannick Béjot, Arielle Wilder Bell, Derrick A Bennett, Isisabela M Bensenor, Woldesellassie Mequanint Bezabhe, Yihienew Mequanint Bezabih, Akshaya Srikanth Bhagavathula, Pankaj Bhardwaj, Kritika Bhattacharyya, Ali Bijani, Boris Bikbov, Mulugeta M Birhanu, Archith Boloor, Aime Bonny, Michael Brauer, Hermann Brenner, Dana Bryazka, Zahid A Butt, Florentino Luciano Caetano dos Santos, Ismael R Campos-Nonato, Carlos Cantu-Brito, Juan J Carrero, Carlos A Castañeda-Orjuela, Alberico L Catapano, Promit Ananyo Chakraborty, Jaykaran Charan, Sonali Gajanan Choudhari, Enayet Karim Chowdhury, Dinh-Toi Chu, Sheng-Chia Chung, David Colozza, Vera Marisa Costa, Simona Costanzo, Michael H Criqui, Omid Dadras, Baye Dagnew, Xiaochen Dai, Koustuv Dalal, Albertino Antonio Moura Damasceno, Emanuele D'Amico, Lalit Dandona, Rakhi Dandona, Jiregna Darega Gela, Kairat Davletov, Vanessa De la Cruz-Góngora, Rupak Desai, Deepak Dhamnetiya, Samath Dhamminda Dharmaratne, Mandira Lamichhane Dhimal, Meghnath Dhimal, Daniel Diaz, Martin Dichgans, Klara Dokova, Rajkumar Doshi, Abdel Douiri, Bruce B Duncan, Sahar Eftekharzadeh, Michael Ekholuenetale, Nevine El Nahas, Islam Y Elgendy, Muhammed Elhadi, Shaimaa I El-Jaafary, Matthias Endres, Aman Yesuf Endries, Daniel Asfaw Erku, Emerito Jose A Faraon, Umar Farooque, Farshad Farzadfar, Abdullah Hamid Feroze, Irina Filip, Florian Fischer, David Flood, Mohamed M Gad, Shilpa Gaidhane, Reza Ghanei Gheshlagh, Ahmad Ghashghaee, Nermin Ghith, Ghazali Ghazali, Sherief Ghazy, Alessandro Gialluisi, Simona Giampaoli, Syed Amir Gilani, Paramjit Singh Gill, Elena V Gnedovskaya, Mahaveer Golechha, Alessandra C Goulart, Yuming Guo, Rajeev Gupta, Veer Bala Gupta, Vivek Kumar Gupta, Pradip Gyanwali, Nima Hafezi-Nejad, Samer Hamidi, Asif Hanif, Graeme J Hankey, Arief Hargono, Abdiwahab Hashi, Treska S Hassan, Hamid Yimam Hassen, Rasmus J Havmoeller, Simon I Hay, Khezhar Hayat, Mohamed I Hegazy, Claudiu Herteliu, Ramesh Holla, Sorin Hostiuc, Mowafa Househ, Junjie Huang, Ayesha Humayun, Bing-Fang Hwang, Licia Iacoviello, Ivo Iavicoli,

Segun Emmanuel Ibitoye, Olayinka Stephen Ilesanmi, Irena M Ilic, Milena D Ilic, Usman Iqbal, Seyed Sina Naghibi Irvani, Sheikh Mohammed Shariful Islam, Nahlah Elkudssiah Ismail, Hiroyasu Iso, Gaetano Isola, Masao Iwagami, Louis Jacob, Vardhmaan Jain, Sung-In Jang, Sathish Kumar Jayapal, Shubha Jayaram, Ranil Jayawardena, Panniyammakal Jeemon, Ravi Prakash Jha, Walter D Johnson, Jost B Jonas, Nitin Joseph, Jacek Jerzy Jozwiak, Mikko Jürisson, Rizwan Kalani, Rohollah Kalhor, Yogeshwar Kalkonde, Ashwin Kamath, Zahra Kamiab, Tanuj Kanchan, Himal Kandel, André Karch, Patrick D M C Katoto, Gbenga A Kayode, Pedram Keshavarz, Yousef Saleh Khader, Ejaz Ahmad Khan, Imteyaz A Khan, Maseer Khan, Moien A B Khan, Mahalaqua Nazli Khatib, Jagdish Khubchandani, Gyu Ri Kim, Min Seo Kim, Yun Jin Kim, Adnan Kisa, Sezer Kisa, Mika Kivimäki, Dhaval Kolte, Ali Koolivand, Sindhura Lakshmi Koulmane Laxminarayana, Ai Koyanagi, Kewal Krishan, Vijay Krishnamoorthy, Rita V Krishnamurthi, G Anil Kumar, Dian Kusuma, Carlo La Vecchia, Ben Lacey, Hassan Mehmood Lak, Tea Lallukka, Savita Lasrado, Pablo M Lavados, Matilde Leonardi, Bingyu Li, Shanshan Li, Hualiang Lin, Ro-Ting Lin, Xuefeng Liu, Warren David Lo, Stefan Lorkowski, Giancarlo Lucchetti, Ricardo Lutzky Saute, Hassan Magdy Abd El Razek, Francesca Giulia Magnani, Preetam Bhalchandra Mahajan, Azeem Majeed, Alaa Makki, Reza Malekzadeh, Ahmad Azam Malik, Navid Manafi, Mohammad Ali Mansournia, Lorenzo Giovanni Mantovani, Santi Martini, Giampiero Mazzaglia, Man Mohan Mehndiratta, Ritesh G Menezes, Atte Meretoja, Amanual Getnet Mersha, Junmei Miao Jonasson, Bartosz Miazgowski, Tomasz Miazgowski, Irmina Maria Michalek, Erkin M Mirrakhimov, Yousef Mohammad, Abdollah Mohammadian-Hafshejani, Shafiu Mohammed, Ali H Mokdad, Yaser Mokhayeri, Mariam Molokhia, Mohammad Ali Moni, Ahmed Al Montasir, Rahmatollah Moradzadeh, Lidia Morawska, Jakub Morze, Walter Muriel, Kamarul Imran Musa, Ahmarshah Jayaraman Nagarajan, Mohsen Naghavi, Sreenivas Narasimha Swamy, Bruno Ramos Nascimento, Ruxandra Irina Negoii, Sandhya Neupane Kandel, Trang Huyen Nguyen, Bo Norrving, Jean Jacques Noubiap, Vincent Ebuka Nwatah, Bogdan Oancea, Oluwakemi Ololade Odukoya, Andrew T Olagunju, Hans Orru, Mayowa O Owolabi, Jagadish Rao Padubidri, Adrian Pana, Tarang Parekh, Eun-Cheol Park, Fatemeh Pashazadeh Kan, Mona Pathak, Mario F P Peres, Arokiasamy Perianayagam, Truong-Minh Pham, Michael A Piradov, Vivek Podder, Suzanne Polinder, Maarten J Postma, Akram Pourshams, Amir Radfar, Alireza Rafiei, Alberto Raggi, Fakher Rahim, Vafa Rahimi-Movaghar, Mosiur Rahman, Muhammad Aziz Rahman, Amir Masoud Rahmani, Nazanin Rajai, Priyanga Ranasinghe, Chythra R Rao, Sowmya J Rao, Priya Rathi, David Laith Rawaf, Salman Rawaf, Marissa B Reitsma, Vishnu Renjith, Andre M N Renzaho, Aziz Rezapour, Jefferson Antonio Buendia Rodriguez, Leonardo Roever, Michele Romoli, Andrzej Rynkiewicz, Simona Sacco, Masoumeh Sadeghi, Sahar Saeedi Moghaddam, Amirhossein Sahebkar, KM Saif-Ur-Rahman, Rehab Salah, Mehrnoosh Samaei, Abdallah M Samy, Itamar S Santos, Milena M Santric-Milicevic, Nizal Sarrafzadegan, Brijesh Sathian, Davide Sattin, Silvia Schiavolin, Markus P Schlaich, Maria Inês Schmidt, Aletta Elisabeth Schutte, Sadaf G Sepanlou, Allen Seylani, Feng Sha, Saeed Shahabi, Masood Ali Shaikh, Mohammed Shannawaz, Md Shajedur Rahman Shawon, Aziz Sheikh, Sara Sheikhbahaei, Kenji Shibuya, Soraya Siabani, Diego Augusto Santos Silva, Jasvinder A Singh, Jitendra Kumar Singh, Valentin Yurievich Skryabin, Anna Aleksandrovna Skryabina, Badr Hasan Sobaih, Stefan Stortecy, Saverio Stranges, Eyayou Girma Tadesse, Ingan Ukur Tarigan, Mohamad-Hani Temsah, Yvonne Teuschl, Amanda G Thrift, Marcello Tonelli, Marcos Roberto Tovani-Palone, Bach Xuan Tran, Manjari Tripathi, Gebiyaw Wudie Tsegaye, Anayat Ullah, Brigid Unim, Bhaskaran Unnikrishnan, Alireza Vakilian, Sahel Valadan Tahbaz, Tommi Juhani Vasankari, Narayanawamy Venketasubramanian, Dominique Vervoort, Bay Vo, Victor Volovici, Kia Vosoughi, Giang Thu Vu, Linh Gia Vu, Hatem A Wafa, Yasir Waheed, Yanzhong Wang, Tissa Wijeratne, Andrea Sylvia Winkler, Charles D A Wolfe, Mark Woodward, Jason H Wu, Sarah Wulf Hanson,



Xiaoyue Xu, Lalit Yadav, Ali Yadollahpour, Seyed Hossein Yahyazadeh Jabbari, Kazumasa Yamagishi, Hiroshi Yatsuya, Naohiro Yonemoto, Chuanhua Yu, Ismael Yunusa, Muhammed Shahriar Zaman, Sojib Bin Zaman, Maryam Zamanian, Ramin Zand, Alireza Zandifar, Mikhail Sergeevich Zastrozhin, Anastasia Zastrozhina, Yunquan Zhang, Zhi-Jiang Zhang, Chenwen Zhong, Yves Miel H Zuniga, and Christopher J L Murray.

#### Affiliations

National Institute for Stroke and Applied Neurosciences (Prof V L Feigin PhD, R V Krishnamurthi PhD), Auckland University of Technology, Auckland, New Zealand; Institute for Health Metrics and Evaluation (Prof V L Feigin PhD, B A Stark MA, C O Johnson PhD, G A Roth MD, C Bisignano MPH, J A Anderson BS, Prof M Brauer DSc, D Bryazka BA, X Dai PhD, Prof L Dandona MD, Prof R Dandona PhD, Prof S D Dharmaratne MD, Prof S I Hay FMedSci, Prof A H Mokdad PhD, Prof M Naghavi MD, M B Reitsma BS, S Wulf Hanson PhD, Prof C J L Murray DPhil), Division of Cardiology (G A Roth MD), Department of Health Metrics Sciences, School of Medicine (G A Roth MD, Prof R Dandona PhD, Prof S D Dharmaratne MD, Prof S I Hay FMedSci, Prof A H Mokdad PhD, Prof M Naghavi MD, Prof C J L Murray DPhil), Department of Neurological Surgery (A H Feroze MD), Department of Neurology (R Kalani MD), Department of Anesthesiology & Pain Medicine (V Krishnamoorthy MD), University of Washington, Seattle, WA, USA; Third Department of Neurology (E V Gnedovskaya PhD), Research Center of Neurology, Moscow, Russia (Prof V L Feigin PhD, Prof M A Piradov DSc); Department of Nursing (G G Abady MSc), Adigrat University, Adigrat, Ethiopia; Department of Internal Medicine (M Abbasifard MD, G Bazmandegan PhD), Clinical Research Development Unit (M Abbasifard MD, G Bazmandegan PhD, Z Kamiab MD), Family Medicine Department (Z Kamiab MD), Department of Neurology (A Vakilian MD), Non-communicable Diseases Research Center (A Vakilian MD), Rafsanjan University of Medical Sciences, Rafsanjan, Iran; Social Determinants of Health Research Center (M Abbasi-Kangevari MD), School of Advanced Technologies in Medicine (S Ahmadi PhD), Prevention of Metabolic Disorders Research Center (S Asgari MSc), Shahid Beheshti University of Medical Sciences, Tehran, Iran; Department of Neurology (Prof F Abd-Allah MD, A Abualhasan MD, S I El-Jaafary MD, M I Hegazy PhD), Cairo University, Cairo, Egypt; Department of Molecular and Functional Genomics (V Abedi PhD), Department of Neuroscience (R Zand MD), Geisinger Health System, Danville, PA, USA; Biocomplexity Institute (V Abedi PhD), Virginia Tech, Blacksburg, VA, USA; Institute of Community and Public Health (Prof N M Abu-Rmeileh PhD), Birzeit University, Ramallah, Palestine; Harvard Medical School (A I Abushouk MD), Brigham and Women's Hospital (Z Aryan MD), TH Chan School of Public Health (Prof T W Bärnighausen MD, I Yunusa PhD), Center for Primary Care (S Basu PhD), Department of Global Health and Social Medicine (A W Bell MSW), Division of Cardiology (I Y Elgendy MD), Department of Medicine (D Kolte MD), Department of Internal Medicine (N Rajai MD), Division of General Internal Medicine (Prof A Sheikh MD), Harvard University, Boston, MA, USA; Department of Medicine (A I Abushouk MD), Neurology Department (Prof N El Nahas MD), Department of Entomology (A M Samy PhD), Ain Shams University, Cairo, Egypt; College of Medicine (O M Adebayo MD), Department of Community Medicine (O S Ilesanmi PhD), Department of Medicine (Prof M O Owolabi DrM), University College Hospital, Ibadan, Ibadan, Nigeria; Department of Family Medicine (Prof G Agarwal PhD), Department of Psychiatry and Behavioural Neurosciences (A T Olagunju MD), McMaster University, Hamilton, ON, Canada; Department of Cardiovascular Medicine (P Agasthi MD), Mayo Clinic, Scottsdale, AZ, USA; The Australian Centre for Public and Population Health Research (ACPPHR) (B O Ahinkorah MPH), School of Health (S Siabani PhD), University of Technology Sydney, Sydney, NSW, Australia; Faculty of Pharmacy (S Ahmad MSc), MAHSA University, Kuala Langat, Malaysia; Database Technology Department (Y Ahmed Salih PhD), College of Informatics (Y Ahmed Salih PhD), Sulaimani Polytechnic University, Sulaymaniyah, Iraq; Faculty of Medicine and Public Health (B Aji DrPH), Jenderal Soedirman University, Purwokerto, Indonesia; Occupational Sleep

Research Center (S Akbarpour PhD), Non-communicable Diseases Research Center (Z Aryan MD, Prof F Farzadfar DSc, S Saedi Moghaddam MSc), School of Medicine (N Hafezi-Nejad MD), Digestive Diseases Research Institute (Prof R Malekzadeh MD, Prof A Pourshams MD, S G Sepanlou MD), Department of Epidemiology and Biostatistics (M Mansournia PhD), Metabolomics and Genomics Research Center (F Rahim PhD), Sina Trauma and Surgery Research Center (Prof V Rahimi-Movaghar MD), Tehran University of Medical Sciences, Tehran, Iran; Institute for Advanced Medical Research and Training (R O Akinyemi PhD), Department of Epidemiology and Medical Statistics (M Ekholuenetale MSc), Faculty of Public Health (M Ekholuenetale MSc), Department of Health Promotion and Education (S E Ibitoye MPH), Department of Community Medicine (O S Ilesanmi PhD), Department of Medicine (Prof M O Owolabi DrM), University of Ibadan, Ibadan, Nigeria; Institute of Neuroscience (R O Akinyemi PhD), Newcastle University, Newcastle upon Tyne, UK; Geriatric and Long Term Care Department (H Al Hamad MD, B Sathian PhD), Rumailah Hospital (H Al Hamad MD), Hamad Medical Corporation, Doha, Qatar; Mayo Evidence-based Practice Center (F Alahdab MSc), Mayo Clinic Foundation for Medical Education and Research, Rochester, MN, USA; Epidemiology and Preventive Medicine (S M Alif PhD), Department of Epidemiology and Preventive Medicine (E K Chowdhury PhD), Department of Epidemiology and Preventive Medicine (Prof Y Guo PhD), School of Public Health and Preventive Medicine (S Li PhD), Department of Medicine (Prof A G Thrift PhD), The School of Clinical Sciences at Monash Health (S Zaman MPH), Monash University, Melbourne, VIC, Australia; Health Management and Economics Research Center (V Alipour PhD, J Arabloo PhD, A Ghashghaee BSc, A Rezapour PhD), Department of Health Economics (V Alipour PhD), Student Research Committee (A Ghashghaee BSc), School of Medicine (N Manafi MD), Preventive Medicine and Public Health Research Center (K Vosoughi MD), Iran University of Medical Sciences, Tehran, Iran (F Pashazadeh Kan BSN); Department of Health Policy and Management (Prof S M Aljunid PhD), Kuwait University, Safat, Kuwait; International Centre for Casemix and Clinical Coding (Prof S M Aljunid PhD), National University of Malaysia, Bandar Tun Razak, Malaysia; College of Medicine (S Almustanyir MD), Alfaisal University, Riyadh, Saudi Arabia; Ministry of Health, Riyadh, Saudi Arabia (S Almustanyir MD); Department of Community Medicine (R M Al-Raddadi PhD), Rabigh Faculty of Medicine (A A Malik PhD), King Abdulaziz University, Jeddah, Saudi Arabia; Centre for Clinical Brain Sciences (Prof R Al-Shahi Salman PhD), Centre for Medical Informatics (Prof A Sheikh MD), University of Edinburgh, Edinburgh, UK; Research Group in Hospital Management and Health Policies (Prof N Alvis-Guzman PhD), Universidad de la Costa (University of the Coast), Barranquilla, Colombia; Research Group in Health Economics (Prof N Alvis-Guzman PhD), University of Cartagena, Cartagena, Colombia; Pharmacy Department (Prof R Ancuceanu PhD), Department of Legal Medicine and Bioethics (S Hostiu PhD), Department of Anatomy and Embryology (R I Negoï PhD), Carol Davila University of Medicine and Pharmacy, Bucharest, Romania; Centre for Sensorimotor Performance (D Anderlini MD), The University of Queensland, Brisbane, QLD, Australia; Neurology Department (D Anderlini MD), Royal Brisbane and Women's Hospital, Brisbane, QLD, Australia; School of Nursing and Midwifery (A Ansar MPH, M Rahman PhD), La Trobe University, Melbourne, VIC, Australia; Special Interest Group International Health (A Ansar MPH), Public Health Association of Australia, Canberra, ACT, Australia; Research Center on Public Health (I Antonazzo PhD), School of Medicine and Surgery (Prof L G Mantovani DSc), Department of Medicine (G Mazzaglia PhD), University of Milan Bicocca, Monza, Italy; Department of Neurobiology, Care Sciences and Society (Prof J Ärnlöv PhD), Department of Medical Epidemiology and Biostatistics (Prof J J Carrero PhD), Department of Medicine (T S Hassan PhD), Karolinska Institute, Stockholm, Sweden; School of Health and Social Studies (Prof J Ärnlöv PhD), Dalarna University, Falun, Sweden; Department of Epidemiology (K D Artanti MSc, A Hargono Dr), Faculty of Public Health (S Martini PhD), Universitas Airlangga (Airlangga University), Surabaya, Indonesia; University Institute of Radiological Sciences and Medical Imaging Technology (T Ashraf MS), Faculty of Allied Health Sciences (Prof S Gilani PhD), University Institute of Public Health (A Hanif PhD,



A A Malik PhD), The University of Lahore, Lahore, Pakistan; Department of Medical Genetics (M Athar PhD), Science and Technology Unit (M Athar PhD), Umm Al-Qura University, Makkah, Saudi Arabia; Department of Forensic Medicine (A Atreya MD), Lumbini Medical College, Palpa, Nepal; School of Business (Prof M Ausloos PhD), University of Leicester, Leicester, UK; Department of Statistics and Econometrics (Prof M Ausloos PhD, Prof C Herteliu PhD, A Pana MD), Bucharest University of Economic Studies, Bucharest, Romania; Unit of Biochemistry (A A Baig PhD), Universiti Sultan Zainal Abidin (Sultan Zainal Abidin University), Kuala Terengganu, Malaysia; Department of Pharmacology & Therapeutics (Prof O C Baltatu PhD), Khalifa University, Abu Dhabi, United Arab Emirates; Center of Innovation, Technology and Education (CITE) (Prof O C Baltatu PhD), Anhembi Morumbi University, Sao Jose dos Campos, Brazil; Department of Hypertension (Prof M Banach PhD), Medical University of Lodz, Lodz, Poland; Polish Mothers' Memorial Hospital Research Institute, Lodz, Poland (Prof M Banach PhD); Department of Neurosciences (Prof M A Barboza MD), Costa Rican Department of Social Security, San Jose, Costa Rica; School of Medicine (Prof M A Barboza MD), University of Costa Rica, San Pedro, Costa Rica; School of Psychology (Prof S L Barker-Collo PhD), University of Auckland, Auckland, New Zealand; Heidelberg Institute of Global Health (HIGH) (Prof T W Bärnighausen MD), Department of Ophthalmology (Prof J B Jonas MD), Heidelberg University, Heidelberg, Germany; Programs, Partnerships, Research and Education (M T U Barone PhD), International Diabetes Federation, São Paulo, Brazil; International Diabetes Federation, Brussels, Belgium (M T U Barone PhD); School of Public Health (S Basu PhD), Imperial College Business School (D Kusuma DSc), Department of Primary Care and Public Health (Prof A Majeed MD, Prof S Rawaf MD), WHO Collaborating Centre for Public Health Education and Training (D L Rawaf MD), Imperial College London, London, UK; Department of Neuroscience (E Beghi MD), Mario Negri Institute for Pharmacological Research, Milan, Italy; Department of Physical Medicine and Rehabilitation (M Beheshti MD), New York University, New York, NY, USA; Department of Neurology (Prof Y Béjot PhD), University Hospital of Dijon, Dijon, France; Dijon Stroke Registry - UFR Sciences Santé (Prof Y Béjot PhD), University of Burgundy, Dijon, France; Department of Social Services (A W Bell MSW), Tufts Medical Center, Boston, MA, USA; Nuffield Department of Population Health (D A Bennett PhD, B Lacey PhD), University of Oxford, Oxford, UK; Department of Internal Medicine (I M Bensenor PhD, A C Goulart PhD, I S Santos PhD), Center for Clinical and Epidemiological Research (A C Goulart PhD, I S Santos PhD), Department of Psychiatry (Prof M F P Peres MD), University of São Paulo, São Paulo, Brazil; University of Tasmania, Tasmania, VIC, Australia (W M Bezabhe BSc); Department of Internal Medicine (Y M Bezabih MD), College of Medicine and Health Sciences (G W Tsegaye MPH), Bahir Dar University, Bahir Dar, Ethiopia (W M Bezabhe BSc); One Health (Y M Bezabih MD), University of Nantes, Nantes, France; Department of Social and Clinical Pharmacy (A S Bhagavathula PharmD), Charles University, Hradec Kralova, Czech Republic; Institute of Public Health (A S Bhagavathula PharmD), Family Medicine Department (M A Khan MSc), United Arab Emirates University, Al Ain, United Arab Emirates; Department of Community Medicine and Family Medicine (P Bhardwaj MD), School of Public Health (P Bhardwaj MD), Department of Pharmacology (J Charan MD), Department of Forensic Medicine and Toxicology (T Kanchan MD), All India Institute of Medical Sciences, Jodhpur, India; Department of Statistical and Computational Genomics (K Bhattacharyya MSc), National Institute of Biomedical Genomics, Kalyani, India; Department of Statistics (K Bhattacharyya MSc), University of Calcutta, Kolkata, India; Social Determinants of Health Research Center (A Bijani PhD), Babol University of Medical Sciences, Babol, Iran; Mario Negri Institute for Pharmacological Research, Ranica, Italy (B Bikbov MD); Stroke and Ageing Research Group, Epidemiology and Prevention Division (M M Birhanu MSc), Monash University, Clayton, Melbourne, Australia; Department of Nursing (M M Birhanu MSc), St Paul's Hospital Millennium Medical College, Addis Ababa, Ethiopia; Department of Internal Medicine (A Bolor MD), Department of Community Medicine (N Joseph MD), Kasturba Medical College (Prof B Unnikrishnan MD), Manipal Academy of Higher Education, Mangalore, India; Faculty of Medicine and Pharmaceutical Sciences (A Bonny MD), University of Douala, Douala, Cameroon; Department of Cardiology (A Bonny MD), Centre Hospitalier Montfermeil (Montfermeil Hospital Center), Montfermeil, France; School of Population and Public Health (Prof M Brauer DSc, P A Chakraborty MPH, Prof N Sarrafzadegan MD), University of British Columbia, Vancouver, BC, Canada; Division of Clinical Epidemiology and Aging Research (Prof H Brenner MD), German Cancer Research Center, Heidelberg, Germany; School of Public Health and Health Systems (Z A Butt PhD), University of Waterloo, Waterloo, ON, Canada; Al Shifa School of Public Health (Z A Butt PhD), Al Shifa Trust Eye Hospital, Rawalpindi, Pakistan; Institute of Microengineering (F Caetano dos Santos PhD), Federal Polytechnic School of Lausanne, Lausanne, Switzerland; Health and Nutrition Research Center (I R Campos-Nonato PhD), Center for Evaluation and Surveys Research (V De la Cruz-Góngora PhD), National Institute of Public Health, Cuernavaca, Mexico; Department of Neurology (Prof C Cantu-Brito PhD), Salvador Zubiran National Institute of Medical Sciences and Nutrition, Mexico City, Mexico; Colombian National Health Observatory (C A Castañeda-Orjuela MD), National Institute of Health, Bogota, Colombia; Epidemiology and Public Health Evaluation Group (C A Castañeda-Orjuela MD), National University of Colombia, Bogota, Colombia; Department of Pharmacological and Biomolecular Sciences (Prof A L Catapano PhD), Department of Clinical Sciences and Community Health (Prof C La Vecchia MD), University of Milan, Milan, Italy; MultiMedica (Prof A L Catapano PhD), IRCCS, Sesto S. Giovanni, Italy; Department of Community Medicine (Prof S G Choudhary MD), Department of Medicine (S Gaidhane PhD), Global Evidence Synthesis Initiative (Prof M Khatib PhD), Datta Meghe Institute of Medical Sciences, Wardha, India; School of Public Health (E K Chowdhury PhD), Curtin University, Perth, WA, Australia; Center for Biomedicine and Community Health (D Chu PhD), VNU-International School, Hanoi, Vietnam; Department of Health Informatics (S Chung PhD), Department of Epidemiology and Public Health (Prof M Kivimäki PhD), University College London, London, UK; Health Data Research UK, London, UK (S Chung PhD); Department of Global Health and Social Medicine (D Colozza PhD), School of Population Health and Environmental Sciences (A Douiri PhD, W Muruet MSc, H A Wafa MPH, Y Wang PhD, Prof C D A Wolfe MD), Faculty of Life Sciences and Medicine (M Molokhia PhD), King's College London, London, UK; Office of Climate Change, Biodiversity and Environment (D Colozza PhD), Food and Agriculture Organization of the United Nations, Rome, Italy; Research Unit on Applied Molecular Biosciences (UCIBIO) (V M Costa PhD), University of Porto, Porto, Portugal; Department of Epidemiology and Prevention (S Costanzo PhD, A Gialluisi PhD, Prof L Iacoviello MD), IRCCS Neuromed, Pozzilli, Italy; Department of Family Medicine and Public Health (Prof M H Criqui MD), University of California San Diego, La Jolla, CA, USA; School of Public Health (O Dadrás DrPH), Walailak University, Nakhon Si Thammarat, Thailand; Graduate School of Medicine (O Dadrás DrPH), Kyoto University, Kyoto, Japan; Department of Human Physiology (B Dagnew MSc), School of Medicine (A G Mersha MD), University of Gondar, Gondar, Ethiopia; Division of Public Health Science (Prof K Dalal PhD), Mid Sweden University, Sundsvall, Sweden; Higher School of Public Health (Prof K Dalal PhD), Health Research Institute (K Davletov PhD), Al Farabi Kazakh National University, Almaty, Kazakhstan; Faculty of Medicine (Prof A A M Damasceno PhD), Eduardo Mondlane University, Maputo, Mozambique; Department of Medical and Surgical Sciences and Advanced Technologies (E D'Amico MD), Department of General Surgery and Surgical-Medical Specialties (Prof G Isola PhD), University of Catania, Catania, Italy; Public Health Foundation of India, Gurugram, India (Prof L Dandona MD, Prof R Dandona PhD, G Kumar PhD); Indian Council of Medical Research, New Delhi, India (Prof L Dandona MD); Department of Public Health (J Darega Gela MPH), Ambo University, Ambo, Ethiopia; Division of Cardiology (R Desai MBBS), Atlanta Veterans Affairs Medical Center, Decatur, GA, USA; Department of Community Medicine (D Dharmnetiya MD, R P Jha MSc), Dr Baba Sahib Ambedkar Medical College and Hospital, Delhi, India; Department of Community Medicine (Prof S D Dharmaratne MD), University of Peradeniya, Peradeniya,

Sri Lanka; Policy Research Institute, Kathmandu, Nepal (M L Dhimal PhD); Global Institute for Interdisciplinary Studies, Kathmandu, Nepal (M L Dhimal PhD); Health Research Section (M Dhimal PhD), Nepal Health Research Council, Kathmandu, Nepal (P Gyanwali MD); Center of Complexity Sciences (Prof D Diaz PhD), National Autonomous University of Mexico, Mexico City, Mexico; Faculty of Veterinary Medicine and Zootechnics (Prof D Diaz PhD), Autonomous University of Sinaloa, Culiacán Rosales, Mexico; Institute for Stroke and Dementia Research (Prof M Dichgans MD), Ludwig Maximilians University, Munich, Germany; Department of Social Medicine and Health Care Organisation (K Dokova PhD), Medical University of Varna, Varna, Bulgaria; Department of Internal Medicine (R Doshi MD), University of Nevada Reno, Reno, NV, USA; Postgraduate Program in Epidemiology (Prof B B Duncan PhD), Prof M I Schmidt PhD, Federal University of Rio Grande do Sul, Porto Alegre, Brazil; Division of Urology (S Eftekharzadeh MD), Department of Radiology (A Zandifar MD), Children's Hospital of Philadelphia, Philadelphia, PA, USA; Division of Cardiology (I Y Elgendy MD, D Kolte MD), Massachusetts General Hospital, Boston, MA, USA; Faculty of Medicine (M Elhadi MD), University of Tripoli, Tripoli, Libya; Department of Neurology (Prof M Endres MD), Charité University Medical Center Berlin, Berlin, Germany; Public Health Department (A Y Endries MPH), St Paul's Hospital Millennium Medical College, Addis Ababa, Ethiopia; Centre for Applied Health Economics (D A Erku PhD), Griffith University, Gold Coast, QLD, Australia; Department of Health Policy and Administration (E A Faraon MD), University of the Philippines Manila, Manila, Philippines; Department of Internal Medicine (U Farooque MD), Dow University of Health Sciences, Karachi, Pakistan; Human Biology Division (A H Feroze MD), Fred Hutchinson Cancer Research Center, Seattle, WA, USA; Psychiatry Department (I Filip MD), Kaiser Permanente, Fontana, CA, USA; School of Health Sciences (I Filip MD), AT Still University, Mesa, AZ, USA; Institute of Gerontological Health Services and Nursing Research (F Fischer PhD), Ravensburg-Weingarten University of Applied Sciences, Weingarten, Germany; Center for Research in Indigenous Health (D Flood MD), Maya Health Alliance, Tecpán, Guatemala; Department of Internal Medicine (D Flood MD), University of Michigan, Ann Arbor, MI, USA; Department of Cardiovascular Medicine (M M Gad MD), Department of Internal Medicine (V Jain MD, H Lak MD), Lerner Research Institute (X Liu PhD), Cleveland Clinic, Cleveland, OH, USA; Gillings School of Global Public Health (M M Gad MD), University of North Carolina Chapel Hill, Chapel Hill, NC, USA; Faculty of Nursing and Midwifery (R Ghanei Gheshlagh PhD), Kurdistan University of Medical Sciences, Sanandaj, Iran; Research Group for Genomic Epidemiology (N Ghith PhD), Technical University of Denmark, Copenhagen, Denmark; Department of Public Health (G Ghozali PhD), University of Muhammadiyah Kalimantan Timur, Samarinda, Indonesia; Neurosurgery Department (S Ghozy MD), Mansoura University, Mansoura, Egypt; Department of Cardiovascular Endocrine-metabolic Diseases and Aging (S Giampaoli MD), Istituto Superiore di Sanità, Rome, Italy; Afro-Asian Institute, Lahore, Pakistan (Prof S Gilani PhD); Medical School (Prof P S Gill DM), University of Warwick, Coventry, UK; Health Systems and Policy Research (M Golechha PhD), Indian Institute of Public Health, Gandhinagar, India; Department of Epidemiology (Prof Y Guo PhD), Binzhou Medical University, Yantai City, China; Department of Preventive Cardiology (Prof R Gupta MD), Eternal Heart Care Centre & Research Institute, Jaipur, India; Department of Medicine (Prof R Gupta MD), Mahatma Gandhi University Medical Sciences, Jaipur, India; School of Medicine (V Gupta PhD), Deakin University, Geelong, VIC, Australia; Department of Clinical Medicine (Prof V K Gupta PhD), Macquarie University, Sydney, NSW, Australia; Department of Clinical Pharmacology (P Gyanwali MD), Tribhuvan University, Kathmandu, Nepal; Department of Radiology and Radiological Science (N Hafezi-Nejad MD, S Sheikhhahaei MD), Health Policy and Management (D Vervoort MD), Division of Gastroenterology and Hepatology (K Vosoughi MD), Johns Hopkins University, Baltimore, MD, USA; School of Health and Environmental Studies (Prof S Hamidi DrPH), Hamdan Bin Mohammed Smart University, Dubai, United Arab Emirates; Medical School (Prof G J Hankey MD), Dobney Hypertension Centre (Prof M P Schlaich MD), University of Western Australia, Perth, WA, Australia; Department of Neurology (Prof G J Hankey MD), Sir Charles Gairdner Hospital, Perth, WA, Australia; Department of Public Health (A Hashi PhD), Jigjiga University, Jigjiga, Ethiopia; Research Centre (T S Hassan PhD), Salahaddin University, Erbil, Iraq; Department of Primary and Interdisciplinary Care (H Y Hassen MPH), University Hospital Antwerp, Antwerp, Belgium; Department of Public Health (H Y Hassen MPH), Mizan-Tepi University, Mizan Teferi, Ethiopia; Skaane University Hospital (R J Havmoeller PhD), Skaane County Council, Malmö, Sweden; Institute of Pharmaceutical Sciences (K Hayat MS), University of Veterinary and Animal Sciences, Lahore, Pakistan; Department of Pharmacy Administration and Clinical Pharmacy (K Hayat MS), Xian Jiaotong University, Xian, China; School of Business (Prof C Herteliu PhD), London South Bank University, London, UK; Kasturba Medical College, Mangalore (R Holla MD, A Kamath MD, J Padubidri MD, P Rathi MD), Department of Community Medicine (C R Rao MD), Manipal Academy of Higher Education, Manipal, India (A Kamath MD); Clinical Legal Medicine Department (S Hostiuc PhD), National Institute of Legal Medicine Mina Minovici, Bucharest, Romania; College of Science and Engineering (Prof M Househ PhD), Hamad Bin Khalifa University, Doha, Qatar; Jockey Club School of Public Health and Primary Care (J Huang MD, C Zhong MD), The Chinese University of Hong Kong, Hong Kong, China; Department of Public Health and Community Medicine (Prof A Humayun PhD), Shaikh Khalifa Bin Zayed Al-Nahyan Medical College, Lahore, Pakistan; Department of Occupational Safety and Health (Prof B Hwang PhD), College of Public Health (R Lin PhD), China Medical University, Taichung, Taiwan; Research Center in Epidemiology and Preventive Medicine (EPIMED) (Prof L Iacoviello MD), University of Insubria, Varese, Italy; Department of Public Health (Prof I Iavicoli PhD), University of Naples Federico II, Naples, Italy; Faculty of Medicine (I M Ilic PhD), Prof M M Santric-Milicevic PhD, School of Public Health and Health Management (Prof M M Santric-Milicevic PhD), University of Belgrade, Belgrade, Serbia; Department of Epidemiology (Prof M D Ilic PhD), University of Kragujevac, Kragujevac, Serbia; College of Public Health (U Iqbal PhD), Taipei Medical University, Taipei, Taiwan; Independent Consultant, Tabriz, Iran (S N Irvani MD); Institute for Physical Activity and Nutrition (S Islam PhD), Deakin University, Burwood, VIC, Australia; Sydney Medical School (S Islam PhD), Save Sight Institute (H Kandel PhD), University of Sydney, Sydney, NSW, Australia; Department of Clinical Pharmacy (Prof N Ismail PhD), MAHSA University, Bandar Saujana Putra, Malaysia; Public Health Department of Social Medicine (Prof H Iso MD), Graduate School of Medicine (Prof K Yamagishi MD), Osaka University, Suita, Japan; Department of Health Services Research (M Iwagami PhD), Research and Development Center for Health Services (Prof K Yamagishi MD), University of Tsukuba, Tsukuba, Japan; Department of Non-Communicable Disease Epidemiology (M Iwagami PhD), London School of Hygiene & Tropical Medicine, London, UK; Research and Development Unit (L Jacob MD), Biomedical Research Networking Center for Mental Health Network (CiberSAM), Sant Boi de Llobregat, Spain; Faculty of Medicine (L Jacob MD), University of Versailles Saint-Quentin-en-Yvelines, Montigny-le-Bretonneux, France; Department of Preventive Medicine (Prof S Jang PhD), Yonsei University, Seodaemun-gu, South Korea; Centre of Studies and Research (S Jayapal PhD), Ministry of Health, Muscat, Oman; Department of Biochemistry (Prof S Jayaram MD), Government Medical College, Mysuru, India; Department of Physiology (R Jayawardena PhD), Department of Pharmacology (P Ranasinghe PhD), University of Colombo, Colombo, Sri Lanka; School of Exercise and Nutrition Sciences (R Jayawardena PhD), International Laboratory for Air Quality and Health (Prof L Morawska PhD), Queensland University of Technology, Brisbane, QLD, Australia; Achutha Menon Centre for Health Science Studies (P Jeemon PhD), Sree Chitra Tirunal Institute for Medical Sciences and Technology, Trivandrum, India; Department of Community Medicine (R P Jha MSc), Banaras Hindu University, Varanasi, India; Center for Global Surgery (Prof W D Johnson MD), Loma Linda University, Loma Linda, CA, USA; Beijing Institute of Ophthalmology (Prof J B Jonas MD), Beijing Tongren Hospital, Beijing, China; Department of Family Medicine and Public Health (J J Jozwiak PhD), University of Opole, Opole, Poland; Institute of Family Medicine and Public Health (M Jürisson PhD),

H Orru PhD), University of Tartu, Tartu, Estonia; Institute for Prevention of Non-communicable Diseases (R Kalhor PhD), Health Services Management Department (R Kalhor PhD), Qazvin University of Medical Sciences, Qazvin, Iran; Public Health Division (Y Kalkonde MD), Society for Education, Action and Research in Community Health, Gadchiroli, India; Sydney Eye Hospital (H Kandel PhD), South Eastern Sydney Local Health District, Sydney, NSW, Australia; Institute for Epidemiology and Social Medicine (A Karch MD), University of Münster, Münster, Germany; Centre for Tropical Diseases and Global Health (P D Katoto PhD), Catholic University of Bukavu, Bukavu, Democratic Republic of the Congo; Department of Global Health (P D Katoto PhD), Stellenbosch University, Cape Town, South Africa; International Research Center of Excellence (G A Kayode PhD), Institute of Human Virology Nigeria, Abuja, Nigeria; Julius Centre for Health Sciences and Primary Care (G A Kayode PhD), Utrecht University, Utrecht, Netherlands; Department of Diagnostic & Interventional Radiology (P Keshavarz MD), New Hospitals LTD, Tbilisi, Georgia; Medical Imaging Center (P Keshavarz MD), Shiraz University of Medical Sciences, Iran; Department of Public Health (Prof Y S Khader PhD), Jordan University of Science and Technology, Irbid, Jordan; Department of Epidemiology and Biostatistics (E A Khan MPH), Health Services Academy, Islamabad, Pakistan; Department of Pediatrics (I A Khan MD), Rutgers University, New Brunswick, NJ, USA; Epidemiology Department (M Khan MD), Jazan University, Jazan, Saudi Arabia; Primary Care Department (M A Khan MSc), NHS North West London, London, UK; Department of Public Health (Prof J Khubchandani PhD), New Mexico State University, Las Cruces, NM, USA; Department of Preventive Medicine (G Kim PhD, Prof E Park PhD), Institute of Health Services Research (Prof E Park PhD), Yonsei University, Seoul, South Korea; Department of Genomics and Digital Health (M Kim MD), Samsung Advanced Institute for Health Sciences & Technology (SAIHST), Seoul, South Korea; Public Health Center (M Kim MD), Ministry of Health and Welfare, Wando, South Korea; School of Traditional Chinese Medicine (Y Kim PhD), Xiamen University Malaysia, Sepang, Malaysia; School of Health Sciences (Prof A Kisa PhD), Kristiania University College, Oslo, Norway; Department of Global Community Health and Behavioral Sciences (Prof A Kisa PhD), Tulane University, New Orleans, LA, USA; Department of Nursing and Health Promotion (S Kisa PhD), Oslo Metropolitan University, Oslo, Norway; Department of Public Health (Prof M Kivimäki PhD, Prof T Lallukka PhD), University of Helsinki, Helsinki, Finland; Department of Environmental Health Engineering (A Koolivand PhD), Department of Epidemiology (R Moradzadeh PhD, M Zamanian PhD), Arak University of Medical Sciences, Arak, Iran; Kasturba Medical College, Udupi, India (S Koulmane Laxminarayana MD); Biomedical Research Networking Center for Mental Health Network (CIBERSAM) (A Koyanagi MD), San Juan de Dios Sanitary Park, Sant Boi de Llobregat, Spain; Catalan Institution for Research and Advanced Studies (ICREA), Barcelona, Spain (A Koyanagi MD); Department of Anthropology (K Krishan PhD), Panjab University, Chandigarh, India; Department of Anesthesiology (V Krishnamoorthy MD), Duke University, Durham, NC, USA; Faculty of Public Health (D Kusuma DSc), University of Indonesia, Depok, Indonesia; National Institute for Health Research (NIHR) Oxford Biomedical Research Centre, Oxford, UK (B Lacey PhD); Department of Otorhinolaryngology (S Lasrado MS), Father Muller Medical College, Mangalore, India; Department of Neurology and Psychiatry (P M Lavados MD), German Clinic of Santiago, Santiago, Chile; Faculty of Medicine (P M Lavados MD), University of Development, Santiago, Chile; UO Neurologia, Salute Pubblica e Disabilità (M Leonardi MD, F G Magnani PhD, A Raggi PhD, D Sattin PsyD, S Schiavolin MSc), Fondazione IRCCS Istituto Neurologico Carlo Besta (Neurology, Public Health and Disability Unit, Carlo Besta Neurological Institute), Milan, Italy; Department of Sociology (B Li PhD), Shenzhen University, Shenzhen, China; School of Public Health (Prof H Lin PhD), Zhengzhou University, Zhengzhou, China; Asbestos Diseases Research Institute, Concord, NSW, Australia (R Lin PhD); Department of Quantitative Health Science (X Liu PhD), Case Western Reserve University, Cleveland, OH, USA; Department of Pediatrics (W D Lo MD), Ohio State University, Columbus, OH, USA; Department of Pediatric Neurology (W D Lo MD), Nationwide Children's Hospital, Columbus, OH, USA; Institute of Nutritional Sciences (Prof S Lorkowski PhD), Friedrich Schiller University Jena, Jena, Germany; Competence Cluster for Nutrition and Cardiovascular Health (nutriCARD), Jena, Germany (Prof S Lorkowski PhD); School of Medicine (Prof G Lucchetti PhD), Federal University of Juiz de Fora, Juiz de Fora, Brazil; Department of Neurosciences and Behavioral Sciences (R Lutzky Saute MD), Department of Pathology and Legal Medicine (M R Tovani-Palone PhD), University of São Paulo, Ribeirão Preto, Brazil; Radiology Department (H Magdy Abd El Razek MD), Egypt Ministry of Health and Population, Mansoura, Egypt; Department of Community Medicine (P B Mahajan MD), Jawaharlal Institute of Postgraduate Medical Education and Research, Karaikal, India; Mass Communication Department (A Makki PhD), University of Sharjah, Sharjah, United Arab Emirates; Non-communicable Disease Research Center (Prof R Malekzadeh MD, S G Sepanlou MD), Health Policy Research Center (S Shahabi PhD), Shiraz University of Medical Sciences, Shiraz, Iran; School of Medicine (N Manafi MD), University of Manitoba, Winnipeg, MB, Canada; Value-Based Healthcare Unit (Prof L G Mantovani DSc), IRCCS MultiMedica, Sesto San Giovanni, Italy; Indonesian Public Health Association, Surabaya, Indonesia (S Martini PhD); Neurology Department (Prof M Mehndiratta MD), Janakpuri Super Specialty Hospital, New Delhi, India; Department of Neurology (Prof M Mehndiratta MD), Govind Ballabh Institute of Medical Education and Research, New Delhi, India; Forensic Medicine Division (Prof R G Menezes MD), Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia; Neurology Unit (A Meretoja MD), Helsinki University Hospital, Helsinki, Finland; School of Health Sciences (A Meretoja MD), Department of Neurology (Prof T Wijeratne MD), University of Melbourne, Melbourne, VIC, Australia; School of Medicine and Public Health (A G Mersha MD), University of Newcastle, Newcastle, NSW, Australia; School of Public Health and Community Medicine (J Miao Jonasson PhD), University of Gothenburg, Gothenburg, Sweden; Center for Innovation in Medical Education (B Miazgowski MD), Department of Propedeutics of Internal Diseases & Arterial Hypertension (Prof T Miazgowski MD), Pomeranian Medical University, Szczecin, Poland (B Miazgowski MD); Woman-Mother-Child Department (I Michalek PhD), Lausanne University Hospital, Lausanne, Switzerland; Internal Medicine Programme (Prof E M Mirrakhimov PhD), Kyrgyz State Medical Academy, Bishkek, Kyrgyzstan; Department of Atherosclerosis and Coronary Heart Disease (Prof E M Mirrakhimov PhD), National Center of Cardiology and Internal Disease, Bishkek, Kyrgyzstan; Internal Medicine Department (Y Mohammad MD), Department of Pediatrics (B H Sobaih MD), Pediatric Intensive Care Unit (M Tamsah MD), King Saud University, Riyadh, Saudi Arabia; Department of Epidemiology and Biostatistics (A Mohammadian-Hafshejani PhD), Shahrekord University of Medical Sciences, Shahrekord, Iran; Health Systems and Policy Research Unit (S Mohammed PhD), Ahmadu Bello University, Zaria, Nigeria; Department of Health Care Management (S Mohammed PhD), Technical University of Berlin, Berlin, Germany; Department of Epidemiology and Biostatistics (Y Mokhayeri PhD), Lorestan University of Medical Sciences, Khorramabad, Iran; Department of Computer Science and Engineering (M A Moni PhD), Pabna University of Science and Technology, Pabna, Bangladesh; Department of Medicine (A A Montasir FMD), TMSS Medical College, Bogura, Bangladesh; Department of Medicine (A A Montasir FMD), Sofia Ismail Memorial Medical Centre, Bogura, Bangladesh; Department of Cardiology and Cardiac Surgery (J Morze PhD), University of Warmia and Mazury, Olsztyn, Poland; School of Medical Sciences (K Musa PhD), Science University of Malaysia, Kubang Kerian, Malaysia; Research and Analytics Department (A J Nagarajan MTEch), Initiative for Financing Health and Human Development, Chennai, India; Department of Research and Analytics (A J Nagarajan MTEch), Bioinsilico Technologies, Chennai, India; Mysore Medical College and Research Institute (Prof S Narasimha Swamy MD), Government Medical College, Mysore, India; Department of Clinical Medicine (Prof B R Nascimento PhD), Clinical Hospital (Prof B R Nascimento PhD), Federal University of Minas Gerais, Belo Horizonte, Brazil; Cardio-Aid, Bucharest, Romania (R I Negoii PhD); Bupa Clemton Park (S Neupane Kandel BSN), Bupa, Sydney, NSW, Australia; Institute for Global Health Innovations (T H Nguyen MSc, L G Vu MSc), Faculty of Medicine (T H Nguyen MSc,

L G Vu MSc), Duy Tan University, Da Nang, Vietnam; Department of Clinical Sciences (Prof B Norrving PhD), Lund University, Lund, Sweden; Centre for Heart Rhythm Disorders (J Noubiap MD), School of Public Health (V Podder HSC), Adelaide Medical School (L Yadav PhD), University of Adelaide, Adelaide, SA, Australia; Department of Pediatrics (V E Nwatah MD), National Hospital, Abuja, Nigeria; Department of International Public Health (V E Nwatah MD), University of Liverpool, Liverpool, UK; Administrative and Economic Sciences Department (Prof B Oancea PhD), University of Bucharest, Bucharest, Romania; Department of Community Health and Primary Care (O O Odukoya MSc), University of Lagos, Idi Araba, Nigeria; Department of Family and Preventive Medicine (O O Odukoya MSc), University of Utah, Salt Lake City, UT, USA; Department of Psychiatry (A T Olagunju MD), University of Lagos, Lagos, Nigeria; Section of Sustainable Health (H Orru PhD), Umeå University, Umeå, Sweden; Department of Health Metrics (A Pana MD), Center for Health Outcomes & Evaluation, Bucharest, Romania; Department of Health Administration and Policy (T Parekh MSc), George Mason University, Fairfax, VA, USA; Research & Development Department (M Pathak PhD), Kalinga Institute of Medical Sciences, Bhubaneswar, India; International Institute for Educational Planning (IIEP) (Prof M F P Peres MD), Albert Einstein Hospital, São Paulo, Brazil; Department of Development Studies (Prof A Perianayagam PhD), International Institute for Population Sciences, Mumbai, India; Cancer Control Alberta (T Pham MD), Alberta Health Services, Edmonton, AB, Canada; Medical College (V Podder HSC), Tairunnessa Memorial Medical College and Hospital, Gazipur, Bangladesh; Department of Public Health (S Polinder PhD), Department of Neurosurgery (V Volovici PhD), Erasmus University Medical Center, Rotterdam, Netherlands; University Medical Center Groningen (Prof M J Postma PhD), School of Economics and Business (Prof M J Postma PhD), University of Groningen, Groningen, Netherlands; College of Medicine (A Radfar MD), University of Central Florida, Orlando, FL, USA; Department of Immunology (Prof A Rafiei PhD), Molecular and Cell Biology Research Center (Prof A Rafiei PhD), Mazandaran University of Medical Sciences, Sari, Iran; Thalassemia and Hemoglobinopathy Research Center (F Rahim PhD), Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran; Department of Population Science and Human Resource Development (M Rahman DrPH), University of Rajshahi, Rajshahi, Bangladesh; School of Nursing and Healthcare Professions (M Rahman PhD), Federation University Australia, Berwick, VIC, Australia; Future Technology Research Center (A Rahmani PhD), National Yunlin University of Science and Technology, Yunlin, Taiwan; Department of Oral Pathology (S Rao MDS), Srinivas Institute of Dental Sciences, Mangalore, India; University College London Hospitals, London, UK (D L Rawaf MD); Academic Public Health England (Prof S Rawaf MD), Public Health England, London, UK; School of Nursing and Midwifery (V Renjith PhD), Royal College of Surgeons in Ireland - Bahrain, Muharraq Governorate, Bahrain; School of Medicine (Prof A M N Renzaho PhD), Translational Health Research Institute (Prof A M N Renzaho PhD), Western Sydney University, Campbelltown, NSW, Australia; Department of Pharmacology and Toxicology (Prof J A B Rodriguez PhD), University of Antioquia, Medellin, Colombia; Department of Clinical Research (L Roever PhD), Federal University of Uberlândia, Uberlândia, Brazil; Department of Neuroscience (M Romoli MD), University of Perugia, Perugia, Italy; Department of Neurology (M Romoli MD), Infermi Hospital, Rimini, Italy; Department of Cardiology and Internal Medicine (Prof A Rynkiewicz PhD), University of Warmia and Mazury, Olsztyn, Poland; Department of Neurology (Prof S Sacco MD), University of L'Aquila, L'Aquila, Italy; Cardiac Rehabilitation Research Center (Prof M Sadeghi MD), Isfahan Cardiovascular Research Institute (Prof N Sarrafzadegan MD), Isfahan University of Medical Sciences, Isfahan, Iran; Applied Biomedical Research Center (A Sahebkar PhD), Biotechnology Research Center (A Sahebkar PhD), Mashhad University of Medical Sciences, Mashhad, Iran; Health Systems and Population Studies Division (K Saif-Ur-Rahman MPH), Maternal and Child Health Division (S Zaman MPH), International Centre for Diarrhoeal Disease Research, Bangladesh, Dhaka, Bangladesh; Department of Public Health and Health Systems (K Saif-Ur-Rahman MPH, Prof H Yatsuya PhD), Nagoya University, Nagoya, Japan; Cardiovascular Intensive Care Unit (R Salah MD), Ministry of Health & Population, Cairo, Egypt; Division of Infectious Diseases (R Salah MD), University of Louisville, Louisville, KY, USA; Emergency Department (M Samaei MD), Brown University, Providence, RI, USA; Faculty of Health & Social Sciences (B Sathian PhD), Bournemouth University, Bournemouth, UK; Hypertension and Kidney Disease Laboratory (Prof M P Schlaich MD), Baker Heart and Diabetes Institute, Melbourne, VIC, Australia; School of Public Health and Community Medicine (Prof A E Schutte PhD), Centre for Big Data Research in Health (M Shawon PhD), School of Population Health (X Xu PhD), University of New South Wales, Sydney, NSW, Australia; Cardiovascular Program (X Xu PhD), The George Institute for Global Health, Sydney, NSW, Australia (Prof A E Schutte PhD); National Heart, Lung, and Blood Institute (A Seylani BS), National Institute of Health, Rockville, MD, USA; Center for Biomedical Information Technology (F Sha PhD), Shenzhen Institutes of Advanced Technology, Shenzhen, China; Independent Consultant, Karachi, Pakistan (M A Shaikh MD); Department of Community Medicine (M Shannawaz PhD), BLDE University, Vijayapur, India; The University of Tokyo, Tokyo, Japan (Prof K Shibuya MD); Department of Health Education and Health Promotion (S Siabani PhD), Kermanshah University of Medical Sciences, Kermanshah, Iran; Department of Physical Education (Prof D A S Silva PhD), Federal University of Santa Catarina, Florianópolis, Brazil; School of Medicine (Prof J A Singh MD), University of Alabama at Birmingham, Birmingham, AL, USA; Medicine Service (Prof J A Singh MD), US Department of Veterans Affairs (VA), Birmingham, AL, USA; Department of Community Medicine & Public Health (J Singh PhD), Tribhuvan University, Janakpur, Nepal; Department No.16 (V Y Skryabin MD), Laboratory of Genetics and Genomics (Prof M S Zastrozhin PhD), Moscow Research and Practical Centre on Addictions, Moscow, Russia; Therapeutic Department (A A Skryabina MD), Balashiha Central Hospital, Balashiha, Russia; Department of Pediatrics (B H Sobaih MD), King Khalid University Hospital, Riyadh, Saudi Arabia; Department of Cardiology (S Stortecky MD), University of Bern, Bern, Switzerland; Department of Epidemiology & Biostatistics (Prof S Stranges MD), The University of Western Ontario, London, ON, Canada; Department of Population Health (Prof S Stranges MD), Luxembourg Institute of Health, Strassen, Luxembourg; Department of Biomedical Sciences (E G Tadesse MSc), Arba Minch University, Arba Minch, Ethiopia; Research and Development Center for Humanities and Health Management (I U Tarigan PhD), National Institute of Health Research & Development, Jakarta, Indonesia; Department for Clinical Neurosciences and Preventive Medicine (Y Teuschl PhD), Danube University Krems, Krems, Austria; Department of Medicine (Prof M Tonelli MD), University of Calgary, Calgary, AB, Canada; Modestum LTD, London, UK (M R Tovani-Palone PhD); Department of Health Economics (B X Tran PhD), Hanoi Medical University, Hanoi, Vietnam; Department of Neurology (Prof M Tripathi MD), All India Institute of Medical Sciences, Delhi, India; Multidisciplinary Department (A Ullah MS), National University of Medical Sciences (NUMS), Rawalpindi, Pakistan; Department of Cardiovascular, Endocrine-metabolic Diseases and Aging (B Unim PhD), National Institute of Health, Rome, Italy; Clinical Cancer Research Center (S Valadan Tahbaz PhD, S Yahyazadeh Jabbari MD), Milad General Hospital, Tehran, Iran; Department of Microbiology (S Valadan Tahbaz PhD), Islamic Azad University, Tehran, Iran; UKK Institute, Tampere, Finland (Prof T J Vasankari MD); Raffles Neuroscience Centre (Prof N Venketasubramanian MBBS), Raffles Hospital, Singapore, Singapore; Yong Loo Lin School of Medicine (Prof N Venketasubramanian MBBS), National University of Singapore, Singapore, Singapore; Faculty of Information Technology (B Vo PhD), Ho Chi Minh City University of Technology (HUTECH), Ho Chi Minh City, Vietnam; Center for Experimental Microsurgery (V Volovici PhD), Iuliu Hațieganu University of Medicine and Pharmacy, Cluj-Napoca, Romania; Center of Excellence in Behavioral Medicine (G T Vu BA), Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam; Foundation University Medical College (Prof Y Waheed PhD), Foundation University Islamabad, Islamabad, Pakistan; Department of Medicine (Prof T Wijeratne MD), University of Rajarata, Saliyapura Anuradhapuraya, Sri Lanka; Institute of Health and Society



(Prof A S Winkler PhD), University of Oslo, Oslo, Norway; Department of Neurology (Prof A S Winkler PhD), Technical University of Munich, Munich, Germany; NIHR Biomedical Research Centre (Prof C D A Wolfe MD), Guy's and St Thomas' Hospital and Kings College London, London, UK; The George Institute for Global Health (Prof M Woodward PhD), University of New South Wales, Camperdown, NSW, Australia; The George Institute (Prof M Woodward PhD), University of New South Wales, Kensington, NSW, Australia; The George Institute for Global Health (J H Wu PhD), University of New South Wales, Newtown, NSW, Australia; Research and Development Division (L Yadav PhD), The George Institute for Global Health, New Delhi, India; Psychology Department (A Yadollahpour PhD), University of Sheffield, Sheffield, UK; Department of Public Health (Prof H Yatsuya PhD), Fujita Health University, Toyoake, Japan; Department of Neuropsychopharmacology (N Yonemoto MPH), National Center of Neurology and Psychiatry, Kodaira, Japan; Department of Public Health (N Yonemoto MPH), Juntendo University, Tokyo, Japan; Department of Epidemiology and Biostatistics (Prof C Yu PhD), School of Medicine (Z Zhang PhD), Wuhan University, Wuhan, China; Department of Clinical Pharmacy and Outcomes Sciences (I Yunusa PhD), University of South Carolina, Columbia, SC, USA; School of Rehabilitation Therapy (M S Zaman MSc), Queen's University, Kingston, ON, Canada; Department of Neurology (R Zand MD), University of Tennessee, Memphis, TN, USA; Addictology Department (Prof M S Zastrozhin PhD), Pediatrics Department (A Zastrozhina PhD), Russian Medical Academy of Continuous Professional Education, Moscow, Russia; School of Public Health (Y Zhang PhD), Hubei Province Key Laboratory of Occupational Hazard Identification and Control (Y Zhang PhD), Wuhan University of Science and Technology, Wuhan, China; Health Technology Assessment Unit (Y H Zuniga BS), Department of Health Philippines, Manila, Philippines; #MentalHealthPH, Inc, Quezon City, Philippines (Y H Zuniga BS).

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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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