Pragmatic solutions to reduce the global burden of stroke: a World Stroke Organization– *Lancet Neurology* Commission

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Executive summary

Stroke is the second leading cause of death worldwide. The burden of disability after a stroke is also large, and is increasing at a faster pace in low-income and middle-income countries than in high-income countries. Alarmingly, the incidence of stroke is increasing in young and middle-aged people (ie, age <55 years) globally. Should these trends continue, Sustainable Development Goal 3.4 (reducing the burden of stroke as part of the general target to reduce the burden of non-communicable diseases by a third by 2030) will not be met.

In this Commission, we forecast the burden of stroke from 2020 to 2050. We project that stroke mortality will increase by 50%—from 6·6 million (95% uncertainty interval [UI] 6·0 million–7·1 million) in 2020, to 9·7 million (8·0 million–11·6 million) in 2050—with disability-adjusted life-years (DALYs) growing over the same period from 144·8 million (133·9 million–156·9 million) in 2020, to 189·3 million (161·8 million–224·9 million) in 2050. These projections prompted us to do a situational analysis across the four pillars of the stroke quadrangle: surveillance, prevention, acute care, and rehabilitation. We have also identified the barriers to, and facilitators for, the achievement of these four pillars.

On the basis of our assessment, we have identified and prioritised several recommendations. For each of the four pillars (surveillance, prevention, acute care, and rehabilitation), we propose pragmatic solutions for the implementation of evidence-based interventions to reduce the global burden of stroke. The estimated direct (ie, treatment and rehabilitation) and indirect (considering productivity loss) costs of stroke globally are in excess of US$891 billion annually. The pragmatic solutions we put forwards for urgent implementation should help to mitigate these losses, reduce the global burden of stroke, and contribute to achievement of Sustainable Development Goal 3.4, the WHO Intersectoral Global Action Plan on epilepsy and other neurological disorders (2022–2031), and the WHO Global Action Plan for prevention and control of non-communicable diseases.

Reduction of the global burden of stroke, particularly in low-income and middle-income countries, by implementing primary and secondary stroke prevention strategies and evidence-based acute care and re-habilitation services is urgently required. Measures to facilitate this goal include: the establishment of a framework to monitor and assess the burden of stroke (and its risk factors) and stroke services at a national level; the implementation of integrated population-level and individual-level prevention strategies for people at any increased risk of cerebrovascular disease, with emphasis on early detection and control of hypertension; planning and delivery of acute stroke care services, including the establishment of stroke units with access to reperfusion therapies for ischaemic stroke and workforce training and capacity building (and monitoring of quality indicators for these services nationally, regionally, and globally); the promotion of interdisciplinary stroke care services, training for caregivers, and capacity building for community health workers and other health-care providers working in stroke rehabilitation; and the creation of a stroke advocacy and implementation ecosystem that includes all relevant communities, organisations, and stakeholders.

Introduction

The global burden of stroke is huge: in 2020, stroke was the second leading cause of death (6·6 million deaths) and the third leading cause of disability (responsible for 143 million **disability-adjusted life-years** [DALYs]) after neonatal disorders (in children) and ischaemic heart disease (in adults).[1,2] Alarmingly, evidence suggests that the incidence of stroke in younger individuals (ie, people younger than 55 years) is increasing worldwide.[3] The absolute number of people affected by stroke, which includes those who die or remain disabled, has almost doubled in the past 30 years.[1] Most of the contemporary stroke burden—86% of global deaths and 89% of global DALYs lost because of stroke in 2020—is in low-income and middle-income countries (LMICs),[1] and the burden of stroke is increasing faster in LMICs than in high-income countries (HICs).[1] Stroke is also a leading cause of depression and dementia, which are other common non-communicable diseases (NCDs).[4,5]

Little progress has been made by most countries towards Sustainable Development Goal (SDG) 3.4—reducing premature mortality from NCDs by a third between 2015 and 2030.[6] Achieving SDG 3.4 worldwide, which would in turn facilitate the achievement of nine other SDGs,[7] would require an additional US$140 billion of spending on NCD interventions from 2023–30, but could help to avert 39 million deaths and generate $2·7 trillion in net economic benefits (with benefits outweighing costs by a factor of 19:1).[6]

Given that the incidence of stroke rises with age, the combination of growing populations and ageing demographics is likely to result in large increases in global deaths and disability in the future unless major improvements occur in population prevention programmes that reduce the risk of stroke.[8] Thus,

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**Disability-adjusted life-years
(DALYs)**
The sum of the years of life lost as
a result of premature mortality
from a disease and the years lived
with a disability associated with
prevalent cases of the disease in
a population. One DALY
represents the loss of the
equivalent of one year of full
health

Key messages

- Stroke is the second leading cause of death, the third leading cause of disability, and a leading cause of dementia worldwide. The age-standardised incidence of stroke in younger individuals (ie, <55 years) is increasing in both high-income countries and low-income and middle-income countries. The absolute number of people affected by stroke (ie, who die from or remain disabled by stroke) has almost doubled during the past three decades, with more than 86% of the stroke burden in low-income and middle-income countries. Our projections show that the global burden of stroke (ie, deaths and disability-adjusted life-years) will continue to grow, with widening gaps between high-income countries and poorer countries.

- Multiple factors contribute to the high burden of stroke in low-income and middle-income countries, including undetected and uncontrolled hypertension, lack of easily accessible, high-quality health services, insufficient attention to and investment in prevention, air pollution, population growth, unhealthy lifestyles (eg, poor diet, smoking, sedentary lifestyle, obesity), an earlier age of stroke onset and greater proportion of haemorrhagic strokes than in high-income countries, and the burden of infectious diseases resulting in competition for limited healthcare resources.

- Major barriers to high-quality stroke surveillance, prevention, acute care, and rehabilitation are: low awareness of stroke and its evidence-based management among communities, health-care professionals, and policy makers, and scarce surveillance data for stroke risk factors, events, management, and outcomes to enable quality improvement and priority setting. Major facilitators include professional stroke organisations and networks that could advocate and build capacity for stroke care and research, and universal health coverage that can facilitate population-wide access to evidence-based care (pre-hospital care, acute care, rehabilitation, and prevention).

- The total cost of stroke (both direct treatment and rehabilitation costs and indirect costs due to loss of income) will rise from US$891 billion per year in 2017 to as much as $2·31 trillion by 2050. However, this increase can be avoided because stroke is highly preventable and treatable. To mitigate this massive expense and reduce the burden of stroke globally, governments, health ministries, and other

stakeholders need to apply the pragmatic approaches that we suggest.

- Global investment in stroke surveillance, prevention, treatment, and rehabilitation will accelerate the achievement of Sustainable Development Goal 3.4, which aims to reduce premature mortality from non-communicable diseases by a third by 2030. Reducing the global burden of stroke is essential for promoting brain health and for overall health and wellbeing.

Key priorities to reduce the burden of stroke

Surveillance
- Incorporate stroke event and risk factor surveillance into national stroke action plans.
- Establish low-cost surveillance systems, ideally within existing systems for non-communicable diseases, to adequately guide prevention and treatment.
- Embed regular national risk factor surveillance in national censuses.

Prevention
- Establish an intersectoral system for population-wide primordial, primary, and secondary stroke prevention. Preventive strategies, with emphasis on lifestyle modification, should be implemented for people at any level of risk of stroke and cardiovascular disease. Primary and secondary stroke prevention services should be freely accessible and supported by universal health coverage, with access to affordable drugs for management of hypertension, dyslipidaemia, diabetes, and clotting disorders. Governments must allocate a fixed proportion of their annual health-care funding for prevention of stroke and related non-communicable diseases. This funding could come from taxation of tobacco, salt, alcohol, and sugar.
- Raise public awareness and take action to encourage a healthy lifestyle and prevent stroke via population-wide deployment of digital technologies (a so-called motivational mass individual strategy for stroke prevention) with simple, inexpensive screening for cardiovascular disease and modifiable risk factors. This strategy should be reinforced by health-care professionals through digital technologies for person-centred primary and secondary prevention of stroke and cardiovascular disease, linked to national electronic health databases.

pragmatic solutions to reduce the burden of stroke and related NCDs are urgently needed to save lives and improve brain health, quality of life, and socioeconomic productivity globally.[8–11]

To proffer solutions for reducing the global burden of stroke, we established the World Stroke Organization–*Lancet Neurology* Commission on Stroke[8,12–14] in collaboration with WHO. In this Commission, we estimate the current and future global burden of stroke,

review evidence-based interventions, and prioritise pragmatic solutions for reducing disease burden across the four pillars of the stroke quadrangle (surveillance, prevention, acute care, and rehabilitation; figure 1).[15] We also do a situational and gap analysis by reviewing stroke-related literature, guidelines, and findings from surveys.[8,13,14] Our pathways for implementation of the evidence-based solutions (based on **implementation science theories**[16]) were created on the basis of thematic

(Key messages continued from previous page)

- Establish protocol-based shifting (or sharing) of tasks from highly-trained health-care professionals to incentivised, supervised, and certified paramedical health-care workers, particularly community-based health-care workers, to facilitate population-wide primary stroke prevention interventions across rural and urban settings.

Acute care
- Prioritise effective planning of acute stroke care services; capacity building, training, and certification of a multidisciplinary workforce; provision of evidence-based equipment and affordable medicines; and adequate resource allocation at national and regional levels.
- Establish regional networks and protocol-driven services, including community-wide awareness campaigns for early recognition of a stroke, regionally coordinated pre-hospital services, telemedicine networks, and stroke centres that can triage and treat all cases of acute stroke, and facilitate timely access to reperfusion therapy, including intravenous thrombolysis or mechanical thrombectomy for ischaemic stroke.
- Integrate acute care networks across the pillars of the quadrangle of resources, including surveillance, prevention, and rehabilitation services, by involving all relevant stakeholders (ie, communities, policy makers, non-governmental organisations, national and regional stroke organisations, and public and private health-care providers) in the stroke care continuum.

Rehabilitation
- Establish multidisciplinary rehabilitation services and adapt evidence-based recommendations to the local context, including the training, support, and supervision of community health-care workers and caregivers to assist in long-term care.
- Invest in research to generate innovative low-cost interventions, in public awareness to improve demand for rehabilitation services, and in advocacy to mobilise resources and financial solutions for multidisciplinary rehabilitation, especially in low-income and middle-income countries.
- Promote the training of stroke rehabilitation professionals. Use digital portals to improve training and to extend the use of assessment tools—such as the modified Rankin Scale and the US National Institutes of Health Stroke Scale—and quality-of-life measures to assess functional impairment and monitor recovery.

analysis of barriers and facilitators (appendix pp 4–16, 50). We believe that the implementation of the pragmatic solutions of this Commission will be crucial for the realisation of the WHO global action plan for the prevention and control of NCDs 2013–2030.[17,18]

An enormous burden of disease can be averted

Previous estimates of the burden of stroke (measured as deaths and disability caused by a stroke) by the Global Burden of Disease (GBD) study were limited to 1990–2019,[1] and the study also forecasted life expectancy, years of life lost, and mortality to 2040.[19] However, for the long-term planning of health care, priority setting, and resource allocation, policy makers and national health services require projections of disease burden for at least the next 30 years. We used the same methods as the GBD study to estimate stroke burden for 2020 to 2050 overall and by age group (<60 years *vs* ≥60 years), World Bank country classification by income level (HICs *vs* LMICs), stroke type (**ischaemic stroke** *vs* **intracerebral haemorrhage** *vs* **subarachnoid haemorrhage**), and GBD super-regions. Our forecasts of stroke burden are based on estimates of mortality, incidence, and prevalence from the GBD 2019 study, and assume that medical procedures and prevention will be the same in 2050 as in 2019.[1,2] Methods for establishing stroke types have been reported elsewhere,[1] and further details of our methods are in the appendix (pp 6–7). Mortality rates for each individual cause were forecasted with a three-component model comprising the underlying (or risk deleted) mortality, modelled as a function of the Socio-demographic Index[2] and time; a risk factor scalar that captures cause-specific combined risk-factor effects based upon the GBD comparative risk assessment, which quantifies risk–outcome associations accounting for risk factor mediation; and unexplained residual mortality. Forecasts of DALYs lost were produced from forecasts of years of life lost (via mortality) and years lived with disabilities (via prevalence and incidence).

Projections of mortality and disability

We estimate that the absolute number of people who will die from stroke worldwide will increase by 50% by 2050: from 6·6 million (95% uncertainty interval [UI] 6·0 million–7·1 million) in 2020, to 9·7 million (8·0 million–11·6 million) in 2050 (table 1). The burden of disability will also increase. The total number of DALYs from stroke is projected to increase by 31%: from 144·8 million (133·9 million–156·9 million) in 2020, to 189·4 million (161·8 million–224·9 million) in 2050 (figure 2, table 1; appendix pp 54, 63–67).

Although population growth and ageing are key drivers in forecasting estimates of stroke deaths and DALY counts, our survey analysis also suggests that an insufficient level of, and inequity in access to, high-quality prevention and acute and rehabilitation services will drive stroke-related deaths and disability, particularly in LMICs.

Mortality and disability according to age

We project an increase in the absolute number of stroke deaths in people aged 60 years or older (from 5·6 million

For more on the **WHO global action plan for NCDs** see https://www.who.int/teams/noncommunicable-diseases/governance/roadmap

For the **Global Burden of Disease study** see https://www.healthdata.org/research-analysis/gbd

Ischaemic stroke
A neurological disease that occurs when the blood supply to part of the brain is blocked, with resulting death of the affected brain cells

Intracerebral haemorrhage
A neurological disease that occurs when there is a bleeding from a blood vessel into the brain tissue, resulting in death of the affected tissue

Subarachnoid haemorrhage
A neurological disease that occurs when there is a bleeding into the space surrounding the brain
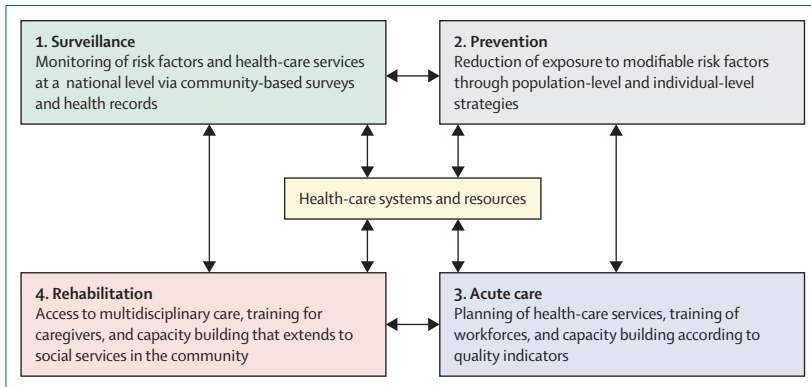
Figure 1: The four pillars of the quadrangle to tackle the burden of stroke: surveillance, prevention, acute care, and rehabilitation

Surveillance strategies include establishing a framework for regular monitoring and assessment of the burden of stroke and its risk factors, and of health-care services at a national level via community-based surveys, data linkage, and electronic health records. These strategies provide the necessary evidence for planning and monitoring prevention, acute care, and rehabilitation interventions. Primordial, primary, and secondary prevention involve implementation of integrated population-wide strategies to reduce modifiable risk factors, such as hypertension and diabetes. Prevention strategies can reduce the incidence, mortality, and prevalence of stroke, and people who develop stroke benefit from secondary prevention (in addition to acute care). Acute stroke care should result in early diagnosis and involves evidence-based management that reduces mortality and improves functional outcomes. Finally, rehabilitation services provide interdisciplinary care for stroke survivors, with the aim of reducing disability-adjusted life-years and improving quality of life. Adapted with permission from Owolabi et al, 2023.[11]

[95% UI 5·1 million–6·1 million] in 2020, to 8·8 million [7·3 million–10·4 million] in 2050; table 1), probably due to ageing of the population. By contrast, the number of deaths in people younger than 60 years in 2050 is predicted to be roughly the same as that in 2020 (table 1). We also forecast a decrease in the **age-standardised rate** of stroke per 100 000 person-years in both people younger than 60 years (from 13·3 [12·1–14·5] in 2020, to 9·9 [7·2–13·7] in 2050) and in those aged 60 years or older (from 565·7 [508·6–613·4] in 2020, to 361·7 [299·1–431·9] in 2050; table 1; appendix pp 50–53, 63–64). The smaller proportional decrease in people younger than 60 years compared with those aged 60 years or older could be related to the reported increase in the prevalence of diabetes and overweight in the younger age group.[20,21]

In HICs, for people of all ages, age-standardised DALYs per 100 000 person-years are expected to decrease substantially, from 699·0 (95% UI 629·9–761·1) in 2020, to 488·3 (415·0–571·1) in 2050, but the absolute number of DALYs overall is projected to remain largely static (figure 2, table 1), probably as a result of population growth and ageing populations.

	Deaths per 100 000 person-years (95% UI)		Millions of deaths (95% UI)		DALYS per 100 000 person-years (95% UI)		Millions of DALYs (95% UI)	
	2020	2050	2020	2050	2020	2050	2020	2050
Global								
Overall	84·89 (77·14–91·57)	105·18 (87·28–125·75)	6·62 (6·02–7·14)	9·72 (8·07–11·62)	1856·63 (1716·88–2010·86)	2048·32 (1750·41–2432·64)	144·84 (133·94–156·88)	189·36 (161·82–224·88)
Overall (age-standardised)	83·00 (75·32–89·61)	54·31 (44·39–66·34)	..	..	1747·70 (1612·34–1892·47)	1229·16 (1029·90–1477·44)	..	..
<60 years*	13·31 (12·10–14·47)	9·93 (7·16–13·65)	1·00 (0·91–1·09)	0·98 (0·71–1·34)	700·94 (638·28–767·75)	649·85 (511·34–825·96)	47·24 (43·01–51·54)	46·40 (36·51–58·98)
≥60 years*	565·65 (508·59–613·37)	361·69 (299·07–431·89)	5·62 (5·08–6·09)	8·75 (7·29–10·37)	9184·71 (8392·76–9959·58)	6795·05 (5890·94–7887·75)	97·61 (89·20–105·85)	142·95 (123·93–165·94)
High-income countries								
Overall	75·97 (64·96–83·79)	73·80 (60·26–85·93)	0·92 (0·79–1·02)	0·91 (0·74–1·06)	1316·64 (1181·93–1435·60)	1260·12 (1075·75–1438·24)	15·95 (14·32–17·39)	15·56 (13·28–17·76)
Overall (age-standardised)	33·65 (29·10–36·88)	18·86 (15·71–22·24)	..	..	699·00 (629·87–761·14)	488·27 (415·02–570·08)	..	..
<60 years*	4·20 (3·92–4·48)	3·15 (2·46–4·13)	0·06 (0·05–0·06)	0·04 (0·03–0·05)	248·23 (224·59–275·23)	200·28 (166·50–245·64)	3·22 (2·93–3·55)	2·43 (2·04–2·97)
≥60 years*	237·65 (203·36–262·05)	127·68 (104·70–148·94)	0·86 (0·73–0·95)	0·87 (0·71–1·01)	3820·45 (3413·56–4172·29)	2482·53 (2125·54–2827·26)	12·74 (11·27–13·95)	13·12 (11·18–14·84)
Low-income and middle-income countries								
Overall	86·50 (78·04–93·82)	109·95 (90·71–132·50)	5·70 (5·14–6·18)	8·81 (7·27–10·61)	1954·66 (1798·69–2120·66)	2168·44 (1832·77–2593·39)	128·81 (118·53–139·75)	173·68 (146·80–207·72)
Overall (age-standardised)	105·82 (95·25–115·00)	64·00 (52·48–77·90)	..	..	2131·91 (1964·62–2315·49)	1391·95 (1161·26–1678·44)	..	..
<60 years*	15·37 (13·89–16·78)	10·95 (7·88–15·15)	0·94 (0·85–1·03)	0·93 (0·67–1·29)	754·92 (684·66–824·59)	533·28 (414·75–682·72)	43·98 (39·89–48·04)	43·93 (34·29–56·03)
≥60 years*	732·10 (658·72–798·25)	431·31 (358·28–514·82)	4·76 (4·28–5·18)	7·87 (6·53–9·37)	11896·98 (10830·18–12957·13)	7337·88 (6301·95–8588·15)	84·83 (77·36–92·39)	129·75 (111·89–151·42)

Global stroke deaths and DALYs (both absolute counts and rates per 100 000 person-years) are shown. DALYs=disability-adjusted life-years. 95% UI=95% uncertainty interval. *Rates per 100 000 person-years are age-standardised, whereas absolute counts are not.

Table 1: Estimates of the global stroke burden, 2020 and 2050, by World Bank income group
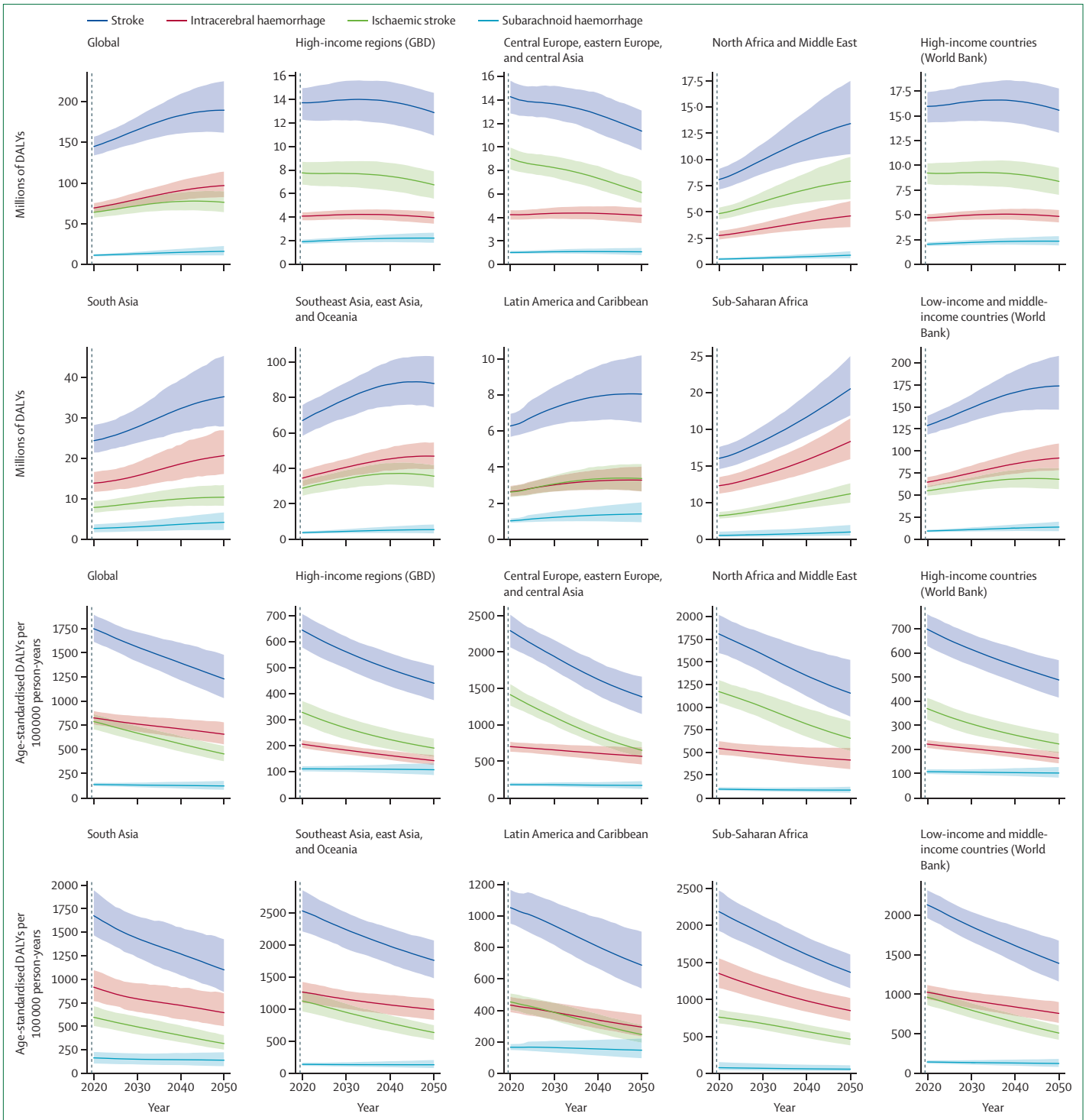
Figure 2: Estimates of DALYs due to stroke, 2020 and 2050, by GBD super-region
Data are absolute counts of DALYs and rates per 100 000 person-years. For comparison, the data are also represented by World Bank income group. Shaded areas represent 95% uncertainty intervals. GBD=Global Burden of Disease. DALYs=disability-adjusted life-years.

We project a non-significant decrease in DALYs in people younger than 60 years (from 47·2 million [43·0 million–51·5 million] in 2020, to 46·4 million [36·5 million–59·0 million] in 2050); in older people, we project a significant increase in DALYs from 97·6 million (89·2 million–105·9 million) in 2020, to

	Deaths per 100 000 person-years (95% UI)		Millions of deaths (95% UI)	
	2020	2050	2020	2050
Southeast Asia, east Asia, and Oceania				
Overall	141·27 (121·11–159·81)	232·25 (192·44–277·01)	3·06 (2·62–3·46)	4·94 (4·09–5·90)
Overall (age-standardised)	127·68 (108·49–144·44)	82·54 (68·37–98·42)	..	..
<60 years*	16·85 (14·51–19·24)	12·39 (9·35–15·59)	0·44 (0·38–0·50)	0·30 (0·22–0·37)
≥60 years*	895·16 (761·93–1014·07)	568·34 (467·50–677·61)	2·62 (2·23–2·96)	4·65 (3·83–5·51)
Central Europe, eastern Europe, and central Asia				
Overall	180·57 (162·50–198·46)	164·32 (140·17–192·41)	0·75 (0·68–0·83)	0·66 (0·56–0·77)
Overall (age-standardised)	119·26 (107·35–131·04)	62·53 (51·83–75·21)	..	..
<60 years*	15·71 (13·89–17·55)	10·98 (6·89–16·45)	0·07 (0·07–0·08)	0·04 (0·03–0·07)
≥60 years*	836·25 (751·08–917·84)	419·53 (357·46–492·06)	0·68 (0·61–0·75)	0·61 (0·52–0·71)
High-income				
Overall	74·69 (63·41–83·43)	69·50 (56·73–80·64)	0·81 (0·69–0·91)	0·78 (0·64–0·86)
Overall (age-standardised)	31·49 (27·14–34·92)	17·21 (14·17–20·20)	..	..
<60 years*	3·66 (3·45–3·93)	2·80 (2·18–3·61)	0·05 (0·04–0·05)	0·03 (0·03–0·04)
≥60 years*	224·15 (190·90–250·25)	116·96 (96·01–136·27)	0·77 (0·64–0·86)	0·75 (0·61–0·86)
Latin America and Caribbean				
Overall	48·58 (43·00–53·88)	61·80 (46·78–80·77)	0·29 (0·25–0·32)	0·42 (0·32–0·55)
Overall (age-standardised)	49·61 (43·68–54·98)	29·26 (21·48–39·93)	..	..
<60 years*	9·07 (8·07–10·24)	6·49 (4·08–10·31)	0·05 (0·05–0·07)	0·05 (0·03–0·08)
≥60 years*	330·39 (285·51–367·33)	186·95 (140·68–246·18)	0·23 (0·20–0·26)	0·37 (0·28–0·48)
North Africa and Middle East				
Overall	51·42 (45·70–57·70)	71·37 (52·93–98·35)	0·32 (0·28–0·36)	0·57 (0·43–0·80)
Overall (age-standardised)	86·57 (77·13–96·40)	48·23 (36·12–65·80)	..	..
<60 years*	12·94 (10·83–15·52)	9·34 (6·05–14·37)	0·07 (0·06–0·08)	0·08 (0·05–0·12)
≥60 years*	596·41 (531·95–660·90)	317·51 (243·27–418·31)	0·25 (0·22–0·28)	0·50 (0·38–0·67)
Sub-Saharan Africa				
Overall	36·80 (32·30–41·65)	38·62 (31·51–46·47)	0·41 (0·36–0·46)	0·78 (0·64–0·94)
Overall (age-standardised)	105·19 (92·64–118·00)	63·06 (52·63–73·21)	..	..
<60 years*	17·20 (14·15–20·43)	11·07 (8·01–15·37)	0·11 (0·09–0·13)	0·18 (0·13–0·26)
≥60 years*	714·50 (625·28–798·08)	423·04 (357·14–484·48)	0·30 (0·26–0·33)	0·60 (0·50–0·69)
South Asia				
Overall	54·30 (46·78–63·19)	75·24 (56·80–98·17)	0·99 (0·85–1·15)	1·56 (1·18–2·04)
Overall (age-standardised)	78·65 (67·53–91·29)	46·82 (35·04–61·58)	..	..
<60 years*	14·49 (12·34–17·01)	11·14 (7·30–17·00)	0·21 (0·18–0·25)	0·29 (0·19–0·44)
≥60 years*	522·96 (447·36–605·91)	293·92 (222·43–374·88)	0·78 (0·67–0·90)	1·27 (0·97–1·62)

Data are absolute counts of deaths and rates per 100 000 person-years. 95% UI=95% uncertainty interval. *Rates per 100 000 person-years are age-standardised, whereas absolute counts are not.

Table 2: Estimates of mortality due to stroke, 2020 and 2050, by Global Burden of Disease super-region

143·0 million (124·0 million–165·9 million) in 2050, probably due to continuous ageing of the population.

Mortality and disability by World Bank group
Our projections of stroke deaths in 2020 and 2050 by World Bank income group (table 2, figure 3) show that, although age-standardised stroke mortality will decline in both HICs (from 33·7 deaths per 100 000 person-years [95% UI 29·1–36·9] in 2020, to 18·9 per 100 000 person-years [15·7–22·2] in 2050) and LMICs (from 105·8 per 100 000 person-years [95·3–115·0] in 2020, to 64·0 per 100 000 person-years [52·5–77·9] in 2050), the absolute

number of people who are projected to die from stroke will only slightly decrease in HICs and will sharply increase in LMICs. In these poorer countries, the proportion of global stroke deaths is projected to increase from 86% in 2020, to 91% in 2050. In other words, more than 90% of the deaths caused by stroke worldwide will occur in LMICs by 2050, if circumstances remain the same as today.

In LMICs, even though the age-standardised DALYs associated with stroke are expected to decrease from 2131·9 per 100 000 person-years (95% UI 1964·6–2315·5) in 2020, to 1392·0 per 100 000 person-years (1161·3–1678·4) in 2050, the absolute number of DALYs
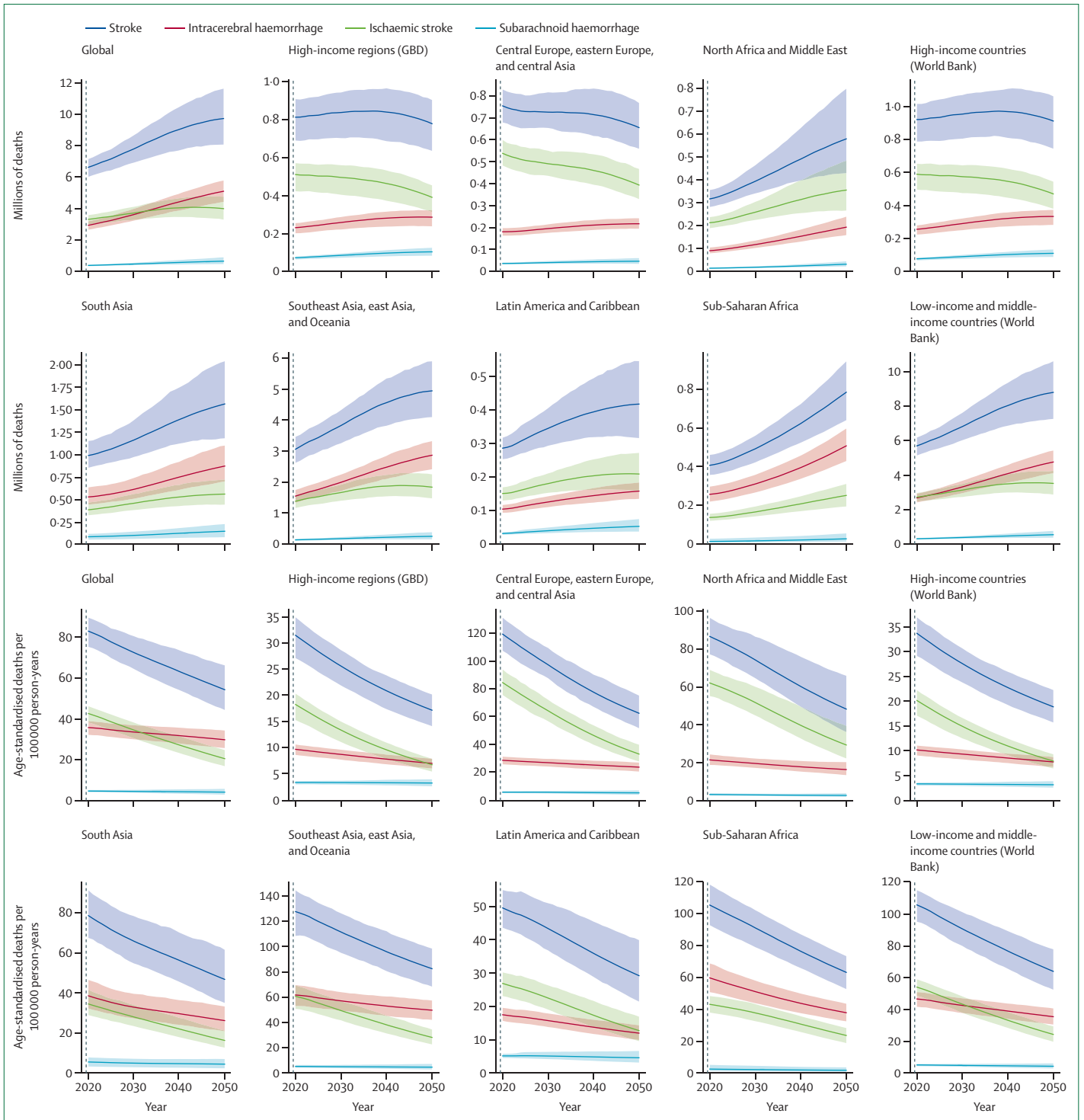
Figure 3: Estimates of mortality due to stroke, 2020 and 2050, by GBD super-region
Data are absolute counts of deaths and rates per 100 000 person-years. For comparison, the data are also represented by World Bank country income group. Shaded areas represent 95% uncertainty intervals. GBD=Global Burden of Disease.

will increase over the same period (table 1), largely because of the growth and ageing of populations in these countries.

Mortality and disability by GBD super-region
In 2050, 4·9 million (95% UI 4·1 million–5·9 million) of the estimated 9·7 million stroke deaths are projected

	DALYs per 100 000 person-years (95% UI)		Millions of DALYs (95% UI)	
	2020	2050	2020	2050
Southeast Asia, east Asia, and Oceania				
Overall	3098·72 (2698·22–3503·00)	4133·29 (3505·36–4851·04)	87·98 (74·61–103·26)	67·10 (58·43–75·85)
Overall (age-standardised)	2531·07 (2210·74–2852·43)	1760·79 (1481·49–2070·58)	..	..
<60 years*	800·34 (695·10–911·04)	616·17 (486·88–760·68)	20·14 (17·56–22·99)	13·93 (11·08–17·13)
≥60 years*	14 515·87 (12 576·37–16 386·97)	9686·91 (8255·21–11 348·06)	46·95 (40·65–53·10)	74·06 (62·82–86·76)
Central Europe, eastern Europe, and central Asia				
Overall	3415·23 (3075·35–3742·91)	2844·59 (2435·30–3283·44)	14·27 (12·85–15·64)	11·35 (9·72–13·10)
Overall (age-standardised)	2292·02 (2064·62–2511·35)	1384·40 (1148·25–1660·84)	..	..
<60 years*	739·83 (655·81–829·48)	548·22 (401·81–739·17)	3·35 (2·98–3·76)	2·15 (1·59–2·86)
≥60 years*	13 040·44 (11 771·67–14 273·44)	7174·71 (6260·53–8178·47)	10·92 (9·86–11·94)	9·20 (8·09–10·40)
High-income				
Overall	1261·84 (1129·63–1375·59)	1150·90 (976·25–1300·84)	13·72 (12·28–14·96)	12·89 (10·93–14·57)
Overall (age-standardised)	644·58 (578·00–706·37)	440·32 (375·18–507·88)	..	..
<60 years*	220·88 (199·20–247·14)	181·82 (150·95–222·68)	2·54 (2·30–2·83)	1·99 (1·67–2·41)
≥60 years*	3578·56 (3178·25–3923·08)	2230·38 (1893·56–2519·85)	11·17 (9·89–12·27)	10·89 (9·31–12·32)
Latin America and Caribbean				
Overall	1069·91 (951·33–1166·16)	1193·46 (958·46–1511·55)	6·29 (5·69–6·96)	8·05 (6·47–10·20)
Overall (age-standardised)	1053·01 (951·34–1166·16)	687·61 (539·05–900·33)	..	..
<60 years*	432·15 (383·19–484·38)	319·56 (231·30–460·02)	2·40 (2·13–2·69)	2·26 (1·66–3·20)
≥60 years*	5352·31 (4787·79–5951·93)	3236·32 (2639·65–4016·78)	3·89 (3·49–4·32)	5·79 (4·71–7·09)
North Africa and Middle East				
Overall	1313·40 (1159·24–1476·81)	1653·14 (1294·32–2154·86)	8·10 (7·15–9·10)	13·42 (10·51–17·50)
Overall (age-standardised)	1807·75 (1596·44–2017·88)	1154·33 (895·49–1521·04)	..	..
<60 years*	666·19 (561·98–781·43)	501·50 (358·19–710·24)	3·60 (3·03–4·23)	4·11 (2·95–5·78)
≥60 years*	9712·70 (8694·54–10 725·79)	5674·98 (4573·65–7234·60)	4·50 (4·02–4·93)	9·31 (7·45–11·96)
Sub-Saharan Africa				
Overall	998·46 (865·76–1138·49)	1009·79 (831·57–1229·82)	11·04 (9·57–12·59)	20·51 (16·89–24·98)
Overall (age-standardised)	2187·52 (1927·11–2473·86)	1367·36 (1151·33–1606·96)	..	..
<60 years*	788·34 (666·08–924·39)	533·78 (407·41–709·48)	5·39 (4·56–6·33)	9·07 (6·90–12·08)
≥60 years*	11 876·43 (10 522·85–13 271·60)	6576·47 (5670·19–7498·59)	5·64 (4·99–6·31)	11·43 (9·86–13·04)
South Asia				
Overall	1336·09 (1174·54–1547·30)	1690·59 (1338·26–2175·00)	24·33 (21·40–28·18)	35·16 (27·82–45·23)
Overall (age-standardised)	1674·76 (1467·14–1945·97)	1100·40 (865·51–1425·27)	..	..
<60 years*	649·37 (562·23–758·80)	515·61 (379·82–711·18)	9·80 (8·50–11·43)	12·89 (9·50–17·72)
≥60 years*	8775·28 (7640·72–10 189·38)	5149·84 (4149·83–6403·86)	14·53 (12·65–16·89)	22·26 (17·97–27·69)

Data are absolute counts of DALYs and rates per 100 000 person-years. DALYs=disability-adjusted life-years. 95% UI=95% uncertainty interval. *Rates per 100 000 person-years are age-standardised, whereas absolute counts are not.

Table 3: Estimates of disability due to stroke, 2020 and 2050, by Global Burden of Disease super-region

to occur in the Southeast Asia, east Asia, and Oceania super-region, accounting for 51% of all projected deaths, and 1·6 million (1·2 million–2·0 million) are projected to occur in the South Asia super-region (table 3). Age-standardised death rates are projected to fall between 2020 and 2050 across all GBD regions (figure 3), with the most substantial reductions in the high-income super-region and the Central Europe, eastern Europe, and central Asia super-region; however, the absolute number of deaths is projected to increase in the Southeast Asia, east Asia, and Oceania, Latin America and Caribbean, North Africa and Middle East, South Asia, and Sub-Saharan Africa super-regions

(table 3). Similar geographical differences in stroke deaths and age-standardised mortality rates were noted for 1990–2019.[1]

The decreases in age-standardised DALYs per 100 000 person-years associated with stroke are projected to be similar across all GBD super-regions in 2050, with the largest decrease in the Central Europe, eastern Europe, and central Asia super-region (table 3). In the North Africa and Middle East and South Asia super-regions, we project a non-significant increase in age-standardised DALYs per 100 000 person-years associated with stroke in people younger than 60 years (table 3; appendix pp 56–59).

	Age-standardised deaths per 100 000 person-years (95% UI)		Millions of deaths (95% UI)		Age-standardised DALYs per 100 000 person-years (95% UI)		Millions of DALYs (95% UI)	
	2020	2050	2020	2050	2020	2050	2020	2050
Ischaemic stroke								
Overall	42·62 (38·23–46·20)	20·50 (16·81–24·68)	3·31 (2·98–3·58)	4·00 (3·29–4·75)	786·92 (706·13–864·10)	452·26 (376·72–535·54)	64·11 (57·47–70·40)	76·33 (64·25–89·78)
<60 years	2·45 (2·17–2·74)	1·16 (0·77–1·72)	0·18 (0·16–0·21)	0·11 (0·08–0·17)	153·88 (132·32–176·66)	101·42 (78·77–127·76)	11·42 (9·81–13·09)	9·42 (7·33–11·81)
≥60 years	320·77 (286·71–347·95)	154·46 (127·28–184·80)	3·12 (2·81–3·38)	3·87 (3·21–4·60)	5170·52 (4665·88–5662·86)	2881·74 (2423·50–3389·98)	52·70 (47·57–57·67)	66·91 (56·56–78·28)
Intracerebral haemorrhage								
Overall	35·75 (32·20–38·85)	29·78 (35·70–34·29)	2·93 (2·65–3·19)	5·10 (4·42–5·78)	824·99 (756·20–895·45)	656·14 (551·13–778·87)	69·40 (63·54–75·35)	96·90 (82·66–113·95)
<60 years	10·08 (9·06–10·97)	9·86 (7·78–12·53)	0·68 (0·61–0·74)	0·70 (0·56–0·89)	393·75 (355·16–430·37)	308·55 (241·47–397·86)	29·25 (26·41–31·99)	29·57 (23·32–37·67)
≥60 years	212·06 (189·37–230·59)	208·80 (181·83–235·46)	2·25 (2·01–2·45)	4·39 (3·82–4·95)	3811·23 (3462·76–4133·93)	3063·13 (2636·05–3545·24)	40·15 (36·52–43·54)	67·32 (58·24–77·27)
Subarachnoid haemorrhage								
Overall	4·63 (4·07–5·15)	4·09 (2·87–5·68)	0·38 (0·33–0·42)	0·65 (0·47–0·89)	135·79 (119·63–153·19)	120·75 (81·48–172·88)	11·33 (9·96–12·78)	16·12 (11·19–22·66)
<60 years	1·81 (1·55–2·17)	1·63 (1·03–2·46)	0·13 (0·11–0·16)	0·16 (0·10–0·23)	90·00 (77·50–106·87)	80·32 (50·56–118·35)	6·57 (5·66–7·78)	7·41 (4·69–10·86)
≥60 years	24·16 (20·90–26·72)	21·15 (15·03–29·17)	0·25 (0·21–0·27)	0·49 (0·35–0·68)	452·89 (400·11–499·95)	400·71 (280·68–555·91)	4·76 (4·20–5·26)	8·71 (6·18–12·03)

Deaths and DALYs (both absolute counts and rates per 100 000 person-years) by stroke type are shown. DALYs=disability-adjusted life-years. 95% UI=95% uncertainty interval.

Table 4: Estimates of global burden of death and disability, 2020 and 2050, by stroke type

Death and disability by stroke type

We predict that an increasing proportion of stroke deaths globally would be caused by intracerebral haemorrhage (44·3% in 2020 *vs* 52·4% in 2050). This increase is largely attributable to the proportional increase of deaths from intracerebral haemorrhages in LMICs (from 2·7 million [95% UI 2·4 million–2·9 million] in 2020, to 4·8 million [4·1 million–5·4 million] in 2050), especially among people aged 60 years or older (from 2·0 million [1·8 million–2·2 million] in 2020, to 4·1 million [3·5 million–4·6 million] in 2050). The proportion of intracerebral haemorrhage in LMICs countries in 2050 is projected to be 1·5 times greater than that in HICs (accounting for 54% *vs* 37% of all stroke deaths), probably because of the higher prevalence and poorer control of hypertension in LMICs.[22]

Deaths from intracerebral haemorrhage among people younger than 60 years are projected to decrease in HICs (from 3·3 per 100 000 person-years [95% UI 3·0–3·5] in 2020, to 2·5 per 100 000 person-years [2·0–3·1] in 2050), probably because of better control of hypertension. Among GBD super-regions, the highest absolute number of deaths from intracerebral haemorrhage in 2050 is projected to be in the Southeast Asia, east Asia, and Oceania super-region (2·9 million [2·4 million–3·3 million]), but the fastest growth of deaths between 2020 and 2050 is projected to be in the Sub-Saharan Africa super-region (figure 3). Similar patterns in deaths from intracerebral haemorrhage were noted for 1990–2019.[1]

Worldwide, we forecast that age-standardised mortality rates will fall for each type of stroke in people of all ages, with the largest reductions for mortality from ischaemic stroke (from 42·6 per 100 000 person-years [95% UI 38·2–46·2] in 2020, to 20·5 per 100 000 person-years [16·8–24·7] in 2050), especially in HICs (table 4; appendix pp 52–55). The least reduced age-standardised mortality rates were projected for subarachnoid haemorrhage (table 4), a finding which is similar to previous observations.[1]

Intracerebral haemorrhage was projected to be the largest contributor of stroke-related DALYs in 2020 (48%) and 2050 (51%; tables 2, 5). Intracerebral haemorrhage accounted for a greater proportion of DALYs in people younger than 60 years (64%) than in those aged 60 years or older in 2050, probably because of more life-years lost and higher mortality in these patients.

Age-standardised DALYs are projected to decrease from 2020 to 2050 for all types of stroke and age groups. We forecast that the highest proportion of age-standardised DALYs will be DALYs associated with intracerebral haemorrhage in the Southeast Asia, east Asia, and Oceania super-region, followed by intracerebral-haemorrhage-related DALYs in the Sub-Saharan Africa super-region, and ischaemic-stroke-related DALYs in the North Africa and Middle East and Central Europe, eastern Europe, and central Asia super-regions (figure 2).

	Low estimate 2017 (US$ billions)	High estimate 2017 (US$ billions)	Low estimate 2050 (US$ billions)	High estimate 2050 (US$ billions)
High-income countries	417·0	597·6	436·6–655·9	578·3–997·0
Upper-middle-income countries	279·1	410·0	273·5–743·6	334·2–1026·4
Lower-middle-income countries	48·3	64·8	159·5–200·4	170·4–252·5
Low-income countries	2·6	4·9	11·2–22·0	13·5–34·1
Global	745·9	1077·2	880·8–1621·9	1096·4–2310·0

The total cost includes both direct costs (associated with providing care for incident stroke cases and deaths) and indirect cost (ie, loss of income). Direct costs were calculated using previously described methods.[8] The 2017 estimates comprise the low-cost and high-cost scenario estimates from Owolabi et al.[8] Low estimates for 2050 assume that costs of treatment and rehabilitation grow at a rate 1% above the rate of non-medical inflation. High estimates for 2050 assume that costs of treatment and rehabilitation grow at 3% above the rate of non-medical inflation. For both low and high 2050 estimates, the range reflects the low-cost and high-cost estimates for acute and post-acute care in Owolabi et al.[8]

Table 5: Estimates of global economic burden of stroke, 2017 and 2050

Primary prevention
Strategies to prevent stroke in persons with no previous history of stroke or transient ischemic attack

Implications of these findings

In summary, our projections show that the absolute number of people who will die from stroke and will get disability due to stroke will continue to increase to 2050, although the pace of the overall increase in the stroke burden from 2020 to 2050 is slower than that in 1990–2019. However, we also project that age-standardised mortality and DALY rates will decrease. We project widening gaps in stroke burden (both in terms of deaths and disability) between rich and poor countries. A projected failure to meet the Sustainable Development Goals 3.4, and our projections of further increases in stroke burden, particularly in the Southeast Asia, east Asia, and Oceania and Sub-Saharan Africa super-regions, call for urgent action to improve stroke prevention and treatment across the globe (panel 1).

Our findings also suggest an increase (compared with 1990–2019) in the contribution of intracerebral haemorrhage to the overall increase in stroke burden in the world, especially in southeast Asia, east Asia, and Oceania. However, the fastest growth in deaths from intracerebral haemorrhage in 2050 is projected to occur in sub-Saharan Africa.

The relevance of hypertension control

Transient ischaemic attack
A brief (usually only minutes or hours but less than 24 h) episode of brain dysfunction from an interruption in the blood supply to the brain or the eye without neuroimaging (CT or MRI) evidence of acute ischaemic brain injury

The main risk factor for stroke—and particularly for intracerebral haemorrhage—is hypertension,[1,28] and thus our projections support a call for improving prevention and treatment of hypertension.[29] The number of people aged 30–79 years with hypertension roughly doubled between 1990 (331 million [95% CI 306 million–359 million] women and 317 million [292 million–344 million] men) and 2019 (626 million [584 million–668 million] women and 652 million [604 million–698 million] men), despite a stable age-standardised prevalence of the disorder.[29] Among those with hypertension, only 23% (95% CI 20–27) of women and 18% (16–21) of men had their blood pressure under control. This increase in the overall prevalence of

hypertension and poor control could be related to the widespread use of a high cardiovascular risk threshold (eg, a 5-year risk of a cardiovascular event of 15% or greater) for initiation of pharmacological treatment of increased blood pressure.[30–34] Targeting individuals with high risk of cardiovascular disease and applying treatment thresholds for **primary prevention** of cardiovascular disease might be effective in an identifiable minority of patients,[35,36] but this approach precludes access to prevention and effective treatment for a large proportion of the population, including individuals whose cardiovascular risk is below the treatment threshold but who have hypertension that requires pharmacological treatment.[37–40] Pharmacological reduction of blood pressure lowers the risk of stroke and cardiovascular disease, even in patients with baseline systolic blood pressures of as low as 115 mm Hg, across all age groups.[41] The World Stroke Organization and the World Federation of Neurology have called for the revision of primary prevention guidelines for stroke and cardiovascular disease[42] to recommend primary prevention strategies in adults with any level of increased stroke or cardiovascular disease risk, with a focus on early detection and adequate management of hypertension.

The situation in LMICs

Prevention and treatment of stroke are crucial for containing mortality and disability. Current detection and control of risk factors is suboptimal and inequitable, and the infrastructure for acute stroke care and rehabilitation is scarce, particularly in LMICs. Roughly half of these countries have implemented less than half of the recommended elements for acute care,[43] meeting only about 30% of the acute care recommendations. Europe and central Asia have the stroke services that best align with evidence-based guidelines, whereas health-care systems in sub-Saharan Africa have implemented the fewest recommendations. Among LMICs, availability of physicians with expertise in stroke management is best in north Africa, the Middle East, eastern Europe, and central Asia and worst in sub-Saharan Africa. Many of the countries in these regions have low doctor-to-population ratios and inadequate numbers of multidisciplinary health-care professionals with training in acute and chronic care of patients with **transient ischaemic attacks** or stroke. Deficiencies in prevention and treatment of stroke due to workforce and resource shortages combine to account for an increased burden of stroke in LMICs.

A huge economic burden

Health-care expenses associated with stroke were estimated to be as high as $315 billion in 2017 (the most recent year for which such data are available), with an additional loss in income of $576 billion: $891 billion in total.[8] The incidence of stroke rises with age. As our projections show, because the world population keeps growing and the proportion of older people increasing, mortality and disability from stroke will grow too. As a

Because of population growth and ageing, the absolute number of people who will die from stroke worldwide will increase by 50%, compared with 2020, to 9·7 million in 2050. We also estimate that disability-adjusted life-years will grow by 31%, to 189·3 million in 2050. Our projections suggest that age-standardised mortality rates will decrease. However, the proportion of global stroke deaths accounted for by low-income and middle-income countries (LMICs) is projected to rise from 86% in 2020 to 91% by 2050. Similarly, the proportion of disability-adjusted life-years accounted for by LMICs will increase from 88% to 92% by 2050. In light of these estimates, by 2050, the substantial increases in the costs associated with stroke will cause distressing financial circumstances for many communities and national health systems. These unsustainable trends in burden and costs underline the importance of identifying interventions to prevent and manage stroke.

Implications
- The burden of stroke will continue to increase worldwide and will disproportionally affect LMICs. The disparities in stroke burden between high-income countries and LMICs are projected to increase even further.
- Current prevention strategies are insufficient, and the Sustainable Development Goals related to reducing the global burden of stroke will not be met.
- Urgent measures to reduce stroke burden worldwide are needed, with an emphasis on LMICs, to increase a trained health-care workforce that can implement effective primary prevention strategies, including the early detection and adequate management of hypertension.
- Effective interventions could result in substantial economic gains (because of reduced treatment and rehabilitation expenses). Evidence suggests that achieving the Sustainable Development Goals[23] and WHO health targets[17] with low-cost interventions—eg, early detection and adequate control of hypertension, reduction of salt content in processed foods, and smoking cessation campaigns—that cost less than US$1 per person per day in low-income countries and less than $3 a day in middle-income countries[24] could reduce mortality from stroke and ischaemic heart disease by about 10%.[25]
- Another promising strategy to reduce stroke incidence and mortality is population-wide primary prevention across the lifespan. It has been estimated that, for every $1 spent on the prevention of stroke and cardiovascular disease, there is a more than $10 return on investment.[26] Additionally, primary prevention efforts directed at stroke would probably yield large gains because of the secondary effects of reducing the risk of heart disease, type 2 diabetes, dementia, and some types of cancer that share common risk factors, thus supporting achievements for a range of Sustainable Development Goals.
- Scaling up of prevention of neurological disorders, including stroke, in 11 countries (Brazil, China, Colombia, Germany, Italy, Japan, Kenya, Lebanon, Romania, the UK, and the USA) to adequate levels by 2030 could save $2·4 trillion according to a 2022 estimate,[27] while scaling up of interventions for treatment and rehabilitation to the required levels could save $911 billion and $727 billion, respectively.[27]

Research priorities
- Monitoring and forecasting of the global burden of stroke, also at regional, national, and sub-national levels.
- Developing interactive tools (including maps and data plots) showing the expected short-term and long-term effects of stroke prevention, treatment, and rehabilitation interventions on global, regional, and national burden (incidence, prevalence, deaths, years of live lost, years lived with disability, disability-adjusted life-years, and economic benefits).
- Calculation of the effect of the burden of stroke on brain-health burden at global, regional, and national levels.

result, the health-care costs associated with stroke might become unsustainable, unless prevention programmes that reduce the risk of stroke get implemented. Our forecasts also suggest that Asia's share of global stroke deaths would rise from 61·3% of the global total in 2020 (about 4·1 million) to about 68·9% of global deaths from stroke in 2050 (around 6·6 million deaths).[8] The proportion of annual global stroke deaths that sub-Saharan African countries will contribute, although smaller than that contributed by Asia, will also rise, from 6·2% in 2020, to 8·0% in 2050. Therefore, by 2050, the economic implications of stroke will be considerable, and they are more likely to be felt in Asia and Africa than elsewhere.[8]

Our methods to calculate the global stroke economic burden estimates for 2050 are supplied in the appendix (pp 33–35). Although our projections show that income losses because of stroke will rise by 2050, the rise is less

sharp than that in direct expenses for two main reasons. First, the working-age population (ie, the proportion of the population aged 15–64 years), the primary driver of income losses from stroke in our projection model, is expected to increase only slightly from 2020 to 2050, but is expected to fall sharply in China and in countries currently classified as HICs per UN projections.[44] Second, in our model we assumed that people would retire aged 65 years, which was the retirement age used to estimate income losses from stroke in 2017.[8] If the proportion of older people (and particularly people older than 65 years) participating in work were to increase over time, our projections will underestimate income losses from stroke in 2050 (appendix pp 68–69).

The estimated aggregate economic costs of stroke, including direct costs and income losses, range from $746 billion to $1·08 trillion in 2017 prices. But by 2050,

these costs are projected to rise to between $880 billion and US$2·31 trillion in 2017 prices (table 5).

Figure 4 shows estimated direct and indirect costs from stroke between 2017 and 2050. We predict large increases in direct costs and income losses from stroke in middle-income countries and increases in direct costs in HICs (appendix pp 68–69). The projections also suggest increased economic impacts of stroke in low-income countries in 2050.

These projections of the economic consequences of stroke should be thought of as indicative, owing to the considerable uncertainties involved in predicting future direct costs and income losses. The accuracy of our projections of the economic implications of stroke in 2050 is crucially dependent on the economic forecasting model used, and we used a particularly simple model, which relied solely on demographics, regional characteristics, and starting gross domestic product per person for each country. We could not account for inflation from 2017 to 2050 (which is unknown), and our baseline cost estimates were for 2017 because no more recent data were available. Although our simple model captures key elements of standard empirical growth models, richer models of economic growth would also have accounted for projected changes in educational attainment, capital investments, changes in the policy environment, and climate implications. However, incorporation of these variables could have further contributed to the potential imprecision of our projected costs. Furthermore, our estimates of the direct costs of stroke are dependent on assumptions about the relative rate of price increase of non-medical goods and stroke treatment. The prices of these goods and treatment will in turn depend on treatment practices, the emergence of new technologies, and application of stroke treatment practices from HICs to the rest of the world, some of which will raise treatment costs. Conversely, economies of scale might lower treatment costs. Our strategy was to assume two different rates of expenditure growth in stroke treatment to try to account for this uncertainty: 1% above non-medical expenditure inflation, and 3% above non-medical expenditure inflation. The former has been used for health expenditure projections in Australia and is about the same as recent estimates for the period 2001–20 for the USA.[8] The latter figure assumes that rapid increases in demand in middle-income and upper-middle-income countries for health services will put further pressures on prices.

Part 1: The importance of stroke surveillance

Epidemiological surveillance systems are fundamental for evidence-based planning, resource allocation, and determination of priorities to reduce the burden of stroke.[45] These systems can provide comprehensive and contemporary information about incidence, prevalence, and outcomes of stroke, and also about risk factors. Data from these systems can be then used to develop, implement, and assess prevention, acute care, and rehabilitation programmes.[46]

Stroke surveillance is a key element recommended by the **World Stroke Organization's Global Stroke Care Guidelines**[43] and by several other international initiatives, including WHO's Intersectoral global action plan on epilepsy and other neurological disorders 2022–2031 (IGAP).[47] The IGAP acknowledges the role of surveillance data in informing evidence-based actions to improve policies, programmes, and services for the prevention and management of neurological diseases. It sets a target of 80% of countries regularly collecting and reporting on core indicators for neurological diseases by 2031.[48] In the context of stroke surveillance, there is a need for countries to regularly collect data for, and report on, core indicators, such as incidence, recurrence, and mortality rates, outcomes, implementation of evidence-based care, participation in clinical registries, and prevalence of risk factors.[43]

In this section, we review advances towards these stroke surveillance goals. We also highlight gaps in stroke surveillance systems and propose pragmatic strategies for improving surveillance systems globally.

A call for national stroke registries

An ideal stroke surveillance system would include nationally representative data for the incidence, prevalence, and outcomes (eg, death, disability) of, and quality of care for, stroke, and for the prevalence of risk factors. These indicators are essential to inform strategies to reduce the burden of stroke. Data for stroke surveillance systems can come from incidence studies, registries, or population-level data for stroke-related hospitalisations and outcomes.[49,50] The incidence and case fatality of stroke are traditionally monitored with so-called **ideal incidence studies**.[51] However, these studies are resource-intensive and often impractical to undertake. For example, in the 2022 review of global stroke statistics,[50] the authors identified only five ideal incidence studies that have been done worldwide in the past decade. By contrast, the number of national stroke registries has grown.[50]

National stroke registries can be a relatively inexpensive supplement or substitute for monitoring the data for fatal and non-fatal strokes. We have reviewed the data collected for the global stroke statistics[50] and found that only 31 (14%) of 216 WHO member countries and territories have optimal stroke surveillance through their national stroke registries. All but seven of these 31 countries were HICs. There is only one national registry in the Central Europe, eastern Europe, and central Asia GBD super-region, one in the South Asia super-region, and three in the Southeast Asia, east Asia, and Oceania super-region (one in each region). No national registries were identified in the North Africa and Middle East, and Sub-Saharan Africa super-regions, showing that fewer resources are available for surveillance in these regions, a situation that is likely to continue unless there is substantial investment from governments. Only five countries (Bahrain, Finland,
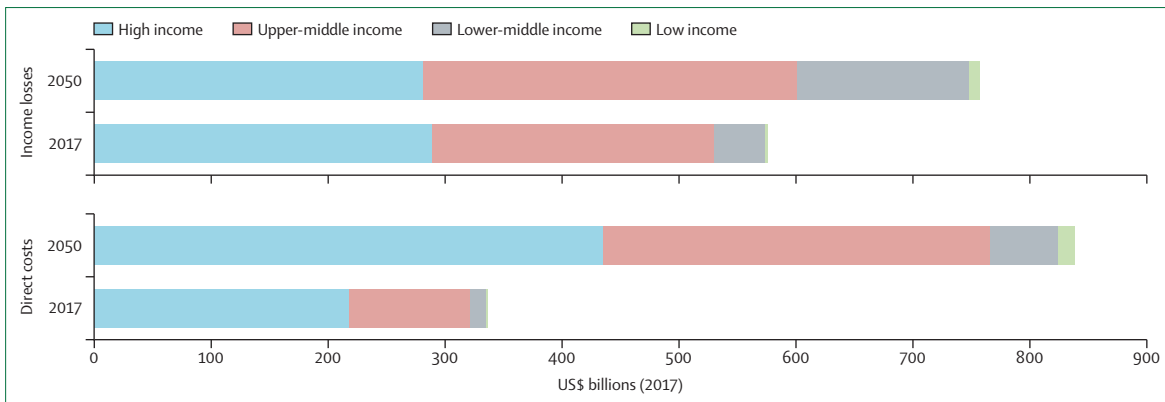
Figure 4: **Estimated direct costs and income losses associated with stroke, 2017 and 2050, by World Bank region**
Our comparison is based on the forecast of regional means in table 1.

Israel, Russia, and Singapore) have stroke registries with the optimal nationwide coverage required for evidence-based health-care planning and resource allocation for stroke care.

Despite the value of these registries, they also have several limitations that restrict their use for optimal stroke surveillance. These limitations include errors in data entry (selection bias) or coding (classification bias),[52] and lack of precision in hospital diagnostic coding of the cause of stroke[53]—eg, use of the International Classification of Diseases code I64 (stroke—not specified as ischaemic or haemorrhagic), or incorrectly coding transient ischaemic attacks or haemorrhagic stroke as ischaemic strokes. Another major challenge for these registries is nationwide coverage.

Data on mortality due to stroke are usually collected in national civil registration and vital statistics systems and submitted annually to WHO. Although these data are not without limitations—eg, data submitted could be incomplete data or not up to date[50]—they remain the most robust source of statistics on stroke mortality. However, only 138 (64%) WHO member countries and territories have submitted stroke-specific mortality data at least once to WHO in the past three decades.[50] Most of the 78 countries that did not provide data were in the Sub-Saharan Africa (42 [54%]) or Southeast Asia, east Asia, and Oceania (18 [23%]) super-regions, potentially reflecting the lack of capacity for surveillance of stroke mortality in these regions. In the absence of data from national registration systems, mortality estimates are often extrapolated from non-representative studies or international demographic and epidemiological statistical models,[54] which might not be as reliable. Given population growth in these regions (estimated to become home to about 45% of the total global population by 2030), ongoing demographic and epidemiological transitions leading to increases in NCDs, and the huge estimated burden of stroke (roughly 46% of the global burden of stroke[1] as of 2019) in these regions, reliable data on stroke events and outcomes are urgently needed to inform public health policy and actions.[55]

Surveillance of risk factors

To reduce the burden of stroke, population-wide monitoring of its risk factors is needed. In settings where resources are limited, efforts should be focused on collecting high-quality data for risk factors that strongly predict stroke (eg, blood pressure, physical activity, lipid profile, diet, bodyweight, psychosocial factors, smoking, diabetes),[28] are highly prevalent,[56] are amenable to individual-level or population-level interventions,[8,57] and are relatively easy and cheap to monitor. Ideal comprehensive surveillance of risk factors for stroke would include monitoring of blood pressure, anthropometrics (eg, weight, waist circumference), biochemical measures (eg, lipid profiles, blood glucose), lifestyle factors (eg, smoking, physical activity, alcohol intake, illicit drug use, stress), clinical factors (eg, atrial fibrillation), and environmental factors (eg, air pollution).

We found information about national health surveys for 196 countries or territories (figure 5). In 84 (43%) countries, the last survey was done before 2018 (appendix pp 70–80). In 37 countries, surveys were done solely by national agencies (eg, the US National Center for Health Statistics[58] to collect information about the health and wellbeing of residents. In most other countries, national agencies were supported by international organisations or development partners, including WHO (ie, the STEPwise approach to NCD Surveillance programme [**WHO STEPS**]; in 75 countries), the EU (31 countries), or the United States Agency for International Development (Demographic Health Survey [DHS]; in 54 countries). Information was unavailable for four HICs or territories (French Guiana, Macau, San Marino, and Monaco), eight countries in the Latin America and Caribbean super-region, six in the Sub-Saharan Africa super-region, Montenegro (in the Central Europe, eastern Europe, and central Asia super-region), and Ryukyu Islands (in the Southeast Asia, east Asia, and Oceania super-region).

Lifestyle factors were measured in national health surveys in 181 (92%) of 196 countries and anthropometrics

WHO STEPS
WHO's approach to surveillance of stroke and other non-communicable diseases, based on a simple, standardised method for collecting, analysing, and disseminating data for key metrics of disease burden (incidence and mortality) and risk factors
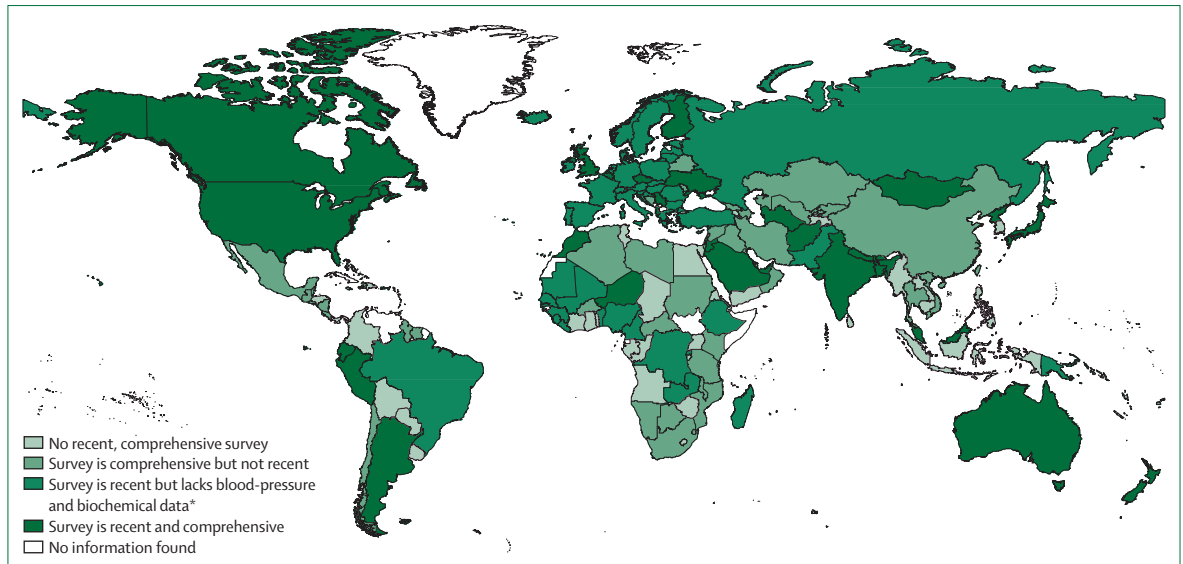
Figure 5: **Availability of national surveillance systems for risk factors of stroke**
Surveys were considered recent if they were done in or after 2018, and comprehensive if they included measurements of blood pressure, anthropometrics (eg, weight, waist circumference), biochemical measures (eg, blood lipid profile, blood glucose), lifestyle factors (eg, smoking, diet, physical activity, alcohol intake), and diagnosis of metabolic conditions (eg, hypertension, overweight or obesity, dyslipidaemia, diabetes, atrial fibrillation). *Biochemical measurements refers to measurement of blood lipid profiles and blood glucose concentrations.

in 164 (84%), and diagnosis of metabolic conditions was recorded in 159 (81%). Most surveys were not comprehensive or recent (ie, were done before 2018). Five countries (Cameroon, DR Congo, São Tomé and Príncipe, Senegal, and Tunisia) did not measure any risk factor for stroke in their last national surveys (as of September, 2022). Although LMICs assessed more risk factors in their last surveys than HICs, their surveys were often not recent (ie, they were done before 2018). Compared with poorer countries, HICs had more often done recent and comprehensive surveys of risk factors for stroke. Overall, of the 112 countries in which surveys have not been done since before 2018, 109 were LMICs. Of the 84 countries with a survey done in or after 2018, only 32 (38%) included measures of blood pressure, and only 27 (32%) included comprehensive surveillance of risk factors for stroke. These gaps in the collection of comprehensive and contemporary information about important risk factors for stroke across the world, but particularly in LMICs, need to be addressed.

Barriers to, and facilitators of, surveillance

We have identified several themes (appendix pp 81–82), including both barriers to, and facilitators of, the creation of high-quality stroke surveillance services—eg, surveillance capacity, information technology, and governance of surveillance activities. These themes were identified in semi-structured interviews with 12 stroke surveillance experts, one from a HIC and one from an LMIC in each of the six WHO regions (appendix pp 7–16).

Surveillance capacity refers to the activities and availability of a trained workforce to capture stroke events or risk factors. Countries with good stroke surveillance have well-funded and trained workforces, can establish nationwide registries to monitor treatment and outcomes, and have regular risk factors surveys linked with population-based approaches, such as integration into censuses. By contrast, countries with poor surveillance capacity do not have nationally representative or standardised data available for stroke treatment or outcomes, generally because efforts are not nationally coordinated at the government level, with stroke surveillance activities instead managed by individual institutions or academic research networks.

Information technology affects the ability to deliver high-quality stroke surveillance services. Countries with strong health information systems can have good stroke surveillance. Internet-based systems allow data collection in real-time, which improves data quality. Digitalisation of medical records, mortality data, and other health databases enables and enhances analysis of stroke and risk factor data to inform policies. Electronic databases also increase access to data and enable data linkage to do complex studies on the epidemiology of stroke. Countries with good stroke surveillance can use data from surveillance systems to raise awareness of stroke and its risk factors in the community and with government stakeholders, leading to strategic investment. Countries with poorer surveillance have fragmented, incomprehensive health databases, limiting the use of data for decision making.

Strong governance facilitates the successful operation of high-quality national stroke surveillance systems. Robust governance requires political commitment, adequate funding, and independent advisory bodies.

Countries with strong governance often have strong health information systems to enable data-driven decision making. Stroke surveillance activities are often government-led, with technical support from experts. A lack of government commitment to stroke surveillance hinders establishment of strong stroke surveillance systems. Poor availability of data for stroke hampers the ability to set priorities and secure funding for stroke services. However, even countries with good data availability and strong political commitment to stroke surveillance still report insufficient funding.

Pragmatic solutions to improve stroke surveillance

WHO recommends that each country establishes a programme that achieves near-universal monitoring of the important indicators of the burden of stroke—ie, incidence, recurrence, and mortality rates, prevalence of risk factors, stroke outcomes, implementation of evidence-based care for stroke, and participation in stroke clinical trials.[59] A good example of such a programme is the Stroke Service Tracker in Europe, a survey developed as part of the action plan for stroke in Europe 2018–2030.[60] This survey collects data for the quality of stroke care and stroke outcomes all over Europe to inform policies, programmes, and services for management and secondary prevention of stroke and to facilitate comparison across European countries.

For regions with limited resources, WHO has developed a three-step standardised surveillance system for stroke in 2002—STEPS.[59,61] In a review[62] of seven studies from nine LMICs that incorporated the WHO STEPS protocol, their adherence to the surveillance methods was variable. There were particular challenges with collecting neuroimaging data and data for non-fatal events in the community.[62] Better training to improve capacity to undertake surveys, feasible surveillance protocols that are codesigned with local experts, electronic data collection, and the inclusion of data on stroke in existing monitoring systems for NCDs could facilitate identification of stroke cases in the community.[62]

One of the most popular and commonly used epidemiological methods for stroke surveillance in LMICs are door-to-door surveys. If a stroke prevalence survey is done with a sufficiently large sample size (ie, 25000–30000 people) and findings are combined with data from death certificates (eg, by using **verbal autopsy** procedures) collected in the same community over at least 3 years, fairly accurate incidence and mortality estimates can be derived. The central tenet of this approach is that non-fatal first-ever stroke events within the preceding 3 years are identified through a prevalence survey and then combined in the analysis with fatal first-ever stroke events, in the same population for the same study period, to calculate cumulative stroke incidence rates.[63] This approach was first used in Italy[64] and China in the 1980s and 1990s.[65] It has more recently been used to update stroke incidence and mortality data

in a large nationwide study[66] in China in the late 2010s. Another epidemiological approach for stroke surveillance in LMICs is to do repeated community-based studies in the same population at different times[67]—an approach that has previously been used in Brazil.[68] However, this approach is resource-intensive.

Key recommendations for improving stroke surveillance are summarised in panel 2 and the appendix (pp 82–83). National stroke registries can be used to monitor hospitalisations for stroke.[69] Registries with nationwide coverage can be coupled with national death registries to give a near complete picture of the burden of stroke.[70] However, in countries with less access to hospital services, registries should be supplemented by case ascertainment of at least fatal (and if possible non-fatal) stroke occurring in the community. WHO standard's verbal autopsy instrument[71] could be used for case ascertainment, an approach that has been validated for use electronically in LMICs.[72]

There is increasing interest in using other large datasets of routinely collected, administrative data (eg, records of hospital admissions for acute stroke care) to monitor hospitalisations, quality of care, and outcomes after stroke.[49] However, standardised methods and systems are needed to enable use of these data to provide timely and reliable estimates of stroke burden. Countries should establish monitoring systems that facilitate increased coverage of electronic medical records and interoperability between systems (to prevent duplication of data capture). Potential barriers to the use of routinely collected administrative data for stroke surveillance include the lack of the resources required to establish and maintain this infrastructure, particularly in poor settings—where access to electricity might be unreliable, for instance, or health workers might have inadequate technological literacy. Concerns have also been raised about the validity of data for diagnoses of stroke and comorbidities recorded in hospital data-collection systems,[73] and about the privacy of electronic health records.[74,75] These concerns can be overcome through appropriate training of staff on data coding, entry, and handling, regular review and audit of the quality of data collected, validation of data entry and coding methods, and appropriate data encryption.[45,76–78]

Irrespective of the monitoring system used, consultation with community groups, physicians and other health-care providers, policy makers, and implementation partners at each stage of their development and implementation is paramount. This engagement will ensure that ethical, legal, and social considerations are met,[8,79] and that the system meets the needs of the community.

National monitoring systems for risk factors
There is a need for countries to establish national, geographically and ethnically representative surveillance frameworks and capacity, including funding and reporting mechanisms, for regular monitoring of

Verbal autopsy
A WHO-standardised method of data collection to establish a possible cause of death based on oral interviews with a close relative or caregiver who witnessed the death of the deceased

important risk factors for stroke.[61] Countries without frameworks can implement one of the three main types of surveys widely used to assess risk factors for stroke: WHO STEPS and the Demographic and Health Survey (DHS), both of which can be adapted by all countries, and the European Health Interview Survey, which can be used in the EU.

The WHO STEPS is a valid and reliable system for the surveillance of risk factors,[61] which emphasises high-quality collection of a few variables, rather than large amounts of poor-quality data. The DHS is largely funded by the United States Agency for International Development, with support from host countries and other agencies (eg, the DHS Program). A major benefit of the DHS is the concurrent capacity building of workers through training and support tools to maximise the collection of high-quality data. The European Health Interview Survey is a collaborative effort between all EU member states in which validated instruments are used to collect standardised self-reported health data. It is complemented by the European Health Examination Survey, which collects data on blood pressure and biochemical measures (eg, lipid profiles, blood glucose concentrations).

Comprehensive surveillance of risk factors for stroke requires additional resources for staff, training, and data

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Panel 2: Key messages about stroke surveillance

- Governments need to establish nationwide systems for monitoring the burden of stroke, through registries, electronic health records, and vital statistics systems. These systems must achieve near-universal surveillance of indicators of stroke burden and risk factors, to reliably inform the development of programmes for stroke prevention, acute care, and rehabilitation. Surveillance systems must become part of national stroke plans and monitoring systems for non-communicable diseases, which should be able to identify stroke cases in the community. Countries with limited capacity or resources could benefit from assistance, collaboration, and funding from international development agencies—eg, WHO, and the United States Agency for International Development.
- Surveillance systems should assess the incidence, prevalence, management, and control of cardiovascular risk factors at the population level, and should be based on reliable measurements—eg, measurement of blood pressure rather than self-reported hypertension. Surveillance systems should include capacity building of personnel to ensure enough adequately trained people to collect and analyse the data. Career pathways for health-care professionals with training in epidemiology and biostatistics should be considered.
- Data on risk factors for stroke should also be gathered as part of national censuses. All countries should have surveys with identified priorities and clearly defined cycles and data-collection. These surveys should be done regularly to detect changes over time. Countries should also invest on research capacity to regularly analyse the data collected and generate high-quality evidence to support decision making.
- Governments should establish national stroke registries of hospitalised, non-hospitalised, fatal, and non-fatal strokes and transient ischaemic attacks. Such registries should be facilitated by linkage of population data for risk factors to hospitalisation and national death registries, which would enable clarification of the relationship between the burden of risk factors and stroke burden at a population level, and could provide a near-complete overview of the burden of stroke.
- Every country should have electronic health-information systems, with interoperability between systems, to prevent duplication of data. In countries with established electronic or web-based platforms for data collection, the collection of data for stroke and its risk factors should be encouraged and incentivised to increase coverage. Large-scale collection of data via electronic systems that enable the ready exchange of health information could, in turn, facilitate the use of these data for surveillance purposes. For such platforms to be valuable and sustainable, staff training is needed to ensure appropriate documentation and coding, and the secure handling of electronic health data.
- Irrespective of the surveillance system, consultation with communities, health-care providers, policy makers, health insurers, and implementation partners at each stage of development is essential. This engagement will ensure that legal, ethical, and socioeconomic considerations are taken into account, and that the system will meet the needs of the local community.

Research priorities

- Mixed-methods research—research yielding both quantitative and qualitative data—focused on models to improve stroke surveillance should be prioritised, particularly in countries with limited resources. Such research should explore how to develop feasible surveillance protocols that address local needs, while ensuring collection of standardised data. Standardisation of data collection could involve adapting well established surveillance protocols (eg, WHO STEPS, Demographic and Health Surveys, European Health Interview Survey) or use of less costly but successful surveillance methods, such as repeated cross-sectional and community-based studies done in strategic locations.
- Validation studies should be done to assess the quality and coverage of data for risk factors available in administrative datasets (eg, hospital records, primary care records).
- Surveillance systems should be able to incorporate data on stroke genetics to facilitate the development of novel prognostic biomarkers and prevention strategies.
- Novel digital tools for population-wide surveillance of stroke and its risk factors should be developed and validated.

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management. Use of digital tools for remote, large-scale collection of data for NCD risk factors is a potential novel approach. However, both the sampling methods (to ensure representativeness and ease of sharing of data) and the tools themselves should be validated before their use in national risk factor surveillance systems. A comprehensive, fully digital national survey of risk factors was recently done in India.[80] It was adapted from the WHO STEPS system and was part of the Indian national NCD monitoring framework. The validated questionnaires used in the survey were digitised for data collection via an offline Android-based app, with standard definitions used for estimation of behavioural and biological risks (tobacco use, alcohol use, diet, physical activity, BMI, raised blood glucose concentrations, and increased blood pressure). Although it was a large (10 659 adults) and nationally representative survey that established sustainable mechanisms for doing further state or district surveys, the usual survey-related limitations applied: the risk factor data gathered were cross-sectional, and there might have been information and sampling biases.

To elucidate the genetics and pathobiology of stroke (and associated risk factors) across diverse ancestries, surveillance systems should incorporate population-based large-scale collection of data and biospecimens for multiomic research. Genomic and multiomic research could facilitate the development of novel predictive, diagnostic, and prognostic biomarkers, and better prophylactic, diagnostic, therapeutic, and restorative interventions. The inclusion of people from LMICs in such research is crucial to ensure that biomarkers and interventions are applicable to high-risk populations worldwide.[81]

Research priorities

As we have shown, stroke surveillance systems are essential for developing, implementing, and evaluating national programs to reduce the burden of stroke. Future research should therefore focus on the development, implementation, and assessment of national stroke surveillance systems, including measures to monitor health-care quality. There is a need to develop and validate methods for calculation of incidence, prevalence, and outcomes of stroke based on administrative data. Mixed-methods research focused on the implementation and assessment of models to improve stroke surveillance is necessary, and should also explore how these data for stroke and its risk factors can be used to improve stroke prevention and management.

The members of the World Stroke Organization participating in this Commission, in collaboration with other stakeholders, will work towards the implementation of the pragmatic solutions that we recommend. Commissioners and national stroke societies will champion co-implementation activities at the national level. A taskforce will leverage global partners to undertake several activities actions to improve stroke surveillance, including implementation of national strategies for stroke surveillance (via digital technologies, when possible), particularly for countries with little available data, and building capacity and resources (governance, training, and infrastructure) in LMICs to enable use of electronic medical records systems that could facilitate surveillance and data linkage.

To implement the recommendations of this Commission, countries should establish sustainable programmes for regular country-wide monitoring and assessment of stroke burden, modifiable risk factors, and stroke-related health services, all of which should be integrated with national stroke plans. Irrespective of the surveillance method used, collaboration is necessary[49] to ensure that stroke surveillance systems sustainably meet the needs of all stakeholders.

Part 2: Strokes can be prevented: the strategies

Globally, one in four individuals older than 25 years will have a stroke, which means that the lifetime risk of stroke is 25%.[82] Therefore, effective primordial, primary, and secondary prevention programmes are crucial to reduce lifetime risk and the effects of the disease.

Primordial prevention is aimed at preventing the emergence of stroke risk factors. Primary prevention involves early detection and control of risk factors, such as hypertension, dyslipidaemia, obesity, and diabetes, to avoid a first stroke event. Members of the World Stroke Organization–*Lancet Neurology* Commission have addressed primordial and primary prevention in a previous paper.[8] Thus, in this Commission, we focus mainly on strategies for secondary prevention.

Secondary stroke prevention is commonly defined as the prevention of stroke in people who already had a stroke or a transient ischaemic attack. Recurrent strokes and transient ischaemic attacks contribute substantially to the overall burden of cerebrovascular disease[83]—about 20–30% of strokes occur in people who previously had a stroke or a transient ischaemic attack.[83–85] People who had a stroke or a transient ischaemic attack are at increased risk of recurrent stroke particularly within the first few days of the index event.[84,86] These recurrent strokes tend to be more disabling and to have poorer outcomes than the first stroke.[87] Evidence suggests that 45–80% of recurrent strokes and transient ischaemic attacks could be prevented.[88–90]

An international cohort study[91] showed that, with proper management, the risk of subsequent disabling or fatal stroke within 5 years of a minor ischaemic stroke or a transient ischaemic attack is only 10%. However, even though the probability of survival after a stroke has improved substantially over the past two decades, stroke recurrence has not been consistently reduced in many countries[85,92,93] (although reductions have been noted in some countries[94,95]).

Prevention of recurrent strokes

The principles of secondary stroke prevention are to identify and treat the underlying causal pathologies of the first stroke to minimise the risk of recurrent stroke and other major vascular events. The evidence-based components of secondary stroke prevention comprise both medical and lifestyle interventions that are targeted to the cause of the first stroke and are aligned to the risk of recurrent stroke.[83,90] Examples of medical interventions include the use of antihypertensives in people with hypertension (the leading modifiable risk factor for stroke) and the use of anticoagulants and anti-arrhythmics in patients with **atrial fibrillation**, whenever indicated.[8] Furthermore, **carotid interventions** (endarterectomy or stenting) might be indicated in some patients with severe stenosis ipsilateral to a non-disabling ischaemic stroke or transient ischaemic attack.[83] Examples of lifestyle interventions include consumption of a healthy diet, smoking cessation, and regular physical exercise.[8]

We have previously reviewed, by country income level, the available guidelines for secondary stroke prevention that address identification and management of risk factors in people after a stroke or a transient ischaemic attack. In our review, we found that secondary stroke prevention was very uncommon in low-income countries, and substantially less common in middle-income countries than in HICs.[14] However, even in HICs, the frequency of the assessment of risk factors for secondary stroke prevention was suboptimal.[96] Routine secondary stroke prevention activities that were uncommonly used across all country income levels include risk assessment scores (eg, the congestive heart failure, hypertension, age ≥75 years [doubled], diabetes mellitus, previous stroke or transient ischemic attack [doubled], vascular disease, age 65–74 years, and female sex [$CHA_2DS_2VASC_c$] score in patients with atrial fibrillation), assessment of biomedical

Atrial fibrillation
An arrythmia (ie, irregular heart rhythm) originating from the atrium of the heart with a characteristic absent P wave on electrocardiograms

Carotid interventions
Surgical interventions to restore or improve blood flow to the carotid vessels—eg, carotid endarterectomy, stenting

Motivational mass individual strategies
Motivational techniques delivered via smartphones that could be used in most of the adult population

Polypills
Pills containing fixed doses of at least two drugs. Polypills containing blood-pressure-lowering and blood-lipid-lowering drugs can be prescribed for prevention of stroke and transient ischaemic attack

and lifestyle risk factors, and patient education about management of risk factors.[14]

Secondary stroke prevention has conventionally been delivered at the individual level and has been established around the doctor–patient relationship (ie, the stroke and its causes would have been diagnosed by a physician, who then would generate and manage a secondary prevention programme in conjunction with the patient). Other complementary inputs can come from family members, community services for education and monitoring (eg, nursing services, allied health care), and public education campaigns, and also from primary prevention strategies at the population level. Primary prevention is targeted at the population as a whole and, therefore, at individuals without clinically established stroke. At the population level, for instance, a 2 mm Hg decrease in systolic blood pressure would result in about a 10–24% decrease in the incidence of a first stroke.[97] Similar interventions can be used in secondary prevention. The management of vascular risk factors at the individual level, with the prioritisation of early detection and control of hypertension, must be part of both primary and secondary stroke prevention strategies[8] (figure 6; appendix pp 93–97).

Primary stroke prevention interventions (eg, limitations on salt content in processed food, smoking cessation campaigns, air pollution reduction, incentives for purchasing healthy foods and disincentives for alcohol and other less healthy products) can be implemented by governments to reduce exposure to risk factors across the lifespan for the entire population, irrespective of the level of risk of stroke or cardiovascular disease. At an individual level, use of mobile technology could be implemented to facilitate control of risk factors (so-called **motivational mass individual strategies** for stroke prevention)[37] along with task shifting (or sharing) of preventive tasks from physicians and nurses to trained and supervised health-care workers, particularly community-based health workers.[98,99] Primary and secondary stroke prevention strategies in people with hypertension, diabetes, or dyslipidaemia can be further improved by using **polypills**.[39,41,100,101] Polypills for primary stroke prevention commonly include a combination of low, fixed doses of blood-pressure-lowering and lipid-lowering drugs in one medication (polypills for secondary prevention of ischaemic stroke could also include fixed doses of antiplatelet drugs).[100,102,103]

Despite these efforts, stroke recurrence remains unacceptably high (20–30%) in many countries. The failure of secondary prevention strategies to tackle stroke recurrence could be exacerbated by several barriers, including insufficient specialised training of physicians; lack of education of patients about the risk factors associated with their first stroke, the long-term risk of recurrence, or the importance of long-term monitoring of risk factors; maintenance of healthy lifestyle behaviours, and adherence to medical therapy;

Primordial prevention
• Improving socioeconomic conditions and reducing poverty
• Building healthy cities and homes
• Universal health coverage
• Provision of affordable healthy food and facilities for physical activity
• Reducing air pollution, tobacco use, and consumption of salt, sugar, trans fats, and alcohol
• Public health campaigns to raise awareness about stroke and stroke risk factors

Primary prevention
• Screening for cardiovascular risk factors
• Risk factor control in all people at any increased risk of stroke
• Interlinked eHealth tools for lay people and clinicians
• Polypill and anticoagulation (when indicated)

Secondary prevention
• Adequate treatment of stroke and transient ischaemic attack, including antithrombotic therapy, use of polypills, and carotid revascularisation

Figure 6: Strategies for stroke prevention
Major strategies for control of stroke risk factors for stroke at the population and individual levels are shown.

insufficient numbers of medical personnel; low affordability of preventive medications (especially in poor settings); and insufficient use of evidence-informed digital tools for developing person-specific and motivational recommendations (eg, the free Stroke Riskometer app for the general public and PreventS-MD for health professionals).[8,37,98,104–110] Physicians' inability to appreciate that these barriers (panel 3) can negatively affect motivation and effective self-management could be compounded by patients' post-stroke sedentary behaviour, mood disorders, and speech and cognitive impairments, which are likely to lead to inadequate adherence to recommendations.[111]

Our survey of specialists of stroke services[13] from 84 countries showed that, overall, only 40–46% of secondary stroke prevention activities were delivered to an acceptable level in participating hospitals (appendix pp 84–91). The strategies most often adopted were the use of antiplatelet drugs, anticoagulants, antihypertensives, and lipid-lowering drugs. The most widely available of these medicines were aspirin (available in 76 [90%] countries), metformin (73 [87%]), and thiazide diuretics (73 [87%]). The survey also showed disparities between regions: whereas stroke services in 31 (91%) of the 34 included countries in the WHO European region reported availability of angiotensin II receptor blockers, services in only four (33%) of the 12 included countries in the African region reported availability of these drugs. Importantly, availability of outpatient stroke or transient ischaemic attack clinics or stroke prevention clinics is better in upper-middle-income countries and HICs than in poorer countries. Education for patients and their families about stroke and lifestyle management was not available in many countries. There was also a lack of digital tools to support clinicians in the implementation and monitoring of secondary stroke prevention.[105,112–114] Use of guidelines for assessment and management of risk factors for secondary prevention in people with stroke or transient ischaemic attack is also very uncommon in low-income countries, and substantially less in common in middle-income countries than in HICs.[13] However, even in HICs, the level of assessment of risk factors for secondary stroke prevention is suboptimum.[96]

Previous findings[115] and those from our survey of specialists in stroke services on the low use of secondary stroke prevention strategies are in line with results from surveys of national scientific societies and stroke experts in Europe[116] and China,[117] and those from a systematic review[118] of ischaemic stroke prevention guidelines. We also noted poor follow-up of patients after stroke or a transient ischaemic attack. Follow-up should be multimodal and structured, and include not only assessment of modifiable risk factors but also other key components identified in the **post-stroke checklist** endorsed by the World Stroke Organization.[119] Scientific evidence is emerging in support of such a systematic integrated approach that addresses not only secondary prevention, but also post-stroke rehabilitation, and community reintegration.[120]

Pragmatic solutions to improve secondary prevention

Successful implementation of secondary prevention strategies in people who had a stroke or a transient ischaemic attack could reduce the burden of stroke by as much as 25%,[84] and effective primary stroke prevention strategies at the individual level could reduce the burden of stroke by as much as 50%.[98] Thus, the need for adequate prevention services has been emphasised in several international publications and initiatives, such as IGAP,[47] the Brain Health Initiative,[121] OneNeurology,[122] the Heart and Brain Initiative,[123] the NCD Alliance, the Global Coalition for Circulatory Health,[124] and the WHO Strategic Technical Advisory Group on NCD-related Research and Innovation.[125]

As the risk factors for stroke are also risk factors for other major NCDs, such as dementia, ischaemic heart disease, peripheral vascular disease, diabetes, chronic obstructive pulmonary disease, and cancer (appendix p 58), reducing exposure to these risk factors should help to prevent not only stroke but also other major NCDs.

The most recent World Stroke Organization guideline and action plan for secondary prevention[43] emphasises the importance of setting up stroke prevention clinics staffed with health-care professionals with expertise in stroke care, risk reduction programmes, and educational tools. A good example of transferring or sharing tasks from highly trained health-care professionals to paramedical health-care workers was reported in India in 2020.[99,126,127] A scalable public health intervention to strengthen control of hypertension in primary care settings yielded substantial improvements in blood pressure control (48·1% increase in the number of patients with their blood pressure under control compared with baseline) compared with that achieved in hospitals (22·9% increase).[128]

Digital technologies have been proposed as a new strategy for improving both primary and secondary stroke prevention. A large randomised controlled trial[129] in India showed the feasibility and acceptability of a mobile health intervention (comprising text messages, educational videos, and a workbook accessed via mobile phones) for secondary stroke prevention. The intervention also led to significant reductions in alcohol intake and smoking and significantly improved medication adherence. Other good examples of the practical use of digital technologies are the validated (including cross-cultural validation) and free Stroke Riskometer app,[106,107,109,130] which is available in 19 languages in 78 countries, and the PreventS-MD webapp for clinicians (appendix pp 36–49).[104,105,110] PreventS-MD has been tested for usability (as measured by the validated System Usability Scale)[35] in 27 countries (12 [44%] of which were LMICs) and was judged to have excellent usability by health-care professionals.[104,110] In primary and secondary stroke and cardiovascular disease

For more on the **Brain Health Initiative** see https://brainhealthinitiative.org/

For more on the **NCD Alliance** see https://ncdalliance.org

World Stroke Organization's post-stroke checklist
A checklist to help health-care professionals identify post-stroke problems amenable to treatment or referral

prevention, PreventS-MD was also rated consistently highly by both health-care professionals and patients in terms of acceptability and usefulness. Patients and health-care professionals expressed a high level of understanding of, and adherence to, the tool's recommendations, including readiness to change their behaviour and to adopt a healthier lifestyle. At 1 month follow-up, 100% of patients reported adherence to the recommendations generated by PreventS-MD.[110] Educational campaigns implemented both digitally and face to face can increase awareness about stroke symptoms and the necessary steps that need to be followed to seek medical help.[131]

The effective integration of governmental policies and public-health campaigns with the multidisciplinary health care needed to provide evidence-based individual management would enable successful implementation of primordial, primary, and secondary prevention strategies worldwide.[8,130,132] A good example of systematic follow-up after stroke is the model applied in the STROKE-CARD study[120] in Austria, in which prevention of secondary stroke and cardiovascular disease were integrated into both a standardised 3-month follow-up visit and a web-based patient portal, which enabled patients to review post-stroke complications and comorbidities and express needs for further rehabilitation, and provided education, counselling, and information on life after stroke.

A tripartite approach comprising behavioural, pharmacological, and health-system-level and societal interventions (based on the **socioecological model**), could minimise the fragmentation and inefficiency of primary stroke prevention.[57] Health-care system-level interventions would include screening for stroke risk factors at every clinical encounter, while societal interventions should include ensuring availability of

Socioecological model
A model that conceptualises health in the context of the complex interplay between individual, family, community, and societal factors

affordable healthy foods, clean air, and spaces for physical activity.

Action plans for primordial, primary, and secondary stroke prevention should align with WHO targets for reducing NCDs.[133] These country-specific and financially sustainable action plans should be developed by local experts on the basis of the best available evidence and informed by national, culturally appropriate, and up-to-date stroke prevention guidelines. Unfortunately, there is a shortage of operational national plans that align with the WHO's Global Action Plan for NCDs.[133] Furthermore, although national guidelines for primary and secondary stroke prevention are available in various HICs,[83,133–136] there is a paucity of evidence-based, context-appropriate, pragmatic guidelines in LMICs.[132] The only available digital tool to support clinicians in evidence-based primary and secondary stroke prevention interventions in both hospital and outpatient settings is the PreventS-MD webapp.[104,105] Although most preventive strategies should be similar in all countries, differences in the population-attributable risks and lifetime risk of stroke, and in the availability and affordability of resources, should be considered when setting realistic and culturally appropriate local goals and priorities.

Guidelines and digital tools
We recommend the use of the most recent high-quality evidence-based guidelines by the American Heart Association, the European Society of Cardiology, and the European Stroke Organisation for primary prevention of stroke and cardiovascular disease[137,138] and secondary prevention in patients after a stroke or a transient ischaemic attack,[83,139–141] which can be adapted

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Panel 3: Facilitators of, and barriers to, high-quality stroke prevention services

- Factors that affect the availability of high-quality stroke prevention services include system capacity (ie, the distribution of services across urban and rural areas, the continuum of these services, and the availability of a trained health workforce), universal health coverage, and governance.
- Lack of trained health-care staff is a major barrier to providing primary and secondary stroke prevention services. The unequal distribution of health-care staff and socioeconomic differences between urban and rural areas creates inequalities in access to services, and negatively affects health literacy. By contrast, countries with a wide network of service delivery by a mixture of staff (eg, doctors, nurses, community health workers) with stroke-specific training can provide a wide range of stroke prevention services.
- Universal health coverage influences access to stroke prevention services. Countries with universal health coverage can provide a wide range of stroke prevention services (eg, regular health checks, lifestyle programmes,

pharmacological treatment) free or at low cost. The absence of universal health care exacerbates inequalities in access to stroke prevention services, and people tend to prioritise out-of-pocket costs for treatment rather than prevention, with few or no regular health checks for stroke risk factors.
- An absence of government-led primary stroke prevention activities is linked to low population health literacy about stroke prevention. Strong governance in stroke prevention facilitates high-quality services. A political commitment to stroke prevention and a national strategy to control risk factors (eg, reduction in smoking prevalence, blood pressure control) enhances both primary and secondary stroke prevention.
- Active participation of stroke organisations enhances governance. Countries with strong governance use health data for decision making, whereas a lack of government commitment to prevention of cerebrovascular diseases or clear national prevention guidelines hinders prevention.

to the local context. The traditional approach to management of risk factors (which targets people at high risk of cardiovascular disease) is complex, expensive, and only moderately successful.[37,39,142] The results of a 2021 WHO systematic review[143] based on several high-quality randomised controlled trials that included a large number of participants clearly showed that screening for cardiovascular risk and risk factors has not reduced cardiovascular morbidity and mortality in the general population. Moreover, serious adverse effects were identified (eg, increased mortality). Absolute-risk thresholds should not be the main and sole criterion for selecting people for pharmacological management of hypertension, diabetes, or dyslipidaemia,[38,42,144] which was the approach used in the recent WHO guidelines for the treatment of hypertension.[145] WHO's cardiovascular disease risk charts[146,147] can be used, when feasible, to target individuals at high risk of cardiovascular disease for primary prevention among an identified minority of the population, but use of this strategy alone means that people at low or moderate risk of cardiovascular disease are overlooked, although up to 90% of all cardiovascular and stroke events occur in these people.[35,36,148] The gap between prevention strategies targeted at people at high-risk of cardiovascular and stroke events and population-wide prevention strategies could be bridged via the wide use of digital tools such as the Stroke Riskometer app[8,37,98,104] and PreventS-MD.[104–109]

We suggest that all countries should have government-endorsed policies, guidelines, and stroke awareness campaigns (delivered via the media, schools, churches, etc). Realistic, culturally appropriate, and financially sustainable action plans for secondary stroke prevention can be integrated with corresponding primary prevention strategies and stroke services. Specific plans should also be established for upskilling of staff, including community health workers. Countries should develop a plan for prioritisation of multisectoral and accessible interventions, including telemedicine and other digital technologies.

Panel 4: Recommendations for stroke prevention

- Access to affordable medications for primary and secondary stroke prevention should be improved, with a focus on essential medications (such as polypills including blood-pressure and lipid-lowering drugs on the WHO list of essential medications)[151,152] and tools (including the free Stroke Riskometer app for the general population and PreventS-MD for health professionals).[104,110] Essential drugs for primary and secondary prevention should be subsidised and made available at all hospitals and outpatient clinics.
- Protocol-based and regulated shifting or sharing of tasks from highly trained health-care professionals such as physicians and nurses, to supervised and trained paramedical health-care workers, particularly community health workers, should be emphasised to facilitate primary stroke prevention interventions at the individual level.[98,99] Incentives for health-care staff in rural areas should be improved to encourage relocation and retention.[98,99]
- A continuum of care for stroke prevention should be established. Preventative strategies, with emphasis on lifestyle modification, should be implemented for people at any increased risk of stroke or cardiovascular disease.[98,153] Primary and secondary stroke prevention services should be freely accessible and thus require the introduction of universal health coverage. Governments need to devote a fixed proportion of the annual health budget to stroke prevention. Funding could come from taxation on tobacco, salt, sugar, and alcohol.[37]
- Population health literacy on stroke prevention should be improved.

Research priorities
- Motivational strategies to improve adherence to medication and lifestyle interventions should be investigated.

- There is an urgent need to develop and update national guidelines for stroke prevention[42] and increase the involvement of key stakeholders, including stroke organisations.[8]
- The best balance of population-wide and individual risk-targeted primary prevention strategies for stroke and cardiovascular disease should be identified to maximise cost-effectiveness and minimise inequalities.[37]
- Validation studies should be done to establish the effectiveness of the four primary stroke and dementia prevention strategies recommended by the World Stroke Organization in different populations—ie, population-wide prevention, motivational mobile or digital technologies, provision of low-dose combinations of generic antihypertensives and lipid-lowering drugs in a polypill for middle-aged and older adults with at least two behavioural or clinical stroke risk factors, and facilitation of the implementation of primary prevention strategies on the individual level by community health workers.
- Implementation research is crucial to discover and test novel lifestyle interventions, drugs, and other interventions for primordial, primary, and secondary prevention of stroke and related cardiovascular and other non-communicable diseases.
- The causes (including socioeconomic causes) of ethnic and racial disparities in stroke risk (including pathological types and causative subtypes) should be investigated, and culturally appropriate primary and secondary prevention strategies should be developed to mitigate these disparities.
- High-quality population-based epidemiological studies are needed to measure global, national, and regional changes in the burden and distribution of risk factors for stroke.
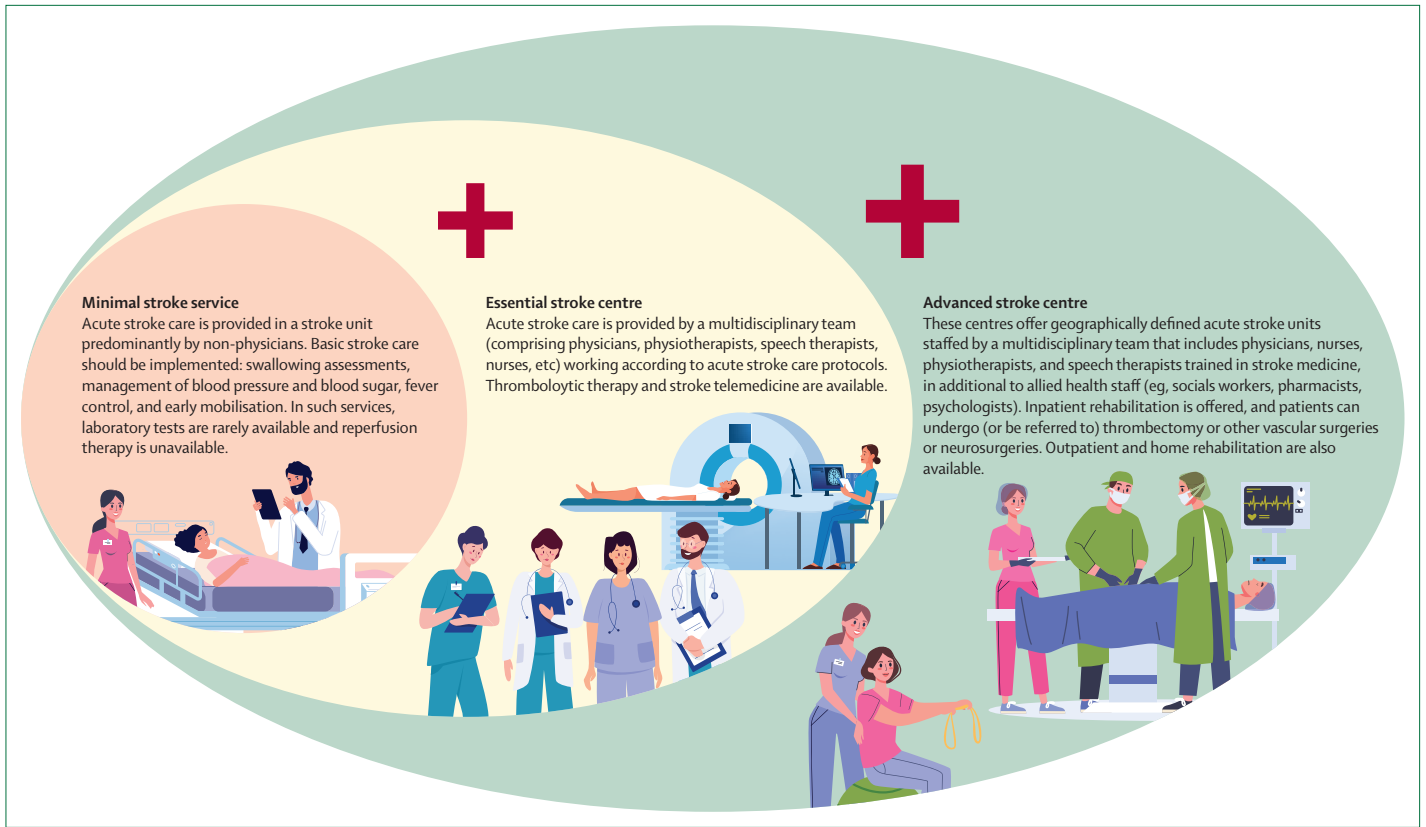
Figure 7: **Overview of the services offered by minimal, essential, and advanced stroke services**
Advanced stroke centres offer all the services provided at essential stroke centres in addition to thrombectomy or referral for thrombectomy, and essential stroke centers offer multidisciplinary care and thrombolytic therapy in addition to services offered by minimal stroke service centres.

Monitoring prevention

As stated previously, all countries should have a nationwide, surveillance system for measuring and monitoring the effects of primary and secondary stroke prevention activities. This system should first identify hospitalisation events (step 1), then identify fatal stroke events in the community (step 2), and then non-fatal stroke events in the same community (step 3), according to the WHO STEPwise approach[149] or similar approaches.[51,63,150]

Generally, the key performance indicators to monitor and assess primary prevention are stroke incidence and prevalence, and the prevalence of risk factors (particularly high blood pressure, atrial fibrillation, dyslipidaemia, diabetes, overweight and obesity, and smoking) over time. Key performance indicators for secondary stroke prevention after a stroke or a transient ischaemic attack should include the proportion of patients whose comorbidities (such as hypertension and diabetes) are under control during follow-up, the proportion without atrial fibrillation who are prescribed an antiplatelet agent, the proportion with atrial fibrillation who are prescribed an anticoagulant, and the proportion who are prescribed a statin. Other key indicators include the proportion of people who had a carotid territory ischaemic stroke or a transient ischaemic attack with symptomatically relevant

extracranial carotid artery disease who undergo carotid revascularisation (when this procedure is indicated), the proportion of people who had either ischaemic or haemorrhagic strokes who are on antihypertensives and who have their blood pressure controlled, and the time from stroke onset to carotid revascularisation. Gaps in secondary stroke prevention can be addressed through national and international policy initiatives and clinical guidelines.[116]

To implement, monitor, and assess the pragmatic solutions recommended by this Commission (panel 4), we have established the World Stroke Organization implementation task force and implementation framework. This framework will leverage global resources, including the WHO and UN non-communicable disease control plan and the WHO intersectoral global action plan on epilepsy and other neurological disorders to address key environmental factors via changes in social policy (ie, social determinants of health) by making default choices healthy (eg, healthy cities, healthy food value chain); enhance stroke literacy through key community influencers who can deliver culturally tailored messages via social media and the media; address motivation and self-management skills; facilitate inclusion of the primary and secondary

prevention recommendations outlined in this section in national stroke and cardiovascular disease management guidelines; and empower stroke Commissioners (country ambassadors for stroke prevention) to advocate for their rigorous implementation and assessment worldwide. The task force and framework are planned to operate at regional, national, and international levels in collaboration with relevant policy makers and implementation partners, including the World Hypertension League, the World Federation for Neurorehabilitation, NCD Alliance, WHO, Resolve To Save Lives, ministries of health, national and regional stroke organisations (including the African Stroke Organization, European Stroke Organisation, Middle East and North Africa Stroke Organization, Asian Pacific Stroke Organization, American Heart Association, and Registry of Stroke Care Quality), and neurological, cardiovascular, and NCD organisations.

Key performance indicators with specific, time-bound, measurable targets and timelines nationally, regionally, and internationally will be co-created and monitored according to the UN Development Assistance Framework theory-of-change approach.[154] A theory of change is a method to explain how a given intervention, or set of interventions, is expected to lead to a specific change, drawing on a causal analysis of available evidence.[154] In the UN Development Assistance Framework, a thorough theory of change helps to guide evidence-based strategies, with needs, assumptions, and risks clearly analysed and spelled out. Key principles for developing a theory of change are that the intervention should be developed consultatively to reflect the understanding of all relevant stakeholders; should be grounded in, tested with, and revised on the basis of robust evidence at all stages; and should support continuous learning and improvement from programme design to programme conclusion.[154]

Research priorities

Further research is needed to identify the best balance between population-wide and individually targeted prevention strategies for stroke and cardiovascular disease, to maximise cost-effectiveness and minimise inequalities (panel 4). Efforts are required to continue research into pragmatic, scalable, and cost-effective primary and secondary prevention interventions. Implementation research is also needed to scale up evidence-informed primordial, primary, and secondary stroke prevention strategies in different populations, including testing of low-risk preventive interventions in routine clinical care. Basic science and translational research leveraging genomics, transomics, and precision medicine to develop prophylactic interventions is also needed.[155] These approaches should include participants from overlooked populations in LMICs and of different ethnicities, to ensure that the interventions are globally applicable.

Part 3: Acute care for all patients with stroke

Acute care refers to the health-care of patients within the 24–72 h after the onset of stroke symptoms.[18] There is robust evidence to support two acute interventions in people with ischaemic stroke: admission to an inpatient stroke unit and use of **reperfusion treatments** (either **intravenous thrombolysis** or **mechanical thrombectomy**).

The main clinical components of acute stroke care (reperfusion treatments for ischaemic stroke, general management for acute stroke, and secondary prevention and treatment of complications in all patients) must be delivered as soon as possible after symptoms onset by a multidisciplinary team in a dedicated stroke unit (figure 7; panel 5). Rehabilitation is started in most cases within 24–48 h of stroke onset. General care for all patients with stroke is fundamental and includes management of blood pressure (with specific protocols for ischaemic and haemorrhagic stroke), blood glucose, body temperature, and oxygen levels. It is crucial that secondary stroke prevention and prevention and management of complications begin immediately after symptoms onset, and that rehabilitation is included in acute care. The implementation of such coordinated acute stroke management through a multidisciplinary team is key to improving long-term outcomes.

Evidence-based acute care

In randomised controlled trials done mainly in well resourced middle-income countries and HICs, organised inpatient (ie, stroke unit) care was associated with reduced odds of poor outcomes (odds ratio [OR] 0·77 [95% CI 0·69–0·87]), death (0·76 [0·66–0·88]), death or long-term residence in institutional care facilities (0·76 [0·67–0·85]), and death or dependency (0·75 [0·66–0·85]) compared with alternative services (eg, treatment on general wards) at the end of scheduled follow-up (median

Reperfusion treatments
An umbrella term for treatment that seeks to restore blood flow to the brain—eg, intravenous thrombolysis, mechanical thrombectomy

Intravenous thrombolysis
A reperfusion treatment in which drugs are used to dissolve blood clots blocking an artery

Mechanical thrombectomy
An endovascular technique for physically removing blood clots from the brain after an ischaemic stroke

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Panel 5: Stroke units and stroke centres

The Stroke Unit Trialists' Collaboration and Cochrane Stroke Group define a stroke unit as a dedicated, clearly defined area or ward in a hospital with beds allocated to patients with stroke where care is provided by nurses, physicians, and therapists with specialised training. This multidisciplinary team coordinates care through regular meetings.[156–158] There are three types of stroke units: acute stroke units with monitored beds for patients in the first 72 h after symptoms onset that can administer intravenous thrombolysis (when indicated); rehabilitation stroke units for stabilised patients 48–72 h after symptoms onset; and comprehensive stroke units that provide acute stroke care (including intravenous thrombolysis), oversee basic interventions such as swallowing assessments, manage also other treatments (such as those for secondary prevention), provide early treatment of complications, and start rehabilitation.

The European Stroke Organisation defines a stroke centre as a hospital with infrastructure and related processes of care that provides a care pathway for patients with stroke.[158] In this definition, patients are admitted to the stroke unit—a key component of stroke centres—which can be clustered on the same ward or scattered throughout the hospital.[158] A stroke centre will provide different levels of institutional care depending on its structure, personnel, and resources.[158]

1 year).[157] Although care on a formal stroke unit is more costly than conventional hospital care, it is cost-effective, at least in high-income countries.[159–161] Despite more than 30 years of evidence showing the benefit of stroke units,[162] many countries (mainly LMICs) do not have any stroke units,[13] and even in HICs the number of beds available in stroke units is often insufficient to provide adequate acute care for all patients with stroke.[157,163,164]

Reperfusion treatments (either intravenous thrombolysis or mechanical thrombectomy) are also supported by robust evidence. The benefits of reperfusion therapy are highly time-dependent, and systems need to be well coordinated to minimise time from onset of symptoms to treatment. Thrombolysis reduces disability in a third of patients and increases the absolute proportion of patients with little to no disability by 10% if administered within 4·5 h of symptom onset.[165] Some benefit can be derived in patients in whom mechanical thrombectomy is not indicated or planned if thrombolysis is administered up to 9 h after symptom onset.[166] Despite the benefits of thrombolysis, the procedure is less effective in strokes caused by **large vessel occlusion**; in these patients, thrombolysis can recanalise only about 4% of intracranial carotid occlusions and 32% of proximal middle cerebral artery occlusions.[167] To overcome this poor efficacy, several studies[168–171] assessed the safety and efficacy of mechanical thrombectomy in patients with large vessel occlusion. Addition of mechanical thrombectomy to thrombolysis in patients with ischaemic stroke due to large vessel occlusion within 6 h of stroke onset increases functional independence (defined as a **modified Rankin score** of 0–2) at 90 days (OR 2·35 [95% CI 1·85–2·98]), but does not significantly reduce mortality (0·77 [0·54–1·10]).[172]

Evidence suggests that the addition of **endovascular thrombectomy** to standard medical therapy (compared with standard therapy alone) 6–16 h after a patient was last known to be well results in significantly better functional outcomes (ie, a modified Rankin score 0–2) at 90 days (OR 2·67 [95% CI 1·60–4·48]) but does not significantly reduce mortality at 90 days (0·55 [0·30–1·02]) in patients with proximal occlusion of the anterior circulation.[173] The DAWN trial[170] showed that, in patients with stroke due to occlusion of the intracranial internal carotid artery or the proximal middle cerebral artery who had last been known to be well 6–24 h previously and who had a mismatch between the severity of the clinical deficit and infarct volume, outcomes for disability and functional independence at 90 days were better in those who underwent thrombectomy plus standard medical care than among those who received standard medical care alone, but there was no significant mortality difference between groups at 90 days (1·0 [1·0–2·0]). However, implementation of intravenous thrombolysis requires trained physicians and nurses, neuroimaging by use of CT or MRI, availability of thrombolytic drugs, and a monitored bed for the treatment. Mechanical thrombectomy requires **angiographic imaging** by CT and

digital **subtraction angiography**, neurointerventionists, anaesthetists, neurosurgeons, specialised equipment, and, in most cases, a bed in an intensive care unit. Despite its enormous beneficial effects, thrombectomy is not yet available in several countries.[13]

As recommended by medical societies (eg, the European Stroke Organisation, the American Heart Association, the American Stroke Association), the organisation of regional acute care networks is fundamental to enable access to stroke centres for more patients, thereby increasing the impact that these centres can have.[158,174,175] Stroke care networks connect hospitals with specialised stroke centres, or with other hospitals with stroke units or hospitals that are less specialised, and their benefits are well documented.[176] We suggest that, because of their expertise, the team at the stroke centre (ie, the hub) is best placed to organise effective regional stroke networks. They should also work with health-care managers, other hospitals, and ambulance services to educate the population to recognise the symptoms of acute stroke and contact emergency medical services, to train pre-hospital staff and implement pre-hospital pathways that are fundamental to speed up access to the right hospital, to create a coordinated pathway to transfer patients from less specialised hospitals to those with stroke units or centres, and to ensure that secondary prevention and rehabilitation are started as early as possible. Stroke centre specialists could also support health-care managers in the creation of regional strategic plans for stroke care and prevention, as occurred in Brazil, Chile, and Egypt.[177,178]

Disparities in acute stroke care worldwide

The World Stroke Organization's roadmap provides a framework for implementation, assessment, and monitoring of stroke services.[43] According to this framework, stroke services are divided into minimal, essential, and advanced relative to a set of resources required for hospitals to attain each category. All hospitals that receive stroke patients in the acute phase but do not offer reperfusion treatments are classed as having minimal stroke services. In hospitals with minimal stroke services, low-cost protocols for general stroke care, which can be implemented even in low-income settings, can be used to improve the outcomes of patients with stroke—eg, swallowing assessments by trained health-care professionals, management of fever, blood pressure, and blood glucose concentrations, and early mobilisation.

Hospitals that provide access to acute stroke care, have an emergency service for stroke, can provide CT and intravenous thrombolysis, and have specialists trained to assist patients either on site or via telemedicine are classed as having essential stroke services. In Canada, the USA, and some other countries, these hospitals are called primary stroke centres. Most stroke centres worldwide fall into the essential services category, which

does not require a high level of technology. To be classed as advanced, centres also need to have a stroke specialist, operating theatres, and a neurosurgeon who can provide stroke care, and to be able to provide endovascular thrombectomy and early inpatient rehabilitation. In the continuum of care, rehabilitation should begin within 24–48 h of hospitalisation.

The effectiveness of organised stroke care specifically adapted to low-resource settings has been shown in Conakry, Guinea, where a facility was set up that consisted of a dedicated area with three beds, and equipment for monitoring of heart rate, blood pressure, and blood oxygen saturation. Implementation of this minimal stroke unit without reperfusion therapy was associated with lower in-hospital mortality (7·2% vs 22·3%; p<0·0001), fewer clinical complications (4·1% vs 27·7%; p<0·001), and less pneumonia (3·3 vs 14·5%; p<0·001) compared with the period before the unit was implemented.[179] Additionally, an epidemiological population-based study[180] sponsored by the Brazilian Ministry of Health showed that some cities in Brazil that did not have any stroke centres had 90-day mortality rates of 40% (Sertãozinho) and 49% (Sobral), whereas in Joinville, a city with full implementation of a stroke network, 90-day mortality was 18%.

Availability of, and access to, acute care

Substantial efforts have been made to establish acute stroke units worldwide.[135–138] However, despite the well-established benefit of acute interventions, implementation has been very slow and mostly partial, especially in LMICs,[13] but also in Europe.[181] A WHO review[182] of the state of global stroke services (194 countries) showed that acute stroke care was available in roughly two-thirds or more of countries in all WHO regions, except for the African region.[183] Disparities across income groups were substantial, with around a third of low-income countries having organised acute care services, compared with around half of lower-middle-income countries, roughly two-thirds of upper-middle-income countries, and four-fifths of HICs.[13]

Our survey of stroke services,[13] with data from 314 hospitals in 84 countries, showed that only 111 (35%) hospitals had the minimum structure required to be considered an organised stroke centre offering reperfusion therapy (appendix pp 98–105).[164,177,184,185] Stroke units were available in 117 (91%) of 129 hospitals in HICs, compared with three (18%) of 17 hospitals in low-income countries. Reperfusion treatments were available in 142 (60%) of 238 hospitals in HICs and upper-middle-income countries and only four (27%) of 15 hospitals in low-income countries. Protocolised swallowing assessments and strategies to minimise **aspiration pneumonia** (eg, appropriate diet and fluids or tube feeding)—cheap and simple interventions that can reduce the morbidity of stroke—were available in only 117 (34%) hospitals wordwide. Inequalities were substantial, with the availability of recommended services increasing with country income level. Guidelines and protocols were more commonly implemented in upper-middle-income countries (50 [46%] of 109) and HICs (54 [42%] of 129) than in lower-middle-income countries (17 [27%] of 63) and low-income countries (one [11%] of nine). In general, the lowest availability of stroke centres and the worst-structured centres (30 [29%] of 104 met the recommended minimal structure of the World Stroke Organization's roadmap) were in the African region.

Europe has the best structured hospitals for acute stroke care (59 [57%] of 104 met the recommended minimal structure),[13] with more than 50% of the recommended elements of acute stroke care implemented in hospitals of all levels. However, a 2017 assessment of the burden of stroke in Europe[164] showed that only about 30% of patients received care in a stroke unit and the proportion of patients treated in a stroke unit varied widely, from 10% in Romania to 80% in Sweden.[164,181] Additionally, most European hospitals do not collect data to monitor stroke care, which makes improvement of the quality of services difficult.

Several quality indicators for acute care are suggested by different guidelines.[43,158,186] It is essential to implement a minimum number of these indicators to monitor stroke care—at least at the individual hospital level, but ideally at a national level.[43] Collection of data from all patients in a **stroke registry** to monitor the quality of stroke care is always challenging, particularly in LMICs. Experts from the European Stroke Organisation and the World Stroke Organization devised several main quality indicators (panel 6) that can be collected easily and that address the process of care (eg, time from arriving at a hospital to treatment, swallowing assessment), the use of treatments for reperfusion and prevention, and the main outcomes after stroke. These indicators were created to be used in the international Registry of Stroke Care Quality, which was followed by the Safety Implementation of Treatments in Stroke Quality Registry. These two registries now have data from a large number of patients from several countries, and have been used by the European Stroke Organisation and the World Stroke Organization Angels Award to recognise centres with good quality indicators (appendix pp 21–24), for the certification of stroke centres by the World Stroke Organization, and for the MT2020 programme (a worldwide campaign implemented by a global peer network of stroke experts since 2016 to accelerate access to thrombectomy). Stroke centre certification could be a helpful framework to encourage and monitor improvements to drive the quality of acute stroke care.

A major gap in acute stroke care worldwide is the implementation of reperfusion therapy, even though alteplase and tenecteplase are included on the WHO list of essential medicines (2021)[187] and devices for thrombectomy are included on the WHO list of priority devices (2021).[188] In well resourced and organised health-care systems, only around 20% of patients with ischaemic stroke are treated

Stroke registry
A systematic approach to identification, diagnostic assessment, and registration of stroke cases in a community

Aspiration pneumonia
An infection of the lungs caused by inhaling saliva, food, liquid, vomit, or small foreign objects

with thrombolysis. In LMICs, less than 1% of patients are treated with thrombolysis,[177,189–191] and some countries such as Ethiopia and Cameroon do not have any hospitals able to deliver thrombolysis, because the drugs are not available there.[192–194] The use of intravenous thrombolysis for stroke increases according to World Bank income level. In our survey, less than 50% of participant hospitals could deliver intravenous thrombolysis available to treat stroke patients, but access was higher in HICs. In the Registry of Stroke Care Quality, in which participating hospitals are mostly stroke centres, have CT facilities, and can offer thrombolysis, the proportion of patients undergoing reperfusion treatment increased according to income level, showing gaps in access to the best treatments and disparities among and within countries. For example, within Nigeria, there are disparities in access to CT and stroke units, with available facilities located mainly in major cities with tertiary hospitals.[13]

Panel 6: Suggested quality indicators for acute stroke care

- Proportion of patients with stroke who attend a stroke unit
- Proportion of patients with stroke who undergo a swallowing assessment before feeding
- Proportion of patients with suspected stroke examined with neuroimaging (ie, CT or MRI)
- Proportion of patients with ischaemic stroke who undergo thrombolysis
- Median door-to-needle time (ie, time from arrival at the hospital to administration of intravenous thrombolysis), and proportion of patients with door-to-needle time <30 min
- Proportion of patients with ischaemic stroke treated with endovascular thrombectomy
- Proportion of patients with symptomatic intracranial haemorrhage after reperfusion therapy
- Proportion of patients with non-cardioembolic ischaemic stroke discharged on antiplatelet agents
- Proportion of patients with ischaemic stroke and atrial fibrillation discharged on oral anticoagulants
- Proportion of patients with stroke discharged on antihypertensives
- Proportion of patients with ischaemic stroke discharged on lipid-lowering therapy
- Proportion of patients with modified Rankin scores of 0–2 at 3 months after index stroke
- Proportion of patients with ischaemic stroke or intracerebral haemorrhage who die within 3 months of index stroke
- Median door-to-puncture time (ie, time from arrival at hospital to the start of endovascular thrombectomy by groin [femoral artery] or elbow [radial artery] puncture) at advanced stroke centres, and proportion of patients with door-to-puncture time <120 min
- Median time from puncture to recanalisation, and proportion of patients with complete or almost complete reperfusion after thrombectomy

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Although mechanical thrombectomy is cost-effective, the needs for the treatment far outstrip supply in LMICs. A survey[195] in India, for example, showed that only 1000–1500 mechanical thrombectomies are done per year, even though more than 270 000 are needed. This lack of treatment in LMICs is mostly due to its cost, which is not affordable to patients, and which is not covered by government or insurance reimbursement in several countries, despite its cost-effectiveness. A paucity of trained interventionalists and angiography-equipped centres, and a lack of awareness of mechanical thrombectomy among physicians, also contribute to its low use in LMICs.

A review[192] of stroke care in Africa showed that mortality at 3 years after stroke was greater than 80%. In 2015, a geospatial analytic study[196] showed that over 70% of people with stroke in Africa took more than 2 h to arrive at a hospital. Only ten countries have stroke units: Algeria, Central African Republic, Egypt, Ghana, Guinea, Mauritania, Morocco, Nigeria, Tunisia, and South Africa.[197] The availability of neuroimaging services (CT or MRI) is very low in many African settings and access to reperfusion therapies is limited but growing. Reperfusion treatments are now available in Algeria, Central African Republic, Egypt, Morocco, Tunisia, and South Africa. Several countries do not have access to thrombolytic agents. A global survey[194] of disparities in the cost of alteplase and its effect on health-care expenditure showed that alteplase costs account for over 200% of per-person health expenditure adjusted for purchasing power parity in LMICs, compared with 18% in HICs.

In Latin American and Caribbean countries, the organisation of acute stroke care has improved substantially in recent years.[177,198] The number of stroke centres, all of which provide thrombolysis, increased from 322 in 2018, to 448 in 2020. The number of countries with dedicated stroke units also increased. All countries in Latin American and the Caribbean deliver thrombectomy in some centres, but the intervention is mostly restricted to a few private hospitals. Ambulance services remain limited in several countries. Use of telemedicine for stroke care has increased, but is restricted to a few hospitals and is not widely available throughout each country. Irrespective of the increasing number of stroke centres, in some countries, patients have to pay for reperfusion therapies, at least in part. For example, in public hospitals, the cost of thrombolysis is covered in full by patients in Bolivia, whereas in three (25%) of 12 countries patients cover half the cost.[177,197] Mechanical thrombectomy is even less available, and the cost is covered by the government in public hospitals in only four (33%) countries, and by health-care insurance in private hospitals in five (42%) countries. The lack of reimbursement for reperfusion therapy limits its access for many patients. Despite this situation, there is evidence supporting the feasibility and cost-effectiveness

of mechanical thrombectomy in Latin America, with the same efficacy as in HICs shown in a clinical trial[199] done in public hospitals in Brazil.[200,201] Before these studies, clinical trials of mechanical thrombectomy had been done only in HICs and the Brazilian health-care authorities had thus claimed that efficacy and cost-effectiveness were unproven in a health system with limited resources.

Barriers and facilitators of acute stroke care

In LMICs, the reasons for governments not to implement acute care are several and include lack of knowledge about its cost-effectiveness, insufficiently trained staff, and concerns about the efficacy of the treatment in these settings because of the complexity of the procedure and the logistic requirements (angiography, interventionalists, anaesthetists, specialist equipment, etc).[36] The good results of the Brazilian trial,[201] along with observational studies of service assessment in other countries, show that improved outcomes from implementation of reperfusion therapies are helping to drive change.[199,202]

Interviews with experts from nine countries (appendix pp 7–14, 106–07) allowed us to identify barriers and facilitators for acute stroke services. The major barriers that we identified were related to awareness, investment, and strategy. Awareness refers to lack of understanding of acute stroke care, which affected availability and access. There was agreement among the experts interviewed that low community awareness of stroke in the general population decreased access to evidence-based care. Lack of awareness among policy makers about stroke care resulted in low prioritisation and funding of stroke services. Furthermore, health professionals, particularly generalists, receive little stroke-specific training, which possibly precludes access to the best care. In terms of investment, all respondents agreed that funding for stroke care was inadequate and that lack of investment resulted in inequalities in access according to location and socioeconomic status. The best care was almost always available only in major large towns with populations of more than 100 000 people. In many countries, people outside major cities, and those without the means to pay out of pocket, have little access to stroke units, thrombolysis, or thrombectomy. Finally, strategy refers to the fact that many countries did not have a national strategy or guidelines for stroke care. Respondents said that countries often did not have professional organisations for health-care professionals interested in stroke, which meant that no national approach to training, accreditation, and advocacy on stroke is available.

The major facilitators for the delivery of high-quality acute care services were related to training, innovation, and networks. The provision of regular, structured training was viewed by respondents as essential for building a stroke care workforce. The best training services, according to respondents, were interdisciplinary, targeted health-care professionals who did not specialise in stroke care (who provide most in-hospital care), and were supported by various public and private funding sources. The increasing demand for thrombectomy has created an urgent need for more interventionalists. Some countries have addressed the growing demand for specialists that can perform thrombectomy by training people from different specialties—eg, cardiology—to perform endovascular clot retrieval. In other countries, tight restrictions on who can perform this intervention means that access to thrombectomy is scarce. In the context of facilitators of acute stroke care, innovation refers to highly motivated and invested workforces driving investments to improve stroke care. Innovation can occur via both formal (eg, government-funded) and informal (eg, WhatsApp groups, telehealth networks providing connected, regionalised stroke care) channels. Governments in some regions are investing in mobile stroke units to increase coverage of care. Innovations in data collection for stroke care are driving quality improvement, with public recognition of high-performing centres viewed as important. Finally, networks are facilitators of acute stroke care because well organised national bodies for stroke care, with strong leadership, increase access to high-quality care, according to respondents. The most effective networks were connected to governments through clear reporting structures (eg, to a minister of health), resulting in endorsed guidelines and funding. Living guidelines provide the potential for harmonised, internationally recognised stroke care guidelines that could be locally adapted.

We describe models of acute stroke care in LMICs, such as Brazil, Chile, China, Colombia, Egypt, Ethiopia, India, and Uruguay in the appendix (appendix pp 16–21). Various successful global initiatives for acute stroke care (the Angel's Initiative, Mission Thrombectomy 2020+, the Latin American Stroke Ministerial Meeting, Global Stroke Alliance, the World Stroke Organization's certification of stroke centres programme, the Registry of Stroke Care Quality, Safe Implementations in Treatments in Stroke, the World Stroke Organization implementation task force, and various American Stroke Association programmes) are also described in the appendix (pp 20–24).

Pragmatic solutions to improve acute stroke care

Effective planning of stroke care at the national or regional level, and adequate resource allocation are key to improving stroke outcomes, and thus reducing the burden of stroke. To effectively organise the delivery of acute stroke care and ensure implementation of guidelines, CT needs to be available to all patients with stroke to, at a minimum, enable health-care professionals to distinguish between haemorrhagic and ischaemic stroke. In the WHO–World Stroke Organization survey,[13] only 179 (57%) of 314 hospitals had access to CT. Even where no CT scanners can be made available, care improvement is still feasible. In 2014, the World Stroke Organization launched

Panel 7: Recommendations for improving acute stroke care

- Organisation of acute stroke care starts by recognising local gaps in structures and care. Many countries, particularly low-income and lower-middle-income countries, have huge intra-country disparities in access to care, and interventions should be tailored to address local needs. The World Stroke Organization roadmap can help in the assessment of available services.
- The next step is to discuss these gaps and recommendations on how to close them with the directors of hospitals and local or national health authorities, and to elaborate action plans. It is crucial to surmount the barriers to availability and affordability of reperfusion treatments.
- Efforts should be made to provide sufficient supply of alteplase worldwide and to reduce the cost of alteplase and tenecteplase in resource-limited settings.[146] Stroke care should be included in universal health coverage packages in WHO member countries. Expensive treatments like intravenous thrombolysis and mechanical thrombectomy should be made affordable. Governments can negotiate with pharmaceutical companies and medical device companies to reduce these costs, as occurred in Brazil.[204]
- Initiatives such as the Latin American Stroke Ministerial Meeting and Global Stroke Alliance can be organised in all regions of the world to bring together health-care managers, including ministers of health, to facilitate discussions and formulation of action plans. Identification of recognised regional and national stroke champions among the World Stroke Organization task force could help in discussions with local health-care authorities and the implementation of evidence-based recommendations.
- The number of stroke units with a multidisciplinary approach needs to increase (the World Stroke Organization suggests at least 50 beds per 1 million people),[43,183] and implementation of evidence-based acute treatments is essential (thrombolysis as a first step, followed by thrombectomy in advanced centres).[177] We recommend the establishment of advanced stroke centres, with at least one centre per 2 million people.[177] The multidisciplinary team should include at least a physician, a nurse, a nurse assistant, a physiotherapist, and a speech therapist.[43]

Telemedicine and training
- In areas without trained stroke specialists, telemedicine can be used to increase access to acute care. Telemedicine has been successfully used in in Ethiopia (appendix pp 21, 25), India,[205] Chile,[177] and Brazil.[177,206]

- Acute stroke care requires well trained staff in ambulances and emergency services for early recognition of stroke signs and rapid transfer of patients to a stroke centre, rapid assessment in emergency departments, initiation of acute stroke treatments in a timely manner, admission to a stroke unit, management by a multidisciplinary team, and early initiation of the rehabilitation interventions.[43,163,186]
- Training of health professionals is fundamental for effective implementation of stroke care guidelines. There are large disparities in the availability of neurology training between high-income countries and low-income and middle-income countries (LMICs).[54,207]
- Digital-based training can be used to build capacity among physicians and nurses to deliver evidence-based stroke care, especially in remote areas without access to trained professionals. Examples of successful training programmes are the Chilean ministry of health programme,[208] which offers free virtual courses for health professionals, the World Stroke Academy, the Angels Initiative, and the Global Stroke Alliance virtual platforms, which provide free, high-quality training for several countries.
- Practical hands-on and simulation-based training for neurointerventionalists are fundamental to develop mechanical thrombectomy skills and to improve the quality of the procedure and patient outcomes. A good example of a peer network to advocate for, and facilitate the global implementation of, mechanical thrombectomy is Mission Thrombectomy 2020+ in the USA.[209]
- A paucity of speech therapists is quite common in LMICs, but nurses or physiotherapists can be trained to do swallowing assessments in the acute phase of stroke care and during rehabilitation.

Monitoring and certification
- For quality monitoring, a nationwide registry with data from all patients with stroke admitted to hospitals should be implemented with a minimum dataset (such as the Registry of Stroke Care Quality, Safety Implementation of Treatments in Stroke Quality Registry, or other platforms). We recommend that hospitals publicly report stroke outcomes. There is some evidence of better outcomes among institutions that publicly report mortality for stroke and myocardial infarction.[210]
- Certification of stroke centres based on an external audit by a national or international agency can help to improve the quality of care delivered and to ensure the implementation of stroke centres, as occurred in Latin America[211] and China.[212]

(Continues on next page)

the global stroke services guidelines and action plan,[107] and created a roadmap with recommendations for regions with low resources, few physicians, and no CT scanners. The guidelines propose general basic stroke care that can be implemented anywhere (including swallowing assessment, fever management, and early mobilisation). These strategies depend only on the availability of trained health-care professionals. Several international initiatives provide free virtual training for basic organisation of stroke services and stroke unit protocols, such as the

(Panel 7 continued from previous page)

Research priorities
We recommend that funding agencies, professional societies, and health-care authorities prioritise and fund research in stroke, especially in LMICs. The research priorities are:
- Assessment of disparities in access to stroke care and prevention within and among countries and regions.
- Further investigation of the use of telemedicine to increase access to specialised stroke treatment in LMICs.
- Development of optimal strategies to increase early recognition, early hospital admission, and access to acute stroke care in LMICs (including reperfusion treatments).

- Assessment of triage strategies in pre-hospital settings and strategies to distribute patients to stroke centres in different health-care systems.
- Assessment of the best approach to manage hypertension in hyperacute (ie, pre-hospital) and acute patients in resource-constrained settings.
- Development and assessment of treatments for dysphagia.
- Clarification of the underlying causes of stroke and risk factors, to unravel new targets for diagnostic and prognostic tools and new treatments.
- Development and assessment of neuroprotective drugs.

	Goals	Targets	Recommendations	Measures of progress
Some countries do not have acute stroke care services	To establish acute stroke services in all countries	To ensure the availability of acute stroke services in all countries by 2030, so that acute stroke care is accessible to all patients worldwide	All countries without acute stroke services should initiate a government programme to establish services and train personnel to deliver interdisciplinary care to patients with stroke in pre-hospital and hospital settings Funding programmes should be developed to facilitate access to acute stroke services in low-income and middle-income countries (government or public–private partnerships) Telemedicine approaches should be used to facilitate access to stroke specialists	The number of countries without acute stroke services in 2022 that have established services by 2030
Some countries do not have sufficient acute stroke care services (in terms of both number and quality)	To increase the number and quality of hospitals with acute stroke care	To increase the number of acute stroke centres, so that every patient with stroke has access to services by 2030 (at least 50 beds per 1 million inhabitants, with a multidisciplinary approach and implementation of evidence-based treatments: thrombolysis as a first step and thrombectomy in advanced centres as the next step) To create more advanced stroke centres providing all necessary treatment options, including thrombectomy, with at least one centre per 2 million inhabitants	Countries with acute stroke hospitals should improve the quality of services provided according to evidence-based guidelines Training programmes should be enhanced to increase the number of personnel available to offer multidisciplinary care Telemedicine can be used to increase access to stroke specialists Certification programmes can be used to improve and maintain the quality of services	The number of new acute stroke services established between 2022 and 2030 in each country National or international quality-indicator registries in hospitals to monitor and improve quality Number of certified stroke services in each country

Table 6: **Pragmatic recommendations to improve acute stroke care by 2030**

World Stroke Academy (delivered in English and Spanish),[203] the Angels Initiative (delivered in several languages), and the Global Stroke Alliance (delivered in Portuguese and Spanish).

The World Stroke Organization's action plan[43] suggests that centres should gradually work to improve their status to achieve all the components required for the essential services level, and for some hospitals to reach the advanced care level. Monitoring is key to achieve improvement over time. To enable the assessment of services, the World Stroke Organization's roadmap is freely available online in English, Portuguese, and Spanish, as a self-assessment tool. A centre can easily assess its status by comparing the proportion of elements implemented with those in the full list of recommendations. The tool can be used by a hospital, by stroke or neurological societies, and by health-care managers to assess local, regional, or national progress towards meeting recommendations.

Dialogue between stroke physicians and policy makers is strategically relevant to raise awareness of the importance of implementing evidence-based strategies. A key step is convincing hospital directors, administrators, and other health-care managers about the cost-effectiveness of stroke units (by citing evidence and showcasing examples from other hospitals or countries). The implementation of stroke units usually depends on the organisation of a team of professionals already available in the hospital (and how they are trained), and the positioning of all stroke beds in the same part of the hospital.

Key evidence-based recommendations for improving acute care by type of stroke are presented in panel 7, table 6, and the appendix (pp 108–12). Although reperfusion is cost-effective, access to interventions is poor in resource-constrained settings. To implement intravenous thrombolysis and mechanical thrombectomy, the drug and devices should be available affordably. Governments should negotiate with pharmaceutical

companies to achieve lower costs for LMICs. The World Stroke Organization has previously helped negotiate in discussions between stroke specialists and ministries of health worldwide. The use of conceptual frameworks, such as the **behaviour-change wheel**, can help countries and regions in the identification, design, and implementation of evidence-based complex interventions like reperfusion treatments.[17]

It is imperative that regional stroke centres are fully equipped and able to deliver and provide training in mechanical thrombectomy. The training of providers in these techniques can follow the model of regional surgical training centres established in response to a study[19] on the provision of essential surgical care in LMICs.[213] Training should be provided by certified neurointerventionalists in large regional comprehensive certified stroke centres that do at least 50 thrombectomies yearly (as recommended by an international guideline),[214] and should be accredited by professional societies or universities. The lack of trained specialists for acute stroke care is an important gap. Telemedicine can be used to increase access to acute care treatments.[201,215–219] Mobile telemedicine could be a cheaper alternative to conventional telemedicine to increase access to reperfusion therapies in areas without neurologists or stroke specialists.[207]

Part 4: Tackling the global burden of disability with rehabilitation

Stroke is the third leading cause of disability worldwide.[1,220,221] Any genuine effort to reduce the global burden of disability needs therefore to identify solutions that can be implemented worldwide to address functional limitations in people after a stroke. The proportion of people with disability (measured as a modified Rankin score 3–5) 5 years after stroke ranges from 25% among those who had minor strokes to about 50% among those who had moderate strokes and 80% among those who had severe strokes.[222] 10 years after a stroke, roughly half of survivors are disabled.[223] Up to two-thirds (or more) of stroke survivors experience motor, sensory, visual, swallowing, language, cognitive, and psychological impairments (ie, functional deficits) that can limit daily activities (such as bathing, or dressing and grooming) and restrict participation in family, work, and social life.[1,222–224] The extent of functional recovery after stroke is variable and depends on several factors, including health and socioeconomic status before the stroke, age, the severity of the stroke, its location and size, comorbidities, and the quality and quantity of rehabilitation received after the event.[222,225]

The aim of stroke rehabilitation is to improve functioning and prolong life without disability. Rehabilitation endeavours to facilitate **neuroplasticity** via function-specific or task-specific and goal-directed training, which is repetitive and challenging enough to maintain attention and to promote gains in functions and capacities. Rehabilitation also involves adaptive and compensatory interventions based on behavioural strategies (such as coping mechanisms) and assistive devices to enable completion of specific tasks,[173] participation in domestic, social, and work life, and optimisation of overall quality of life and wellbeing.[226,227] Research is underway to augment neural repair, regeneration, and connectivity by means of stem cells, growth factors, and other therapies[228,229]

Differences in stroke rehabilitation worldwide

There are substantial gaps in the availability of inpatient, outpatient, and community rehabilitation services for stroke across and within countries and in the quality of services provided. These gaps are caused by the scarcity of evidence-based protocols for stroke rehabilitation, a lack of evidence for some interventions, and a lack of trained personnel and equipment (appendix pp 26–33).[230–232] According to various comprehensive datasets,[13,233–235] most countries offer less than half the stroke rehabilitation services recommended by the American Heart Association. Compared with the other three pillars of the stroke-tackling quadrangle (ie, surveillance, prevention, and acute care), availability of rehabilitation services was the lowest in terms of proportions of LMICs with such services available in every global region.[12] Compared with HICs, LMICs have a substantially lower availability and provision of (and substantially lower quality) inpatient rehabilitation, home assessments, community rehabilitation services, education of carers and patients, early hospital discharge programmes, and rehabilitation protocols.[13] The 2017 WHO Atlas for neurological disorders[236] showed that only 17 (16%) of the 105 countries investigated had specialised neuro-rehabilitation services and only 18 (17%) had general rehabilitation services. This lack of rehabilitation services affects economic productivity in LMICs, especially in places where stroke occurs at a younger age, such as in Africa and India, thus affecting the workforce.[192,237–239] The availability of rehabilitation services increases with increasing income strata.[13,240]

The lack of rehabilitation for stroke survivors is associated with depression, poor quality of life, and low frequency of return to work.[240] Older people, women, people with impaired consciousness at admission, people with a previous history of stroke, people in rural and remote regions, and people not referred to, or counselled on, the need for rehabilitation are less likely to undergo rehabilitation.[241,242]

Effective rehabilitation services should include several components: an experienced multidisciplinary team (including physicians, speech therapists, physiotherapists, occupational therapists, nurses, prosthetists, orthotists, and other health-care professionals trained in stroke rehabilitation; appendix p 62), an individualised goal-oriented approach, and equipment and facilities to provide rehabilitation interventions (a lack of which substantially affects community reintegration of stroke

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Behaviour-change wheel
A conceptual model that combines 19 frameworks for behaviour change. It is a guide for policy makers, practitioners, intervention designers, and researchers and incorporates systematic, theory-based methods, key concepts, and practical tasks

Neuroplasticity
The ability of the nervous system to change its activity in response to intrinsic or extrinsic stimuli by reorganising its structure, functions, or connections after injuries, such as a stroke

survivors). Low availability of effective services, alongside low intensity of services (ie, delivering interventions to patients at too low a frequency or too short a duration, or not offering therapies that are engaging, challenging, and of sufficiently high quality), could explain the differing recovery patterns after stroke in patients in LMICs compared with those in HICs.[232,243–245] The provision of simple interventions, including education of patients about their self-management, was recorded in 29 (35%) of the 84 countries included in the World Stroke Organization survey.[13]

Telemedicine and telerehabilitation are potential solutions to poor availability and low uptake of rehabilitation. Although telerehabilitation is viewed positively by both health-care staff and patients with stroke when offered in a research setting, there can be challenges with equipment setup, the scope of exercises that can be counselled on is restricted,[219,246] and there are difficulties with patient assessment, interface problems, and time constraints (ie, health-care professionals do not always have sufficient time to offer telerehabilitation assistance in addition to their other duties) in a clinical setting.[247] Further investigations into the feasibility, safety, efficacy, and cost-effectiveness of telerehabilitation in different regions are needed.

Meanwhile, poor service organisation and a lack of protocols for rehabilitation in LMICs and some HICs has led to prolonged waiting times for the assessment of individual needs and intervention, to hospital discharge without a rehabilitation plan in place (a major requirement in discharge schemes), inadequate long-term support, inadequate screening and care for depression, and little psychological and social support.[245,248]

Barriers to, and facilitators of, rehabilitation

On the basis of in-depth interviews with experts, we have identified major barriers to, and facilitators of, the delivery of high-quality stroke rehabilitation services (appendix p 89). Barriers were related to the complexity and scope of rehabilitation services and lack of awareness. The complexity of rehabilitation services, due to the interdisciplinary (rehabilitation specialists, physiotherapists, speech therapists, psychologists, prosthetists and orthotists, occupational therapists, nutritionists, and nurses) and inter-setting (ie, acute care, inpatient care, outpatient care, community care, and home care via public and private providers) nature of rehabilitation, creates barriers in terms of prioritising and securing funding, governance of workforce and services, data capture and reporting, and quality improvement and care coordination. According to our interviewees, most stroke rehabilitation efforts were focused on a small range of services, for a limited time, and in only some settings. Respondents stated that often only physiotherapy was available, with very little access to other specialties (eg, speech therapy, occupational therapy, and neuropsychology). Publicly

funded rehabilitation services were mostly provided with acute care, and not in the community or patients' homes, or via telemedicine approaches. Generally, the broadest scope of services was available only in large cities to patients who could afford to pay privately. Respondents reported low awareness of the role of rehabilitation after stroke across a broad range of stakeholders (eg, in the community and among health-care professionals and policy makers). This lack of awareness resulted in low political will to fund services and little advocacy to increase access to, or the scope of, services. However, some shifts in awareness, particularly among health-care professionals, linked to the growing evidence base and professionalisation of the allied health workforce, were reported in countries with trained therapists across several regions.

The major facilitators of the delivery of high-quality rehabilitation services were related to implementation of evidence-based care, universal health care, and capacity building. Evidence-based guidelines, frameworks, and protocols for stroke rehabilitation can assist with service planning and ensure quality of care. Respondents expressed regret that data were not used to plan services nationally and that data were recorded only for people with strokes treated in hospital settings. In countries with universal health coverage, most people get access to some rehabilitation after stroke. Although most respondents agreed that public services were underfunded, they also thought that allied health professionals were doing their best with available resources. The importance of the private sector for providing access to a wide range of services for stroke rehabilitation in diverse settings, including long-term services for discharged patients in the community, cannot be understated.

Capacity building facilitates stroke rehabilitation through training (undergraduate and postgraduate education) and certification by professional organisations of allied health professionals. There is little capacity for allied health training outside nursing and physiotherapy in many LMICs. In several regions, stroke rehabilitation was the responsibility of a few individuals who propagate services and run training programmes. In this context, mentoring and communities of practitioners can contribute to capacity building. Online, internationally led mentoring programmes for people in LMICs are important to prevent the so-called brain drain of health professionals who have to emigrate to get training, but do not subsequently return to apply the skills gained in their country of origin.

A survey from the World Federation for Neurorehabilitation

The World Federation for Neurorehabilitation issued more than 150 specific evidence-based recommendations for stroke rehabilitation practice in 2021.[177] In 2022, this organisation did an international survey of health-care professionals (clinicians) involved in neurorehabili-

	Goals	Targets	Recommendations	Measures of progress
	Some countries do not have stroke rehabilitation services	To establish and strengthen neurorehabilitation services in various settings in all countries	To ensure the availability of multidisciplinary neurorehabilitation facilities and personnel in all countries by 2030, so that rehabilitation is accessible to all patients worldwide	All countries without multidisciplinary neurorehabilitation services should initiate a programme to establish these services and train personnel to deliver multidisciplinary care to patients after a stroke in hospital and in community settings Funding solutions are needed to facilitate access to neurorehabilitation services for patients with stroke in low-income and middle-income countries	Number of countries without multidisciplinary neurorehabilitation services in 2019 for stroke patients who have established such services by 2030
	Many countries do not have sufficient stroke rehabilitation services (in terms of both number and quality)	To increase the number of facilities offering high-quality multidisciplinary care for patients with stroke and to increase adherence to best practice guidelines along the continuum of care, including inpatient, outpatient, community, and home-based rehabilitation	To increase the number of facilities offering high-quality multidisciplinary care for patients with stroke with a continuum-of-care approach and inter-setting organisation, such that every patient with stroke has access to these services by 2030 The number and type of services required will depend on the burden of stroke in each region and country	Multidisciplinary care and inter-setting organisation along the continuum of care should be available for patients with stroke Countries with stroke rehabilitation services should improve the quality of these services according to evidence-based guidelines Training programs should be enhanced to increase the number of personnel available to offer services Performance indicators for rehabilitation that address major impairments and patient and carer needs should be developed A repository for best-practice rehabilitation protocols for sharing and adaptation to different countries and settings should be created	Number of new rehabilitation services established between 2019 and 2030 in each country Improved adherence to clinical practice guidelines

Table 7: Pragmatic recommendations to improve stroke rehabilitation by 2030

tation. The survey asked them about the extent to which these practice recommendations could be implemented in their region (not necessarily in their institution or by themselves). If the recommendations could not be implemented as indicated, respondents were asked why not (appendix pp 120–23). A fundamental lack of implementation of basic approaches to stroke rehabilitation—such as a multidisciplinary team approach, early initiation of stroke rehabilitation on stroke units (and continuation after discharge), integration and coordination of health-care professionals involved in care (and team work), use of WHO's International classification of functioning, and identification of patient-centred individualised rehabilitation goals—was reported in 20–40% of health-care settings worldwide. Thus, a global perspective is required to address such service deficiencies. Additionally, disparities were noted between HICs and LMICs in terms of availability of and access to rehabilitation services and of the needs to be addressed regionally, nationally, and internationally. Whereas a multidisciplinary approach to stroke rehabilitation seemed to be standard in HICs, it was less common in LMICs, where more than a third of services did not have multidisciplinary input. A similar disparity between HICs and LMICs was noted in terms of continuation of stroke rehabilitation after discharge (26% of LMIC respondents reported much less post-discharge continuation of rehabilitation than stipulated in recommendations *vs* 6% of respondents in HICs). Accordingly, there is a substantial need for capacity building in LMICs. Conversely, in HICs where continuation of rehabilitation is implemented, the lack of specific knowledge of stroke rehabilitation among health-care workers in community settings seemed to be an issue. Thus, training of clinicians in a multidisciplinary rehabilitation approach in the community needs to be addressed.

Grading of Recommendations, Assessment, Development, and Evaluations (GRADE)
A transparent framework for developing and presenting summaries of evidence that provides a systematic approach for making clinical practice recommendations

Prism adaptation
Adaptation of the motor and sensory systems that occurs after the visual field has been artificially shifted by using prisms

Guidelines and priorities

There is a paucity of evidence-based guidelines, especially in LMICs, for stroke rehabilitation.[14] Some guidelines in LMICs recommend treatments that are not recommended in guidelines in HICs and for which there is little evidence of effect (eg, cryotherapy, range-of-motion exercises for paresis, magnetotherapy for spasticity). Also, some guidelines in LMICs include recommendations that might be taken for granted in HICs (eg, to train nursing staff in early stroke rehabilitation).[249]

Equally apparent are gaps when practice recommendations are not supported by evidence of at least low quality (according to **GRADE**).[249] Examples include recommendations for complex interdisciplinary rehabilitation to be provided for patients with prolonged disorders of consciousness after stroke, and recommendations about the optimal approach to speech therapy in patients with aphasia.[250] Evidence for how best to treat post-stroke neuro-visual disorders, including unilateral spatial neglect, is of low quality, except for **prism adaptation**,[251] and is hardly sufficient to guide clinical decision making, even though these sequelae are frequent and have substantial effects on activities of daily living and recovery. Similarly, there are gaps in the evidence base for specific interventions for post-stroke fatigue and cognitive, emotional, and behavioural disorders. These disorders greatly affect activities of daily living and social participation and yet there is little evidence for rehabilitation protocols. These evidence gaps highlight an urgent need to engage in collaborative rehabilitation research, ideally globally. Brain recovery research (by basic science) could help to generate new therapeutic notions that can be tested with translational research. Translational findings could then lead to clinical trials and consequently systematic reviews and meta-analyses to guide clinical decision making.[252]

The WHO Package of interventions for rehabilitation[253] provides an overview on interventions for rehabilitation relevant to people with stroke. To implement these

> **Panel 8: Key messages for stroke rehabilitation**
>
> - There is an urgent need to invest in the creation of multidisciplinary rehabilitation services, and in research to generate innovative low-cost interventions (especially in low-income and middle-income countries), and in training of stroke rehabilitation professionals.
> - Assessment tools such as the modified Rankin Scale, the US National Institutes of Health Stroke Scale, and quality-of-life scales should be used to document the type and severity of disability and impairments.
> - Dissemination of multidimensional assessment tools, solutions, training videos (including self-management), and advocacy targeting all stakeholders should be implemented for stroke rehabilitation in all regions. Telemedicine and digital channels could be harnessed.
>
> **Research priorities**
> - Multidimensional characterisation of the life course after a stroke.
> - Investigation of the prevalence and management of risk factors for functional dependence and mortality after stroke at the population level.
> - Establishment of the capacity and needs of the health services and workforce for stroke rehabilitation in terms of education, skill and competencies, and availability of
>
> required tools and equipment—eg, by using the WHO rehabilitation competency framework.[272]
> - Development of performance indicators to monitor rehabilitation quality.
> - Development of tailored rehabilitation protocols for low-income and middle-income countries.
> - Assessment and monitoring of country coverage and outcomes of stroke rehabilitation with routine data collection from facilities—eg, by using WHO's Routine health information systems—rehabilitation toolkit.[273]
> - Validation of the effectiveness of educational tools for stroke rehabilitation, including telerehabilitation, training videos (including self-management tools and programmes), and mobile health (including the role for delivering remote care).
> - Investigation of the feasibility, safety, effectiveness, and coverage of home-based rehabilitation (including self-management), and community-based rehabilitation.
> - Investments in regenerative medicine, novel medications to modify neuroplasticity, low-cost and accessible robotics, neuromodulation tools, and brain–computer interface approaches.
> - Discovery of novel biomarkers for prognostication and quantification of neural repair and recovery.

interventions, there is a great need to establish interdisciplinary rehabilitation facilities and training programmes in tertiary institutions, especially in LMICs. In the face of accumulating evidence for stroke rehabilitation interventions that promote functional recovery, health-care staff need training in clinical decision-making (ie, knowledge about the best available evidence) and the skills to provide newly developed rehabilitation interventions.[252] In the interim, implementation of the forthcoming WHO Basic rehabilitation package[253] and supervised task sharing among available personnel and caregivers (to avoid stress and burnout, caregivers should be provided with adequate support) can bridge the gap and deliver sufficient task-oriented practice to facilitate recovery.[9,254–256] In a family-led stroke rehabilitation trial[257] in India, 1250 patients were randomly assigned to trained rehabilitation by caregivers at home or usual care after stroke. The functional outcomes at 6 months did not differ between the two groups. However, semi-structured interviews with participants showed that family-led rehabilitation (with education as an important component for raising stroke awareness) was an acceptable community-based package for patients and their relatives, and was considered a necessary model of care for poor and rural populations who could not access rehabilitation in a clinical setting.[257]

Telerehabilitation could be offered in various settings, including intensive care, inpatient care, outpatient care, and community-based and family-based care.[258–261]

Therefore, training gaps could be targeted by developing educational tools (including videos and apps) that can be disseminated globally. The results of a trial[262] suggest that use of video conferencing to connect rehabilitation specialists in urban areas to specialists in rural areas is feasible in LMICs.

Local manufacturing of drugs, assistive devices, and rehabilitation equipment could improve access by reducing out-of-pocket costs in LMICs. Health insurance systems and subsidies could also improve access. Meanwhile, better use of available resources through protocols is essential[14] globally, including in some HICs[263] that do not have standardised approaches to follow-up.[264] Most guidelines originate in HICs. In the absence of alternatives, there is a need to adapt these guidelines to LMICs until local evidence becomes available. A major facilitator of high-quality rehabilitation is the regional adaptation of practice recommendations by making use of the evidence[265] to actively transform recommendations into clinical pathways that reflect local health-care priorities, settings, and capacities.[266]

Research priorities
Future research in stroke rehabilitation should investigate the determinants of functional dependence in different populations, the effectiveness of supervised task sharing of rehabilitation with available personnel and caregivers to overcome the shortage of health-care professionals (as compared with **traditional care models**),

Traditional care models
Models that are focused on medical diagnoses, disability, and deficits, based on standardised assessments and treatments
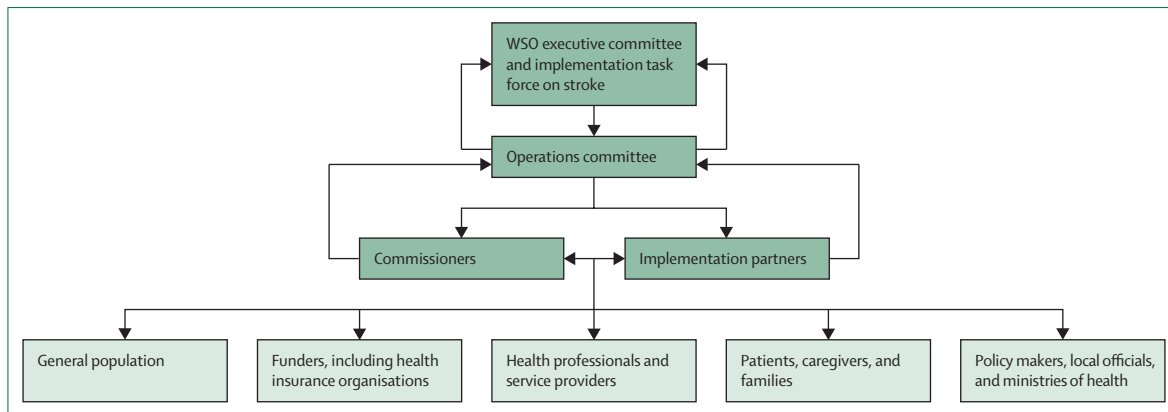
Figure 8: Global ecosystem for the management, implementation, and dissemination of tangible actions to reduce stroke burden devised by the World Stroke Organization—*Lancet Neurology* Commission

Monitoring and reducing the global burden of stroke necessitates equitable and inclusive pragmatic solutions for maximum effect. Therefore, we adopted a synergistic approach to motivate all relevant stakeholders. Bidirectional arrows show a symbiotic bottom-to-top and top-to-bottom approach and intend to convey a sense of joint ownership, which should help to attract global resources. The WSO executive committee implementation task force and the operations committee will communicate with global implementation partners. The operations committee, comprising stroke experts from the six WHO regions, can also advocate for the necessary implementation work through the commissioners. Coordination of the ecosystem by the implementation task force and executive committee will include contextualisation of the key performance indicators and targets, and implementation of the pragmatic solutions across the six WHO regions in collaboration with regional stroke organisations. In addition to WHO, which co-initiated our Commission, our international partners will include the World Federation of Neurology, the World Federation for Neurorehabilitation, the World Hypertension League, the World Heart Federation, the Global Coalition for Circulatory Health, and the Non-Communicable Disease Alliance. Implementation partners will include national stroke support organisations and national ministries of health. The World Bank and other agencies and philanthropists will be approached for funding and support by the executive committee or by the implementation task force. Adapted versions of the global ecosystem will be adopted as regional and national ecosystems to suit local environments. Commissioners will become country ambassadors. WSO=World Stroke Organization. Adapted with permission from Owolabi et al, 2023.[11]

the effectiveness of community-delivered and home-delivered (including self-management) rehabilitation versus facility-based rehabilitation models, regenerative interventions, and low-cost and accessible robotics, neuromodulation devices, and brain–computer interfaces.[267] Validation studies to clarify the effectiveness of rehabilitation-based educational tools, including telerehabilitation, training videos (eg, demonstrations of therapeutic procedures and sessions), and mobile health are also needed. Validation studies are also needed to assess the effectiveness and cost-effectiveness of locally manufactured rehabilitation and assistive devices. Assessment of health-care services and workforces for stroke rehabilitation in terms of training and availability of tools, and research into tailored rehabilitation protocols for LMICs, are also urgently needed.

Pragmatic solutions to improve stroke rehabilitation

We present some pragmatic solutions to improve stroke rehabilitation services worldwide in table 7 and the appendix (pp 124–70).

A novel approach is the concept of so-called living guidelines, whereby experts from across the world participate in the continuous development and updating of evidence-based guidelines that can be adapted in the local context. For example, an online living guideline[268] with a dynamically updating summary of evidence to guide clinical practice and policy development for stroke rehabilitation services has been adopted in Australia. The success of living guidelines is dependent on strong leadership and coordination, and would need to be adequately financed.

The development of international, evidence-based stroke rehabilitation guidelines that focus on therapeutic approaches rather than on organisational issues could also be useful to set up regional or local stroke rehabilitation pathways.[266] Such international practice recommendations for stroke rehabilitation were developed by the World Federation for Neurorehabilitation.[266,269] These recommendations followed a dual process: the context-independent identification of evidence-based practice recommendations for interventions in stroke rehabilitation, and then integration into contextualised regional clinical pathways that take into account regional priorities, resources, and organisational backgrounds (including health-care structures).[269] These recommendations have been integrated into our recommendations (table 7; appendix pp 124–70).

In view of the increasing number of stroke survivors and the limited resources for community rehabilitation, effective and accessible self-management programmes or tools for stroke survivors and caregivers are crucial. Evidence suggests that self-management programmes are feasible and can improve survivors' outcome expectations.[270,271] Good educational tools include videos about stroke self-management endorsed by both the World Stroke Organization and World Federation for Neurorehabilitation.[271] Our key messages on stroke rehabilitation are presented in panel 8.

Conclusions

Despite available evidence-based interventions, there are huge intra-country and inter-country variations in stroke surveillance, prevention, acute care, and rehabilitation worldwide, with fewer services in LMICs. Effective planning of stroke surveillance, prevention, acute care, and rehabilitation is needed to tackle the global burden of stroke. To maximise the effect of the limited resources available, cost-effective and evidence-based pragmatic solutions need to be deployed, with active engagement of all stakeholders, including policy makers and local communities. Region-specific adaptations of stroke prevention and care guidelines and incorporation of these guidelines into clinical practice are essential to bridge the gaps in stroke care between HICs and LMICs. Population-wide detection and control of modifiable risk factors through task sharing and digital tools are needed to reduce the incidence of stroke across the life course. Establishment of stroke units, stroke centres, and rehabilitation services should be prioritised worldwide, particularly in resource-limited settings. Promotion of universal health coverage will enable wider usage of thrombolysis and mechanical thrombectomy. Simple interventions focusing on managing fever, swallowing assessments, and control of blood glucose are low-cost strategies that improve stroke outcomes.

The ecosystem proposed by the World Stroke Organization (figure 8) could play a pivotal role in supporting the implementation of recommended cost-effective strategies to reduce stroke burden worldwide. Implementation will also require training of health-care professionals, research to generate innovative, low-cost interventions, empowerment of both patients and health-care providers with updated information on evidence to improve outcomes, and advocacy to mobilise resources and financial solutions. A biennial ranking of countries in terms of their provision of stroke surveillance, prevention, acute care, and rehabilitation will stimulate healthy competition and improvement. Efforts to mobilise funding via the international stakeholders and implementation partners in the ecosystem are crucial, because stroke, a leading cause of disability, is also a leading cause of catastrophic spending, especially in LMICs. Most LMICs rely on out-of-pocket payments for health care, which is grossly deficient and inadequate for the life-long care required for prevention and functional recovery after a stroke.[171,172]

Synergy with existing international initiatives

A neurological revolution is taking place.[11,274] The new WHO Intersectoral Global Action Plan on epilepsy and other neurological disorders 2022–2031 is an integrated approach to brain health throughout the life course that is propelling neurology to the forefront of the global health and development agenda.[47,274–280] The Global Action Plan leverages the recommendations and actions from other WHO initiatives, including WHO Rehabilitation 2030,[47,281] WHO global action plan for the prevention and control of NCDs,[282] the UN Joint action plan on One Health,[283–285] and other international brain health programmes.[286] These WHO programmes are important for stroke, which is a leading cause of death among NCDs.

Overall, NCDs cause about 74% of deaths globally.[282] The determinants of NCD deaths are not only biological, but also social, environmental, and commercial. Addressing the major risk factors that can lead to NCDs—hypertension, diabetes, dyslipidaemia, smoking, unhealthy diet, misuse of alcohol, physical inactivity, and air pollution—could simultaneously prevent and delay substantial disability and a large number of deaths from stroke and other NCDs. Every member state of the UN has committed to the SDGs, which include a target to reduce premature death from NCDs by a third by 2030.[282] Achieving this goal could save millions of lives, but few countries are on track to meet it. Small additional investments in NCD prevention and treatment could make a big difference: spending an additional $18 billion per year across all LMICs could generate net economic benefits of $2·7 trillion over the next 7 years.[282] This investment would have benefits far beyond health. Poverty and inequity can be reduced through the introduction of universal health coverage, which would prevent catastrophic expenditure on treatment for many people with NCDs who are uninsured. Furthermore, introduction of healthy food systems as part of stroke prevention programmes would also have wider health and socioeconomic benefits.

The WHO Rehabilitation 2030 Initiative[281] draws attention to the profound unmet need for rehabilitation worldwide for stroke and other conditions. The initiative emphasises that rehabilitation care should be available for everyone, throughout the life course, that efforts to strengthen rehabilitation should be directed towards supporting the health system as a whole and integrating rehabilitation into all levels of health care, and that rehabilitation is an essential health service that should be included in universal health coverage. WHO's call for action articulates strategic steps for improving access to rehabilitation worldwide.[47,281]

A global partnership

Overall, partnering with global and regional professional organisations, WHO, and policy makers is essential in the dissemination and implementation of evidence-based interventions for stroke.

The World Stroke Organization implementation ecosystem will work with partners, including non-governmental organisations and national and regional stroke societies to create, implement, and monitor pragmatic solutions to reduce the global burden of stroke. Global, regional, and national key performance indicators and targets will be devised to improve stroke surveillance, prevention, acute care, and rehabilitation.

Panel 9: A case study in Nigeria

P, a 39-year-old man, was going about his duties in a biochemistry laboratory at the University College Hospital, Ibadan (Ibadan, Nigeria), when a colleague suddenly heard him repeatedly mutter to himself "It is well!", after which he staggered and tried to grab the wall to avoid falling. He was rushed to the emergency department of the hospital, where he received a diagnosis of ischaemic stroke. P also had raised blood pressure and serum lipid concentrations, which he had not been previously aware of. His stroke was managed conservatively, because reperfusion treatment was unavailable. He was discharged to his home after 10 days in hospital. At discharge, he was in a wheelchair and had severe functional disability: he could not handle basic activities of daily living without assistance and could neither talk nor walk unassisted.

P was the main income provider for his family before his stroke. However, he did not have health insurance. As the family income dwindled, he could not pay for physiotherapy or nursing services, which led to the development of joint contractures and decubitus ulcers, complicating his functional impairment. He did not have access to speech therapy either. He was unable to keep his outpatient clinic appointments, and his family considered traditional medicine. He developed post-stroke depression. Eventually, about 3 months after discharge, he also developed a fever, difficulty breathing, and unilateral limb swelling, so he was rushed to the emergency department again. Investigations revealed that he had a deep vein thrombosis, probably because he was sedentary and not moving the affected limb actively enough.

Although P clearly had an inadequate support system as a result of major gaps in the availability of acute care and organisation of post-stroke rehabilitation services in his country, provision of educational materials to him or his caregivers about self-management and some rehabilitation tips could have gone a long way towards avoiding some of the complications he experienced after discharge. Furthermore, community-based rehabilitation, which is generally less expensive than hospital care, could have been useful, or perhaps telemedicine-based care.

The practical goal of these efforts would have been to help P with basic activities of daily living and to reintegrate him into family and social life (and, if possible, into his work), which would have reduced the burden of care on his family, and would have given his child a better opportunity to survive. His stroke could have been prevented if P had been aware of his risk factors and encouraged to adopt lifestyle modifications, and attend regular annual check-ups, to get his blood pressure and lipid profile under control.

Our implementation partners include WHO, the NCD Alliance, the Global Coalition for Circulatory Health, the Global Rehabilitation Alliance, the World Federation of Neurology, the World Heart Federation, One Neurology, the Angels Initiative, Resolve to Save Lives, and Mission Thrombectomy 2020. Regional and national stroke societies are crucial drivers in the ecosystem for the adoption of pragmatic solutions across regions—eg, the European Stroke Organisation incorporating the Stroke Action Plan Europe, in collaboration with the Stroke Alliance for Europe, the African Stroke Organization,[287,288] the Middle East and North Africa Stroke Organization, the Asia Pacific Stroke Organization, the Stroke Society of Australasia, the Indian Stroke Association, the Ibero-American Stroke Organization, the International Stroke Recovery and Rehabilitation Alliance, and the American Heart Association and American Stroke Association.

Because of the wide availability of smartphones, including in LMICs, mobile health and telerehabilitation solutions, including training videos and advocacy videos, can be widely disseminated in various languages to enhance stroke prevention, care, and rehabilitation. Multiple interactive channels to communicate and deploy solutions should be targeted to all stakeholders (including patients, the wider population, and policy makers). The implementation cycle[18] and stroke control measures based on the behaviour-change wheel approach should be implemented to inform, involve, and empower all stakeholders to collaborate. Interventions should be developed to improve awareness and increase demand for, and use of, stroke prevention, diagnosis, and rehabilitation services.[289] The importance of awareness in the general population about risk factors, stroke warning signs, adequate acute care, and rehabilitation is illustrated by a case study (panel 9).

We recommend the collection and monitoring of key quality indicators for stroke services worldwide. Such monitoring of acute stroke care, for example, would facilitate planning actions for improvement of stroke centres and enable comparison between different centres and countries. Adherence to key indicators of service availability and quality is consistently associated with reduced risk of death and disability after stroke.[290] Quality indicators can be used to monitor adherence to guidelines and to support the transfer of evidence into everyday clinical practice.[291,292] Standardised core outcome measures for stroke rehabilitation, which are broadly not available in LMICs,[293] are also needed for comparisons of the effectiveness of interventions across settings.

Overall, if the recommendations of this Commission are implemented, the burden of stroke will be reduced substantially worldwide by 2031 and beyond, which will accelerate the attainment of SDG 3.4 and other SDGs, and improve brain health and overall wellbeing worldwide.

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Commission that was circulated to all commissioners for their final review and approval. SEV, AES, VLF, GR, and MOO designed the stroke burden projections, and JD, JC, BD, NB, and JK did the analyses of stroke burden. SG designed the thematic study. SG and MTO wrote the first draft of the surveillance section. SG and TPN wrote the first draft of the thematic analysis. SM and JP wrote the first draft of the acute care section. MOO, JY, FA-A, JP, WF, and TP wrote the first draft of the stroke rehabilitation section. JY and MOO handled integration of all content and overall flow of the document. AM, MI, and MOO developed the economic analysis section. All other coauthors provided critical intellectual contributions and contributed to the overall structure and concepts; wrote and edited the executive summary and key messages and recommendations; reviewed the Commission for important intellectual content; and approved the final version. VLF submitted the final, approved version of the Commission for publication.

Declaration of interests

VLF states that the free Stroke Riskometer app and PreventS-MD webapp are owned and copyrighted by AUT Ventures, which is owned by his employer, Auckland University of Technology (Auckland, New Zealand). VLF has no financial relationship with the apps, but AUT Ventures intends to commercialise PreventS-MD via its social enterprise business, for which VLF serves as chief scientific advisor. PreventS-MD was not involved in any aspect of the design, conduct, analysis, or content of this Commission. GAF has received grants from Novartis, consulting fees from CSL Behring, and honoraria from Astellas and Bayer; has served on data safety monitoring boards, data-monitoring committees, and steering committees for Pharmagenesis and Boehringer Ingelheim; and is a non-executive director of the UK National Institute for Health and Care Excellence and a trustee of Health Services Research UK. DCG has received travel support from the World Federation for Neurorehabilitation and Conventus Travel, and is a past president of the World Federation for Neurorehabilitation. WH has participated on data safety monitoring boards for IFS Institut für anwendungsorientierte Forschung und klinische Studien and Imperical College, London, and is a past president of the World Stroke Organization. GJH has received consultation fees from Janssen Research and Development, Bristol Myers Squibb, and Bayer, and has participated on data safety monitoring boards for Janssen Research and Development. PL has received honoraria from Pfizer, Boehringer Ingelheim, and RAPID-AI iSchemaView; has received travel support from Angels–Boehringer Ingelheim; has participated on data safety monitoring boards and steering committees for Pfizer and Janssen; and is the president of the Chilean Stroke Association and vice-president of the Iberoamerican Stroke Society. BN has received honoraria for serving on data safety monitoring boards work for Simbec-Orion. TP is a member of the Data Safety Monitoring Board for a publicly funded trial in Germany, with public grant money paid to his institution. AR has received honoraria from the University of Texas at Austin (Austin, TX, USA) and Medical College of Virginia (Richmond, VA, USA), and travel support from Fiji National University. PNS is a leader or member of advisory boards for Medtronic and the Angels Initiative (funded by Boehringer-Ingelheim). DY has served as consultant for the Athersys, Johnson & Johnson, Medtronic, Rapid Medical, Gravity Medical Technology, Guidepoint Global, Poseydon, Vascular Dynamics, Royal Caribbean Cruises, and Stryker; holds stocks or stock options in Athersys, Poseydon, and Rapid Medical; has received honoraria payments from Emory University (Atlanta, GA, USA); and is founder and global co-chair of the Society for Vascular and Interventional Neurology's Mission Thrombectomy. All other authors declare no competing interests.

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APPENDIX

INTRODUCTION

Stroke is the second most common cause of death and the third leading cause of disability in the world.[1] It is highly preventable disease affecting all ages, ethnicities, and socioeconomic groups.[1, 2] Although the total incidence and mortality rates of stroke and other CVDs are declining, the absolute number of people affected by stroke has almost tripled over the last three decades.[1, 3, 4] While ageing and population growth are the main drivers of the increased burden of stroke and CVD,[5] not all of the increased burden can be accounted for by these demographic changes.[1, 6, 7] For example, from 1990 to 2019, the total number of stroke-related disability-adjusted life-years (DALYs) lost increased from 108.2 million to 143.2 million.[1] Furthermore, over the last decade, a worrisome trend towards increasing stroke incidence rates in adults <60 years has been observed.[1, 7-9] Although 45-80% of recurrent strokes and transient ischaemic attack (TIAs) could be prevented[10-12] and stroke mortality rates have decreased,[1] no major trends in reducing stroke recurrence rates have been observed over the last two decades in most countries.[13-17]

The increasing incidence rates of stroke in young adults, and the overall increasing absolute number of people affected by stroke/CVDs and other major non-communicable disorders (NCDs) sharing common risk factors with stroke/CVDs, such as type 2 diabetes mellitus, dementia, chronic obstructive pulmonary disease, and cancer, indicate that existing stroke/NCDs prevention strategies are not sufficient.[1, 18] This further indicates that additional, complimentary paradigms for primary and secondary prevention of stroke and CVD are needed.[19-21] A potential remaining opportunity is to facilitate engaging HCPs in augmenting prevention of stroke and other NCDs – as HCPs, such as general physicians (GPs), are presently an underutilised resource. This is mainly due to their busy schedule and their inadequate access to the right digital tools (accessible, affordable, accurate, fast and integrated with the patients' details).[22] Yet GPs are consulted by most patients before they ultimately experiencing their first-ever or a recurrent stroke. The lack of adequate post-discharge support/care[23] and insufficient efficacy of simple advice or a brochure from a GP for secondary stroke prevention[19] have also been documented.

Appropriately designed motivational digital tools (including computer-based tools to assist in clinical decision-making) with user-friendly functionality to collect and use patient data can improve adherence to national guidelines and lead to improved quality of care.[24-26] Evidence-based health-related digital technologies that can be used in tandem by HCPs and their patients and target multiple major NCDs have been identified as critical tools to enhance prevention interventions for stroke/CVD and other NCDs.[27-33] Based on the validated and internationally endorsed Stroke Riskometer algorithm,[34-37] PreventS-MD webapp[31, 37] is a cognitive behaviour theory-based motivational digital support system for HCPs to assess a patient's risk of stroke/CVD and provide primary and secondary prevention management advice based on this assessment, in hospital or outpatient settings.[30, 31] However, the usability of this digital tool has not yet been established.

The overarching aim of this international study was to provide HCPs at the point of care with an actionable, user-friendly digital decision support solution which generates person-centered recommendations for primary and secondary stroke/NCDs prevention drawn from the endorsed stroke/CVD prevention[38-40] and digital health guidelines.[25, 29, 31] Specific objectives of the study were to: (a) evaluate usability and feasibility of PreventS by HCPs and individuals at risk of stroke/CVD (including recurrent stroke); (b) determine patterns of use

and engagement by individuals at risk of stroke/CVD with the recommendations generated within the tool; (c) update the PreventS functionality/interface based on feedback received from the study HCPs; and (d) test usability of the modified version of the PreventS (PreventS-MD) webapp that was updated using feedback from the study HCPs and individuals at risk of stroke/CVD.

METHODOLOGY OF THE STUDY

DEVELOPMENT OF PREVENTS-MD

Based on focus-group discussions and consultations with different health care professionals (HCPs), health care policymakers and IT experts, we developed and tested for internal validity a prototype version of the PreventS-MD webapp (PreventS). This webapp is designed specifically for HCPs to deal with three major inter-related problems in primary and secondary prevention of stroke and CVD within the clinical workflow as outlined below:

1. One of the main obstacles for effective primary and secondary prevention of stroke is the absence of an evidence-based stroke/CVD digital tool to empower HCPs with a patient-centred approach to support decision-making and improve uptake of guidelines to prevent stroke/CVD.[31, 41] The PreventS-MD webapp is designed to be used by HCPs in conjunction with existing electronic patient management systems of outpatient clinics and hospitals. By communicating with the electronic patient management system of the health provider, this webapp, based on cognitive behavioural theory[42] enables semi-automatic collection of information on risk factors for stroke. It further calculates an absolute and relative 5- and 10-year risk of stroke and 10-year risk of acute coronary syndrome. In addition, it generates an editable individual patient-tailored summary of individual risks[31] and evidence-based recommendations[19, 38, 39, 43] for primary and secondary prevention of stroke/CVD.

2. Another major issue is the time constraint in developing effective person-centred recommendations for primary and secondary prevention.[44] HCPs can complete the details in the PreventS-MD webapp in only a few minutesThe time required is less if the data on stroke risk factors are pre-populated from medical records. The webapp further provides individually tailored recommendations for primary and secondary prevention of stroke/CVD for each patient. These recommendations take into account the individual's stroke risk profile, are evidence-based, and can be further edited by the HCP to make it more specific and appropriate for a particular individual.

3. Individuals also lack knowledge and motivation to manage their risk factors.[19, 45, 46] The algorithm helps solve this by providing individuals with estimates of not only their absolute but also their relative risk of having a stroke within the next 5-10 years, and risk of acute coronary syndrome within the next 10 years. The traditional way of providing absolute 5- or 10-year risk has been shown to have low motivational value,[47] and is less likely to lead to behavioural changes for control of risk factors. The webapp is unique in that it provides relative risk, the risk of having a stroke or CVD compared to someone of the same age, sex and ethnicity without any additional risk factors. Therefore, even if the individual has only a few risk factors, their personal relative risk of stroke/CVD can be 2, 3 or more times greater compared to someone without these risk factors. Naturally, people with increased relative risk would be interested to know why their risk is increased and how they can control it. The significant motivation of this approach has been shown in a pilot randomised controlled trial.[47] There are several other built-in motivational tools[48] in PreventS-MD, including interactive risk communication graphs showing contribution of various risk factors to the risk of stroke and CVD, trends in the risk (with repeated assessments), and desirable targets for risk factor control; evaluation

of and trends in (with repeated assessments) the patient's motivation to control identified risk factors; and Specific, Measurable, Achievable, Relevant, and Time-Bound (SMART)[49] goal setting.

In developing the PreventS-MD webapp and its prototype, we utilised a user-centred participatory design approach in which HCPs and individuals at risk of stroke/CVD participated in pretesting the programme. These individuals contributed to refining the layout and functionality of the programme throughout the entire development process.[50] This included creating the content, designing and programming, pretesting and final testing of the programme.

STUDY PARTICIPANTS

The invitation consisted of brief information about the research, inclusion criteria and contact details of the primary researcher (email address and mobile phone number). Information sessions were held via Zoom for those HCPs who wished to know more about the study and the PreventS-MD webapp. HCPs who expressed their interest in testing the PreventS-MD webapp using hypothetical data were given individual password-protected one-month access to the PreventS-MD webapp (after the agreed expiry date access to the system was terminated). After completing testing of the system, the HCPs were invited to participate in a survey on the usability and feasibility of the PreventS-MD webapp and gave consent to participate in the study via the secure password-protected REDCap system. Only those who gave informed consent to participate in the study were provided with access to the online REDCap anonymised survey questionnaire.

SYSTEM USABILITY SCALE

Evaluation of the PreventS-MD programme utilised the commonly used System Usability Scale (SUS).[51]

Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I think that I would like to use this PreventS system frequently					
I found the PreventS system unnecessarily complex					
I thought the PreventS system was easy to use					
I am satisfied with the level of time/resources consumed in performing those tasks					
I found the various functions in this PreventS system were well integrated					
I thought there was too much inconsistency in this PreventS system					
I would imagine that most people would learn to use this PreventS system very quickly					
I found the PreventS system very cumbersome to use					

I felt very confident using the PreventS system					
I needed to learn a lot of things before I could get going with this PreventS system					

ADDITIONAL STUDY QUESTIONS

Demographic information including age, gender, clinical area of practice ("General practice", "Hospital, specify department", "Community health" and "Other, specify"), and the number of years since the respondent completed undergraduate clinical training were collected. We evaluated their experience in using the Stroke Riskometer app with a question "Prior to your participation in the present survey had you used or seen the Stroke Riskometer App?". The next questions were divided into two blocks: needs for innovative primary stroke/CVD prevention strategies (Section A) and PreventS-MD for primary stroke/CVD prevention (Sections B and C).

Details of sections A, B, and C are shown below.

STATISTICAL ANALYSIS

Data collected from both phases were analysed using quantitative and qualitative methods. Quantitative data were analysed using descriptive analysis methods, including an empirical evaluation of the SUS.[51] The SUS is composed of 10 statements that are scored on a 5-point scale of strength of agreement. For items 1, 3, 5, 7, and 9, the score contribution is the scale position (e.g., 4=agree) minus 1. For items 2, 4, 6, 8, and 10, the contribution is 5 minus the scale position (to account for the negative phrasing of these questions). We then multiplied the sum of the scores by 2.5 to obtain the overall SUS composite score,[51] with a possible range from 0 to 100, where higher scores indicate better usability. With the validated mean SUS score of 68 (SD 12.5) as the benchmark for usability of digital health apps,[52] the overall SUS score was analysed and usability was categorised into 4 groups: unacceptable (0-50), poor (51-68), good (69-80.3) and excellent (>80.3).[53] Pre-determined sub-group analyses exploring effects of various covariates on the SUS composite score were also conducted. A statistical significance level of $p \leq 0.05$ was considered as significant.

Transcripts from qualitative interview were transcribed verbatim and, along with the open-ended questions from the surveys/questionnaires, were analysed using conventional direct content analysis[54] focusing more on a qualitative understanding of the usability of PreventS-MD from HCPs and patients. NVivo software was used to manage the data, with dual coding from two independent researchers of all transcripts. We examined the feedback from two study HCPs and ten patients to identify patterns and relevant responses, with the aim of gathering actionable suggestions to revise the prototype and develop the final webapp (PreventS-MD). De-identified, illustrative quotes (appendix pp.13-16) were used when reporting these data according to the COREQ reporting guidelines.[55]

CLINICIAN SURVEY QUESTIONNAIRE

Demographics

Date of survey competion _____

What sex do you identify with?

☐ Male   ☐ Female   ☐ Other   ☐ I would prefer not to disclose

Which age range includes your age?

25-34 years	☐ 55-64 years
35-44 years	☐ 65+ years
45-54 years	

What is your clinical area of practice?

General practice

Hospital, specify department_____

Community health

Other, specify_____

Years since completed undergraduate clinical training _____

Prior to your participation in the present survey had you used or seen the Stroke Riskometer App?

Yes

No

Please indicate how much you agree/disagree with the following statements on the usability of PreventS:

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
There is a gap between current knowledge in stroke prevention and awareness and the knowledge and awareness of the population.					
Despite current primary prevention strategies, there is a lack of motivation from patients at risk of stroke to modify and control their risk factors?					
Primary stroke prevention can be significantly improved with a validated, easy to use stroke management and prevention tool embedded into the existing electronic patient management system.					

Except for smoking, most recommendations on the management/control other lifestyle factors for stroke and other CVDs prevention are currently not given in the patient's summary. What do you think is the main reason for that?	Lack of time					
	Lack of knowledge					
	I see no need to provide this information in the patient's summary					
	Other reason	Please explain:				

If your time allows, would you like to spend more time on primary prevention? If yes, how much time it would ideally require _____ (minutes)

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I would find **PreventS** useful and timesaving in my primary prevention efforts with patients					
I would discuss the data collected in **PreventS** with the patient to promote the impact of the recommendations					
PreventS would improve patients understanding of their risk factors, and ways they could manage their risks as well as stroke awareness					
PreventS would help my patient-clinician communication concerning stroke prevention					
I would have the capacity within my day-to-day clinical role to use **PreventS**, without much effort					
I would recommend **PreventS** to my colleagues when relevant					
I trust the information provided within **PreventS**, which is based on the current internationally recognised guidelines for stroke and CVD prevention					
I am confident Appending my discussion with patients on primary stroke prevention with information from PreventS as opposed to brochures and leaflets					

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Software updating – Constant feature update					
Internet access – Ability to use the application without the mandatory requirement to have an internet connection					
Compatibility - Ability to be installed on any computer or tablet without any additional adjustment					
Virtualisation - Ability to run in multiple or all computers/tablets within the client intranet					
Monitoring risk of stroke & risk factors - Ability to store individual's personal data and link them with individual's previous assessments for monitoring of the individual's progress					
Pre-population of the Variables - Ability to pre-populate patient data based on their electronic clinical records					
In-house Data Storage - Ability to store individual's personal data in client's (health provider) data system					
In-house Cloud Data Storage - Ability to store individual's personal data in secure client's cloud system					
Third-party Cloud Data Storage - Ability to store individual's personal data in secure third-party cloud system					
In-house Data Integration - Allows data integration with other medical databases within client's databases					
Third-party Data Integration - Allows data integration with other medical databases outside of client's databases					
Software Adaptation/Modification - Ability to modify the risk prediction algorithm and other features of the application for specific purposes					

Describe any benefits you see in implementing use of PreventS into daily routine care.

1._____

_____

2._____

_____

3._____

_____

Describe any barriers to implementing use of PreventS into daily routine care.

1._____

_____

2._____

_____

3._____

_____

The following list provides broad themes and related questions to be covered in the interview/focus group with those who consent to participate.

A broad introductory question will be posed first, with subsequent questions as fits with each response. To ensure a smooth conversation, themes and specific questions may not be asked verbatim or in the order outlined below. Additional follow-up probes will be used to explore responses. For example, what makes you say that?" This will allow an in-depth understanding of responses.

Introduction

Welcome and thank participant/s for their time. Confirm that it is OK to record interview. Advise that:

- Can stop at any time, reconvene later or not, whatever suits

- Important to respect all participants views and opinions, even if they differ from yours

- Responses will remain anonymous and confidential, with individual statements attributed to *participant 1* or *clinician 2*

Any questions before getting started?

The following outlines general questions, including potential prompts that may be used by the interviewer for additional information
General views about the PreventS
1. What made you want to use PreventS initially?
2. What worked well? What did not work well?
3. Are you aware of any alternatives of PreventS for stroke prevention? If yes, what are the advantages and disadvantages of PreventS compared to them

Potential prompts
    a) What did you hope to achieve by using PreventS?
Experiences related to the PreventS testing
4. How did you find/ or what was your experience using the PreventS?

Potential prompts
c) Did you have any trouble installing PreventS on your desktop or Tablet?
d) Was pre-populating PreventS data related to stroke risks straightforward?
e) Was entering data related to stroke risks of your patient straightforward?
f) Was it easy to navigate around or not? What did you find difficult? Could you do this by yourself, or did you require assistance?
g) Did PreventS save your time in providing patient-specific stroke prevention recommendations? If yes, how much time (in minutes) it saved?
h) Were there any challenges or limitations that you experienced specifically related to using PreventS?

Future
5. Would you continue to use PreventS? If yes, why? If no, why not?
6. Would you recommend your fellow clinicians to use PreventS? If not, why?
7. To what extent do you think PreventS will improve patient outcomes and behaviour, (which aspects specifically)?

Conclusion
6. Are there things which we could do better to improve PreventS?
7. Is there something else you would like to say, that we have not talked about in the interview?

SEMI-STRUCTURED INTERVIEWS OF HCPs AND INDIVIDUALS AT RISK

After obtaining written informed consent from the two physicians and 10 individuals in New Zealand, the two study physicians from Te Whatu Ora - Health New Zealand Waitematā carried out an assessment of the individual at the risk of stroke and/or acute coronary syndrome using the web version of PreventS-MD. The clinician then reviewed and, if required, modified individual-specific recommendations for stroke/CVD prevention and printed out a summary of the evaluation and recommendations for the individual. After completion of the real-life assessments, the HCPs who conducted the assessments and individuals who underwent the assessment were contacted by a qualitative study researcher for a semi-structured telephone interview about their experience of using PreventS-MD. The HCPs were also asked to complete the RedCap-based SUS questionnaire[51] once more (appendix p. 6-10). After this, all agreed modifications of the PreventS-MD were implemented and the development of the webapp was finalised. One month after the initial assessment all patients were interviewed about their experience of the implementation of the preventative recommendations, including their self-reported adherence to the recommendations.

PATIENT SURVEY QUESTINNAIRE

Background: Stroke is up to 90% preventable if the risk factors for stroke are well controlled. However, the awareness and control of risk factors is poor, and the burden of stroke is increasing across the globe.

The Electronic patient management system PreventS was developed by Auckland University of Technology experts (Prof. Valery Feigin, Project Lead; A/Prof. Rita Krishnamurthi; Dr Alexander Merkin, Study Manager; Parn Jones, webapp Developer) in collaboration with WDHB staff (Luke Skinner, Stroke Fellow; Dr Yogini Ratnasabapathy, Stroke Rehabilitation Lead physician; and David Ryan, Information Systems Change Manager). It is built on the internationally endorsed (World Heart Federation, World Stroke Organization, World Federation of Neurology, European Stroke Organisation) and validated free Stroke Riskometer app.

This survey is being conducted to examine your impressions of the usability of the PreventS for your stroke prevention. It would take only about 20 minutes to complete.

Date of survey competion_____

Please indicate how much you agree/disagree with the following statements regarding use of PreventS

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I plan to use stroke prevention recommendations from PreventS screening to reduce my risk of stroke					
I plan to use stroke prevention recommendations from PreventS screening to link to the Stroke Riskometer app					
Is understanding your risk factors for stroke and cardiovascular disease still important to you?					
Information provided by my doctor from PreventS screening improved my knowledge of ways to reduce my stroke risk					
Knowing my risk of stroke and my risk factors and how to control them (from **PreventS)** motivated me to make changes to my health					

The information and recommendations provided by my doctor from **PreventS** screening was easy to understand					
I was able to easily incorporate recommendations provided by **PreventS** and into my day-to-day life					
I prefer to be informed of my risk factors via **PreventS**, rather than via other means					
I was confident in my ability to implement recommendations provided to me by **PreventS**					
I was able to implement most changes to my health based on recommendations from **PreventS**					

Have you continued to make lifestyle changes related to your risk factors since the last PreventS assessment by your doctor?

      Yes, specify_____

      _____
      _____
      No

Semi-structured interview of patients (over the phone or face-to-face):
The following list provides broad themes and related questions to be covered in the interview with those who consent to participate.

A broad introductory question will be posed first, with subsequent questions as fits with each response. To ensure a smooth conversation, themes and specific questions may not be asked verbatim or in the order outlined below. Additional follow-up probes will be used to explore responses. For example, what makes you say that?" This will allow an in-depth understanding of responses.

Introduction
Welcome and thank participant for their time. Confirm that it is OK to record interview. Advise that:
- Can stop at any time, reconvene later or not; whatever suits
- Important to respect all participants views and opinions, even if they differ from yours
- Responses will remain anonymous and confidential, with individual statements attributed to *participant 1* or *clinician 2*

Any questions before getting started?

The following outlines general questions, including potential prompts that may be used by the interviewer for additional information

General views about the PreventS screening and recommendations
      1. What were your thoughts and experiences during the study?
Potential prompts
               a) What worked well? What did not work well?
               b) Did you have any concerns about the evaluation?

Experiences related to the PreventS recommendations
      2. To what extent do you think PreventS will lead to (or have led to) changes in your health/lifestyle?

Potential prompts

        a) Did you have any trouble understanding PreventS recommendations?

        b) Do you believe PreventS recommendations were useful? Why were they useful, or why were they not useful (*prompt relating to following elements of PreventS*)

2. Knowledge of stroke risk factors
2. Knowledge of stroke signs/symptoms
2. Knowledge of absolute Risk score – was it meaningful
2. Knowledge of relative Risk score – was it meaningful

        c) Would you recommend others (family, friends) use PreventS?

Future

        a) Do you think you will continue to use PreventS recommendations? If yes, why? If no, why not?

        b) Any suggestions for future development of PreventS?

Conclusion

Are there things which we could do better to improve your motivation to control your risk factors?

Is there something else you would like to say, that we have not talked about in the interview?

UPDATED VERSION OF PREVENTS-MD USED FOR THE SECOND PHASE OF TESTING

After summarising and discussing feedback received from the testers, the following changes in the interface and functionality were implemented:

- We added total cholesterol and high-density lipoprotein cholesterol (in both mmol/L and mg/dL units) variables to allow prediction of estimates of 10-year risk of acute CVD (myocardial infarction and acute heart failure) using the validated and scientifically derived algorithm based on the Framingham Heart Study.[56]
- We optimised the user interface of PreventS by reducing the number of screens a HCP had to view and re-arranged the screen items in a more 'clinically sensible' and compact way of presentation.
- We developed three digital versions of PreventS to make it suitable for integration into clinical practices with different software and data protection requirements/settings. So, ultimately health care decision-makers could choose from:

(1) A PreventS-MD desktop version to be used on a personal computer/laptop compatible with Windows/Mac platforms with no access to Internet, where patient data are securely stored only on the hard drive of the computer/laptop. This version is designed to be used in private GP offices and other clinical services with no access to cloud-based electronic medical record (EMR) management systems.

(2) A Prevents-MD Application Programming Interface (API) module version. This version was designed for deep integration with existing EMR management systems. A user has an option to add functions of risk estimates and generation of patient-specific preventative recommendations to their EMR system. Patient data could be stored in the client's existing data storage with all features/applications of client's EMR system also available at all times. This version is designed for stand-alone health organisations and for health organisations of a particular region/country linked into the same client's EMR system, with all the data securely stored within the EMR system.

(3) A PreventS-MD webapp version that offers access to the service for all authorised HCPs in the client institution/organisation via a web browser (e.g., Safari, Google Chrome, Firefox etc.) and original

Prevents-MD interface from any device in the client's intranet (e.g., gadgets, computers), thus allowing patient data to be entered in a patient waiting room or hospital ward by a nurse or another HCP using a gadget which is automatically linked/transferred to the patient data of the HCP computer. The PreventS-MD service server and data storage are hosted in the client's intranet or cloud system. This plug-in webapp version allows integration with any client's EMR. In this case, access authorisation and data storage will happen in the EMR system. All other procedures are performed in the PreventS-MD webapp. This version is designed for stand-alone health organisations and for health organisations of a particular region/country when they share the same client's intranet or cloud system, with all the data securely stored within the client's systems.

Qualitative study (content analysis)

Data were analysed using a manifest analysis[57] in which concepts around usability, acceptability and benefits were explored.

Patients (interviews within first 2-3 days after the assessment)

1. Positive experience with the screening software with easy to understand recommendations provided
    a. "I thought it was brilliant…it quantifies exactly what to do and to reduce risk levels" (#11)
    b. "It was explained very simply" (#7)
    c. I'm one of those people that needs the science behind things, not just get told. Well, if you do this, this will happen and…I've been shown the science [through the software] and the numbers." (#11)
    d. "It certainly gives you guidelines to follow" (#8)

2. Patients acknowledged that the responsibility to reduce their risk factors is on the individual
    a. "It makes sense to just do what I can to help myself" (#7)
    b. "I think that's really up to me…the hospitals have done what they can… I mean it's up to the person to look after themselves…they're [doctors] giving you the guideline. So, it's up to you to follow them" (#8)

3. Took the advice from the screening software seriously and made changes to their lifestyle to reduce their risk factors for having another stroke in the future
    a. "I've already started the changes like…it's no more smoking. I haven't smoked it over the week" (#7)

4. Patients would recommend other people to use the screening software because of all the instructions provided on the chart.
    a. "It's good for people to know what the signs [of stroke] are and how they can reduce them…to improve their lifestyles so they don't have a stroke" (#8)

5. A lot of information was shared in a short span of time, and it was difficult to take everything at once
    a. "A 15-minute information and all coming to me. It's sort of just makes you think really quick" (#7).
    b. "It was a bit hard to take it all in…you know now I am 83-84" (#12)

6. The wording of the chart is a bit harsh

a. "Some of the way its worded, it says identified risk factors says that excessive weight like according to the BMI that they have got for me and what I weighed, I am not even 3 kilos overweight." (#8)

7. Good to have a website for people in general to increase their understanding/awareness about the stroke symptoms
   a. "It would be great if, like there was a website where that you could…like what are your risks of having a stroke or a heart attack…it's a quiz type thing and you can answer the questions honestly and it gives you a ratio or a score at the end of it" (#8)

8. All the participants said that they would continue to use the screening software recommendations as it provides means through which they can improve their health and prevent their stroke in the future

9. All the participants started implementing the changes in their lifestyle recommended in their screening, particularly their food habits and exercise

10. There were no concerns about the screening software and patients were satisfied with the information provided to them

Patients (interviews one month after the assessment)

1. All the participants still have the recommendations prescribed to them by the doctor.

2. All the participants are following the recommendations
   a. "I think everything that was recommended for me to do and I have done so" (#6)
   b. "I have restricted my alcohol intake… I would say 90% of the time" (#2)
   c. "I am not having oily foods anymore" (#10)

3. Positive experience of following the recommendations – are able to see improvement in their health
   a. "I find it quite helpful and I find that it has helped me to achieve a lot of things" (#6)

4. Motivation for the participants to follow the recommendations included - *"to get better"* (#2), *"I am eating better and losing weight"* (#1)
   a. "The motivation was to be able to get back" (#6)
   b. "I just want to get back to where I was and I'll get back to what some sort of normality" (#8)
   c. "it's certainly that, that that the print out is motivated me to actually do something" (#1)

5. All the participants stated that it was easy to follow the recommendations.

6. Some participants expressed forgetting to follow the recommendations due to work commitments. *"I do what I can do… telling is one thing but following is another"* (#5).

       a. "Just back at work and by the time I get home, it's too hot. You know, if I go walking when it's hot, it's uncomfortable" (#8).

7. Participants felt better and improved health by following the recommendations

8. All the participants stated that they would use the recommendations in the future as well since they are witnessing positive changes concerning their health

       a. "This is like to look after myself now. To me it was a more ohh bit of a small warning. You know like you need to look after yourself and lead a healthier lifestyle" (#8)

       b. "Best thing because it's coming from the doctor's side, for our health" (#10)

       c. "because of reducing the risk of another stroke" (#1)

Clinician 1

1. More time consuming
2. Provides holistic approach for the patient
3. Every person was able to understand the recommendations provided through the screening software even though language was a barrier, everyone was able to understand at least little bit about the risk factors
4. 3/4 of the patients in xxx hospital are non-English speakers. It will be good to have the recommendations in multiple languages, particularly Hindi, Tongan, Samoan and Mandarin
5. If the software can be integrated into the DHB system where it can pre-populate the demographic information of the patient, that will save time of the clinician
6. People who attend the follow-up sessions are self-motivated. Most of the people don't come for a follow-up session and therefore it becomes difficult to perform assessment on them.

Clinician 2

1. Difficult to do the assessment in a clinic setting, but in a hospital setting it's much easier to use it because it's more time consuming and in the clinic setting, time frame is really short to put all the details in the software and then explain the recommendations
2. It's an easy way of getting all the information in one go to the patient. Otherwise, patients need to be given multiple templates for hypertension control, cholesterol and so on
3. It will be better if the software integrates with the hospital system that will repopulate the information already present in the portal
4. Graphical representation is interesting for the patient and its customised according to the patient's needs. This helps the patient to understand the risk factors in a better way and tell the patient what exactly is recommended for their health
5. Using the screening software is a straightforward process, well written and very well formulated.
6. Participants found a lot easier to understand than what they used previously (charts – paper based).
7. It was very individualised; the clinician could see the "interest in the patient's eyes" and it could focus on that patient's issues and risk of further stroke. When the clinician gave them their own recommendations, they could see the "spark" and felt they were going away looking motivated.

8. The patients could really see what difference an intervention made e.g., the difference between eating more or less vegetables.
9. It gives more care to the patient and looking at them in a more holistic way. This felt more satisfying.
10. It didn't work so well for those not fluent in English. Even if the prevention part had a translation (she thought Tonga, Samoan, Hindi and Mandarin would be a good start).
11. Detail provided around the recommendations were more effective with those who were more highly educated or with a higher level of health literacy. Some people had difficulty in understanding the 5- and 10-year risk of stroke.
12. It took longer than a usual consultation, but it was more effective. It also gave useful information for the support person (wife, daughter etc), so could have a "roll on" effect with other family members.
13. The clincian would keep using the software if given a chance.
14. The clincian thought it was a great product and could be used in other areas of the hospital too e.g., for cardiovascular. Also, if other doctors had access (say in general medicine) this could be done before the person is discharged. This could especially target the DNAs (Did not attend), who are unlikely to come back for a follow up appointment.

RESULTS

First phase of the study

During the first phase of the study, 83 HCPs from 27 countries (55% [15/27] from high-income countries [HICs] and 45% [12/27] from low- to middle-income countries [LMICs]; Figure 2) were approached and initially expressed their interest to participate in the study. Among these, 83.1% (69/83) provided informed consent and 86% (59/69) of those who consented, completed the survey. There were no detectable sex differences between those completing phase 1 and phase 2 of the study (Table 1; p=0.29). The majority of testers (88.1%; 52/59) were aged 35-64 years, had 23.7 (SD 10.9) years of working experience (after completion of undergraduate clinical training), with 67.8% (40/59) working in hospitals and 11.9% (7/59) working in outpatient clinics. Females comprised 42.4% (25/59) of respondents. Prior to the survey 86.4% (51/58) had used or seen the Stroke Riskometer app. In total, the PreventS prototype was tested 240 times using hypothetical data of 155 'patients'.

The percentage agreement for individual survey items exceeded 90% for the items in Section A which assessed the needs for innovative primary stroke/CVD prevention strategies, more than 90% agreed to six of the eight items of Section B which assessed the advantages of using PreventS-MD and over 83% agreed to 10 of the 12 items of Section C concerning important features of the PreventS-MD for primary stroke/CVD prevention (appendix Table 1A and Table 2).

The SUS mean score of 80.2 (95%CI [77.0, 83.5]) for phase 1 indicated that the app was rated in the A-band of good acceptability with scores ranging from 55 to 100 (Appendix Table 1A). The SUS scores did not appear to be affected by the age, sex, working experience and speciality of the HCPs (all p-values >0.05). We also compared the SUS scores between people with or without prior experience of the Stroke Riskometer app and were unable to detect a difference between these groups (p=0.56).

Consistent with the SUS scoring, almost all testers indicated that PreventS was useful and timesaving in their primary prevention efforts (93.2% [55/59]). They thought it would improve patients' understanding of their risk factors and ways that they could manage their risks as well as stroke awareness (98.3% [58/59]), and improve patient-clinician communication concerning stroke prevention (93.2% [55/59]). The majority of testers stated that they would: have the capacity within their day-to-day clinical role to use PreventS without much effort (74.6% 44/59]); discuss the data collected in PreventS with the patient to promote the impact of the recommendations (94.9% 56/59]); recommend PreventS to their colleagues when relevant (98.3% [58/59]); trust the information provided within PreventS, which is based on the current internationally recognised guidelines for

stroke and CVD prevention (94.9% 56/59]); and use PreventS-based information in preference to brochures and leaflets (88.1% [52/59]).

HCPs reported a need for primary stroke prevention, numerous reasons for not including many lifestyle factors in patient summaries, additional usability points of the PreventS system, preference for availability of new features of the PreventS system, and expected frequency of use of the PreventS system in their practice (appendix Tables 2-10). Lack of time was the main reason (84.7% agreement) for not including recommendations on the management/control of lifestyle factors for stroke (except for smoking) and other prevention strategies in the patient summary. HCPs also indicated that they would like to spend more time on primary prevention ranging from 3 to 120 minutes with a mean of 20.4 minutes (*SD*= 20 min). The PreventS webapp would also assist the 32.8% of HCPs who indicated a lack of knowledge impeded them from providing the information in the summary. The usefulness of PreventS for primary stroke/CVD prevention was consistently rated very high with percentage agreement ranging from 88%-98%. More than 80% of HCPs agreed that 10 of the 12 features of PreventS were critical for primary prevention of stroke/CVD (Section C; appendix Table 2).

Conventional content analysis of open-ended questions from the surveys and interviews of the clinical practice testers and patients showed that comments on usability fell into two general themes (appendix pp 11-14 and Tables 7 and 8): (a) Benefits in implementing and use of PreventS into daily routine care; and (b) Barriers to implementing and use of PreventS into daily routine care. Suggestions for improvement of the tool also fell into two themes (appendix Table 9): (a) Perspectives on the Stroke Riskometer algorithm; and (b) Perspectives on PreventS recommendations. For details and quotes, see appendix pp.11-14 and Tables 7-9.

In subgroup analyses (e.g., age, sex, place of medical practice), we found no significant difference between those who did and did not believe in the need for innovative primary stroke prevention strategies and usability of PreventS (chi square of independence test *p*=0.22).

After summarising and discussing feedback received from the testers (HCPs), the following changes in the interface and functionality were implemented for the second phase of the study: We added total cholesterol and high-density lipoprotein cholesterol (in both mmol/L and mg/dL units) variables to allow prediction of estimates of 10-year risk of acute CVD (myocardial infarction and acute heart failure) using the Framingham risk score.[56] We optimised the user interface of PreventS by reducing the number of screens a HCP had to use and re-arranged the screen items in a more 'clinically sensible' and compact way of presentation. We also developed three digital versions of PreventS-MD to make it suitable for integration into clinical practices with different software and data protection requirements/settings (appendix pp.10).

Second phase of the study

In the second phase of the study we tested PreventS-MD for usability by employing quantitative (SUS survey) and qualitative methods (semi-structured interview) in 58 of the 72 HCPs who consented (response rate 81%) using hypothetical and actual patients' data. The average SUS usability score was 81.7 (95% CI [79.1, 84.3], meaning that the webapp was rated in the A-band of excellent acceptability (Table 2). Similar to the first phase of testing of the prototype, this score was not affected by the age, sex, or speciality of the HCPs (*p* >0.05). The results of testing on hypothetical 'patients' were consistent with reslts of testing on real patients. However, more experienced HCPs rated PreventS-MD significantly better with a moderate effect size (β=0.30, *p*<0.001). We also compared the SUS scores between people with or without prior experience of Stroke Riskometer app and were unable to detect a difference between these groups (*p*=0.69).

Content analysis of qualitative interviews with 10 patients at risk of stroke and CVD and two of their HCPs (general physician, geriatrician) showed high level of understanding and usefulness of PreventS-MD by both patients and HCPs. There was also high level of intention to adherence to the recommendations resulting from the assessment, including readiness to change their behaviour

towards a healthier lifestyle. For more details see appendix pp.11-14. The qualitative follow-up interviews with the participants at one-month after a stroke risk assessment and prevention consultation using PREVENTS-MD indicated a 100% adherence to recommendations. Many stated that the recommendations were *"easy to follow"* and *"one of the best things coming from their doctor's side"*. Some participants stated they were *"able to witness positive changes in their health even in this short time"* and were *"motivated towards continuing them in future".* Overall, the participants believed that the recommendations were tailored and not only helped them reduce their stroke risk but also aimed to improve their overall health and lifestyle. In addition, the PreventS-MD was shown to save time for HCPs (from the everage time of 20 minutes to 3-5 minutes) and improve uptake of evidence-based guidelines for providing effective person-centered recommendations for primary and secondary prevention of stroke and primary prevention of CVD, as evidenced by the qualitative aanalysis and one-month follow-up. As suggested by clinicians participating in the study, based on recent evidence from the Multi-Ethnic Study of Atherisclerosis and asssociations of the Life's Simple 7 with the risk of noncardiovascular disease[58] we also added to PreventS-MD a measurement of blood glucose and estimates of 10-year risks for developing any malignant neoplasm, dementia, chronic kidney disease and indicators of end-stage kidney disease, pneumonia, deep venous thrombosis or pulmonary embolism, chronic obstructive pulmonary desease, and hip fracture, correctively responsible for approximately 74% of the disease burden in the world.[59]

Qualitative themes (stage 2 of the study -baseline)

Patients
Positive experience with the screening software and it was easy to understand the recommendations provided
"I thought it was brilliant…it quantifies exactly what to do and to reduce risk levels" (#11)
"it was explained very simply" (#7)
I'm one of those people that needs the science behind things, not just get told. Well, if you do this, this will happen and…I've been shown the science [through the software] and the numbers." (#11)
"it certainly gives you guidelines to follow" (#8)

Patients acknowledged that the responsibility to reduce their risk factors is on the individual
"it makes sense to just do what I can to help myself" (#7)
"I think that's really up to me…the hospitals have done what they can… I mean it's up to the person to look after themselves…they're [doctors] giving you the guideline. So, it's up to you to follow them" (#8)

Took the advice from the screening software seriously and made changes to their lifestyle to reduce their risk factors for having another stroke in the future
"I've already started the changes like…it's no more smoking. I haven't smoked it over the week" (#7)

Patients would recommend other people to use the screening software because of all the instructions provided on the chart.
"it's good for people to know what the signs [of stroke] are and how they can reduce them…to improve their lifestyles so they don't have a stroke" (#8)

A lot of information was shared in a short span of time, and it was difficult to take everything at once

"A 15-minute information and all coming to me. It's sort of just makes you think really quick" (#7).

"it was a bit hard to take it all in…you know now I am 83-84" (#12)

The wording of the chart is bit harsh

"some of the way its worded, it says identified risk factors says that excessive weight like according to the BMI that they have got for me and what I weighed, I am not even 3 kilos overweight." (#8)

Good to have a website for people in general to increase their understanding/awareness about the stroke symptoms

"it would be great if, like there was a website where that you could…like what are your risks of having a stroke or a heart attack…it's a quiz type thing and you can answer the questions honestly and it gives you a ratio or a score at the end of it" (#8)

All the participants said that they would continue to use the screening software recommendations as it provides means through which they can improve their health and prevent their stroke in the future

All the participants started implementing the changes in their lifestyle recommended in their screening, particularly their food habits and exercise

There were no concerns about the screening software and patients were satisfied with the information provided to them

Dr. 1
More time consuming
Provides holistic approach for the patient
Every person was able to understand the recommendations provided through the screening software even though language was a barrier, everyone was able to understand at least little bit about the risk factors
3/4th of the patients in Waitakere hospital are non-English speakers. It will be good to have the recommendations in multiple languages, particularly Hindi, Tongan, Samoan and Mandarin
If the software can be integrated into the DHB system where it can pre-populate the demographic information of the patient, that will save time of the clinician
People who attend the follow-up sessions are self-motivated. Most of the people don't come for a follow-up session and therefore it becomes difficult to perform assessment on them.

Dr. 2
Difficult to do the assessment in a clinic setting, but in a hospital setting it's much easier to use it because it's more time consuming and in the clinic setting, time frame is really short to put all the details in the software and then explain the recommendations.

It's an easy way of getting all the information in one go to the patient. Otherwise, patients need to be given multiple templates for hypertension control, cholesterol and so on

It will be better if the software integrates with the hospital system that will repopulate the information already present in the portal

Graphical representation is interesting for the patient and its customised according to the patient's needs. This helps the patient to understand the risk factors in a better way and tell the patient what exactly is recommended for their health

Using the screening software is a straightforward process, well written and very well formulated.

Qualitative themes (stage 2 of the study – 1 month follow-up)

1. All the participants still have the recommendations prescribed to them by the doctor.
2. All the participants are following the recommendations
   a. "I think everything that was recommended for me to do and I have done so" (#6)
   b. "I have restricted my alcohol intake… I would say 90% of the time" (#2)
   c. "I am not having oily foods anymore" (#10)
3. Positive experience of following the recommendations – are able to see improvement in their health
   a. "I find it quite helpful and I find that it has helped me to achieve a lot of things" (#6)
4. Motivation for the participants to follow the recommendations included - *"to get better"* (#2)*, "I am eating better and losing weight"* (#1)
   a. "The motivation was to be able to get back" (#6)
   b. "I just want to get back to where I was and I'll get back to what some sort of normality" (#8)
   c. "it's certainly that, that that the print out is motivated me to actually do something" (#1)
5. All the participants stated that it was easy to follow the recommendations.
6. Some participants expressed forgetting to follow the recommendations due to work commitments. *"I do what I can do… telling is one thing but following is another"* (#5).
   a. "Just back at work and by the time I get home, it's too hot. You know, if I go walking when it's hot, it's uncomfortable" (#8).
7. Participants felt better and improved health by following the recommendations
8. All the participants stated that they would use the recommendations in the future as well since they are witnessing positive changes concerning their health
   a. "This is like to look after myself now. To me it was a more ohh bit of a small warning. You know like you need to look after yourself and lead a healthier lifestyle" (#8)
   b. "Best thing because it's coming from the doctor's side, for our health" (#10)
   c. "because of reducing the risk of another stroke" (#1)

TABLES

Appendix Table 1A. Evaluating PreventS using SUS usability scale (first phase; n=59)

Survey questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I think that I would like to use this PreventS system frequently (n, %)	0 (0%)	0 (0%)	7 (12.3%)	31 (54.4%)	19 (33.3%)
I found the PreventS system unnecessarily complex (n, %)	18 (31.6%)	30 (52.6%)	7 (12.3%)	1 (1.8%)	1 (1.8%)
I thought the PreventS system was easy to use (n, %)	0 (0%)	1 (1.7%)	3 (5.2%)	27 (46.6%)	27 (46.6%)
I am satisfied with the level of time/resources consumed in performing those tasks	0 (0%)	0 (0%)	4 (6.9%)	32 (55.2%)	22 (37.9%)
I found the various functions in this PreventS system were well integrated (n, %)	0 (0%)	0 (0%)	4 (6.9%)	36 (62.1%)	18 (31.0%)
I thought there was too much inconsistency in this PreventS system (n, %)	23 (39.7%)	28 (48.3%)	5 (8.6%)	1 (1.7%)	1 (1.7%)
I would imagine that most people would learn to use this PreventS system very quickly (n, %)	0 (0%)	0 (0%)	3 (5.2%)	31 (53.4%)	24 (41.4%)
I found the PreventS system very cumbersome to use (n, %)	24 (42.1%)	26 (45.6%)	5 (8.8%)	1 (1.8%)	1 (1.8%)
I felt very confident using the PreventS system (n, %)	0 (0%)	0 (0%)	11 (19.0%)	31 (53.4%)	16 (27.6%)
I needed to learn a lot of things before I could get going with this PreventS system (n, %)	18 (31.0%)	26 (44.8%)	7 (12.1%)	5 (8.6%)	2 (3.4%)

10-item SUS mean score (SD): 80.22(12.37). Total number of HCPs who participated in the first (59) may not sum up for some of the answers, because not all HCPs who participated in the first survey answered each of the questions

Appendix Table 1B. Evaluating PreventS using SUS usability scale (second phase; n=58)

Survey questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I think that I would like to use this PreventS system frequently (n, %)	0 (0%)	0 (0%)	6 (10.3%)	35 (60.3%)	17 (29.3%)
I found the PreventS system unnecessarily complex (n, %)	19 (33.3%)	26 (45.6%)	6 (10.5%)	4 (7.0%)	2 (3.5%)
I thought the PreventS system was easy to use (n, %)	0 (0%)	2 (3.4%)	2 (3.4%)	35 (60.3%)	19 (32.8%)
I think that I would need the support of a technical person to be able to use this product.	33 (56.9%)	20 (34.5%)	2 (3.4%)	3 (5.2%)	0 (0%)
I found the various functions in this PreventS system were well integrated (n, %)	0 (0%)	0 (0%)	1 (1.7%)	40 (69.0%)	17 (29.3%)
I thought there was too much inconsistency in this PreventS system (n, %)	21 (36.2%)	35 (60.3%)	2 (3.4%)	0 (0%)	0 (0%)
I would imagine that most people would learn to use this PreventS system very quickly (n, %)	0 (0%)	1 (1.7%)	1 (1.7%)	38 (65.5%)	18 (31.0%)
I found the PreventS system very cumbersome to use (n, %)	26 (44.8%)	30 (51.7%)	1 (1.7%)	1 (1.7%)	0 (0%)
I felt very confident using the PreventS system (n, %)	0 (0%)	0 (0%)	3 (5.2%)	36 (62.1%)	19 (32.8%)
I needed to learn a lot of things before I could get going with this PreventS system (n, %)	26 (44.8%)	23 (39.7%)	7 (12.1%)	2 (3.4%)	0 (0%)

10-item SUS mean score (SD): 81.71 (9.97). Total number of HCPs who participated in the second survey (58) may not sum up for some of the answers, because not all HCPs who participated in the second survey answered each of the questions

Appendix Table 2. Need for innovative primary stroke prevention strategies (completed by HCPs)

Survey questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
There is a gap between current knowledge in stroke prevention and its awareness in the population (n, %)	0 (0%)	2 (3.4%)	2 (3.4%)	24 (41.4%)	30 (51.7%)
Despite current primary prevention strategies, there is a lack of motivation from patients at risk of stroke to modify and control their risk factors (n, %)	0 (0%)	0 (0%)	2 (3.6%)	31 (55.4%)	23 (41.1%)
Primary stroke prevention can be significantly improved with a validated, easy to use stroke management and prevention tool embedded into the existing electronic patient management system (n, %)	0 (0%)	0 (0%)	5 (8.6%)	24 (41.4%)	29 (50.0%)

Table 2. Percentage agreement of HCPs to survey items

HCPs Survey Items	Agreement (%)
Section A: needs for innovative primary stroke/CVD prevention strategies	
There is a gap between current knowledge in stroke prevention and awareness and the knowledge and awareness of the population	93.2%
Despite current primary prevention strategies, there is a lack of motivation from patients at risk of stroke to modify and control their risk factors	96.5%
Primary stroke prevention can be significantly improved with a validated, easy to use stroke management and prevention tool embedded into the existing electronic patient management system	91.5%
Except for smoking, most recommendations on the management/control of other lifestyle factors for stroke and other CVDs prevention are currently not given in the patient's summary What do you think is the main reason for that?	
Lack of time	84.7%
Lack of knowledge	32.8%
I see no need to provide this information in the patient's summary	5.2%
Other reason	34.1%
Sections B: PreventS-MD for primary stroke/CVD prevention	
I would find PreventS-MD useful and timesaving in my primary prevention efforts with patients	93.2%
I would discuss the data collected in PreventS-MD with the patient to promote the impact of the recommendations	94.9%
PreventS-MD would improve patients' understanding of their risk factors, and ways they could manage their risks as well as stroke awareness	98.3%
PreventS-MD would help my patient-clinician communication concerning stroke prevention	93.2%
I would have the capacity within my day-to-day clinical role to use PreventS-MD, without much effort	74.6%
I would recommend PreventS-MD to my colleagues when relevant	98.3%
I trust the information provided within PreventS-MD, which is based on the current internationally recognised guidelines for stroke and CVD prevention	94.9%
I am confident supplementing my discussion with patients on primary stroke prevention with information from PreventS as opposed to brochures and leaflets	88.1%
Sections C: PreventS-MD important features for primary stroke/CVD prevention	
Software Updating - Constant feature update	81.4%
Ability to use the application without the mandatory requirement to have an internet connection	82.8%
Ability to be installed on any computer or tablet without any additional adjustment	98.2%
Ability to run in multiple or all computers/tablets within the client intranet	89.7%
Monitoring risk of stroke & risk factors - Ability to store individual's personal data and link them with individual's previous assessments for monitoring of the individual's progress	96.6%
Pre-population of the Variables - Ability to pre-populate patient data based on their electronic clinical records	93.2%
Ability to store individual's personal data in client's (health provider) data system	86.2%
Ability to store individual's personal data in secure client's cloud system	84.7%
Ability to store individual's personal data in secure third party cloud system	39.0%

Allows data integration with other medical databases within client's databases	84.7%
Allows data integration with other medical databases outside of client's databases	49.2%
Software Adaptation/Modification - Ability to modify the risk prediction algorithm and other features of the application for specific purposes	86.2%

Appendix Table 3. Lack of lifestyle recommendations (except smoking)

Except for smoking, most recommendations on the management of other lifestyle risk factors for stroke and other CVDs prevention are currently not given in the patient's summary. What do you think is the main reason for that?

Survey questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Lack of time (n, %)	0 (0%)	4 (6.9%)	5 (8.6%)	35 (60.3%)	14 (24.1%)
Lack of knowledge (n, %)	8 (14.0%)	16 (28.1%)	14 (24.6%)	11 (19.3%)	8 (14.0%)
I see no need to provide this information in the patient's summary (n, %)	30 (52.6%)	18 (31.6%)	6 (10.5%)	1 (1.8%)	2 (3.5%)

Other reasons (please list all reasons stated here by the tester):

- Do not want to offend patient on obesity, diet issues
- I selected this to be able to clarify that in my practice (I'm heading a large hospital plus out-patient neurological and stroke unit) we do address other CVDs lifestyle factors, not just smoking
- I think that there is a lack in knowing how to tackle and maintain modifications in lifestyle
- Lack of commitment to thinking about all modifiable strategies of stroke prevention
- Lack of interest in preventative health by many clinicians and patients
- Lack of motivation from both patient and physician
- Laziness
- Motivation, attitude and involvement in patient care
- Non unavailability of electronic links to add to discharge summaries
- People often know what they should do in order to stay healthy, but they struggle to implement it into their everyday life. More services are needed to support behaviour change
- Stroke/dementia risk is hidden under cardiovascular risk
- The recommendations for lifestyle modification are neglected by the doctors

If your time allows, would you like more time on primary prevention? If yes, how much time it would ideally require (mean time and SD)	20.4 (20.0)

Appendix Table 4. Additional usability points of PreventS

Survey questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I would find PreventS useful and timesaving in my primary prevention efforts with patients (n, %)	0 (0%)	0 (0%)	4 (6.9%)	35 (60.3%)	19 (32.8%)
I would discuss the data collected in PreventS with the patient to promote the impact of the recommendations (n, %)	0 (0%)	0 (0%)	3 (5.2%)	32 (55.2%)	23 (39.7%)
PreventS would improve patients' understanding of their risk factors, and ways they could manage their risks as well as stroke awareness (n, %)	0 (0%)	1 (1.7%)	0 (0%)	35 (60.3%)	22 (37.9%)
PreventS would help my patient-clinician communication concerning stroke prevention (n, %)	0 (0%)	1 (1.7%)	3 (5.2%)	28 (48.3%)	26 (44.8%)
I would have the capacity within my day-to-day clinical role to use PreventS, without much effort (n, %)	1 (1.7%)	3 (5.2%)	10 (17.2%)	31 (53.4%)	13 (22.4%)
I would recommend PreventS to my colleagues when relevant (n, %)	0 (0%)	0 (0%)	1 (1.7%)	29 (50.0%)	28 (48.3%)
I trust the information provided within PreventS, which is based on the current internationally recognised guidelines for stroke and CVD prevention (n, %)	0 (0%)	1 (1.7%)	2 (3.4%)	25 (43.1%)	30 (51.7%)
I am confident Appending my discussion with patients on primary stroke prevention with information from PreventS as opposed to brochures and leaflets (n, %)	0 (0%)	0 (0%)	7 (12.1%)	32 (55.2%)	19 (32.8%)

Appendix Table 5. Features of PreventS the testers would prefer to have available

Survey questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Software updating – Constant feature update (n, %)	0 (0%)	1 (1.7%)	10 (17.2%)	32 (55.2%)	15 (25.9%)
Internet access - Ability to use the application without the mandatory requirement to have an internet connection (n, %)	0 (0%)	2 (3.5%)	8 (14.0%)	28 (49.1%)	19 (33.3%)
Compatibility - Ability to be installed on any computer or tablet without any additional adjustment (n, %)	0 (0%)	0 (0%)	1 (1.8%)	28 (50.0%)	27 (48.2%)
Virtualisation - Ability to run in multiple or all computers/tablets within the client intranet (n, %)	0 (0%)	1 (1.8%)	5 (8.8%)	29 (50.9%)	22 (38.6%)
Monitoring risk of stroke & risk factors - Ability to store individual's personal data and link them with individual's previous assessments for monitoring of the individual's progress (n, %)	0 (0%)	0 (0%)	2 (3.4%)	27 (46.6%)	29 (50.0%)
Pre-population of the variables - Ability to pre-populate patient data based on their electronic clinical records (n, %)	0 (0%)	1 (1.7%)	3 (5.2%)	30 (51.7%)	24 (41.4%)
In-house Data Storage - Ability to store individual's personal data in client's (health provider) data system (n, %)	0 (0%)	0 (0%)	8 (14.0%)	28 (49.1%)	21 (36.8%)
In-house Cloud Data Storage - Ability to store individual's personal data in secure client's cloud system (n, %)	1 (1.7%)	1 (1.7%)	7 (12.1%)	31 (53.4%)	18 (31.0%)
Third-party Cloud Data Storage - Ability to store individual's personal data in secure third-party cloud system (n, %)	5 (8.6%)	6 (10.3%)	24 (41.4%)	18 (31.0%)	5 (8.6%)
In-house Data Integration - Allows data integration with other medical databases within client's databases (n, %)	0 (0%)	1 (1.7%)	8 (13.8%)	33 (56.9%)	16 (27.6%)
Third-party Data Integration - Allows data integration with other medical databases outside of client's databases (n, %)	2 (3.4%)	6 (10.3%)	21 (36.2%)	24 (41.4%)	5 (8.6%)
Software adaptation/modification - Ability to modify the risk prediction algorithm and other features of the application for specific purposes (n, %)	0 (0%)	2 (3.5%)	5 (8.8%)	35 (61.4%)	15 (26.3%)

Appendix Table 6. Expected frequency of the PreventS programme use in practice

Survey questions	Almost always	Occasionally (about ½ the time)	Almost never
Patients who have experienced stroke or TIA (n, %)	44 (75.9%)	13 (22.4%)	1 (1.7%)
Stroke or TIA free patients but are, in my opinion, at increased risk (n, %)	36 (62.1%)	20 (34.5%)	2 (3.4%)
Stroke or TIA free and are not, in my opinion, at increased risk (n, %)	14 (24.6%)	29 (50.9%)	14 (24.6%)

Theme 1: Feature specific benefits of PreventS	
Sub-theme	**Supporting quotes**
Comprehensive risk factor evaluation and education on	• Provide objective risk re-assessment in follow-ups, after risk factor(s) modification • Acts as a checklist and made sure all risk factors are addressed • Raised awareness, knowledge, and action about stroke risk in the population • Comprehensive assessment • Good overview of risk and background information • Focus discussion on preventable risk factors • Improved risk management • Mass awareness • Risk evaluation • Increase awareness of stroke prevention • Education; monitoring • Education
Scientifically founded tool	• It uses science to support your arguments • It a good tool to educated patients • Great academic material • Evidence based information based on the patient's risk • Access to evidence-based advice
individualised approach to vascular risk management	• Systematisation of recommendations • Ability to provide tailored advice on multiple risk factors • individual approach to vascular risks management • It helps to identify the risk factors for an individual patient, • Tailored advice for patient • Can customise recommendation for practice in the open ended additional comment field
Fast and user friendly: important for the doctor, important for the patient	• It is quick and easy to use • Convenient to access and take not much time • Easy to use, 3. easily accessible • Easy to understand, easy to use • Easy to use • Easy to use, important for the doctor, important for the patient • Fast and user friendly • Reduces time to generate recommendations • Saves time, • Easy to explain to patient about the risk factor • Efficient time • Simple and fast to use • Less time consuming for health care provide • Time saving for prevention.
Practical recommendations for lifestyle change	• Guide to make lifestyle changes • Concrete recommendations for patients how to modify their lifestyle • Getting all data needed, giving recommendation to patient

	• Practical recommendations that are based on patient's health status to be shared with patient within few minutes
Patients understand easier with graphs and numbers	• Data visualisation, easy way of explanation to my patients • Being able to provide a "graphical summary" and topics for further review by the patients after consultation (patient education) • Graphics are helpful to be explained to the patient • Patients can understand easier with graphs and numbers • Provides clients with a visual of how much they could reduce risk • Provides % and numbers which patients prefer • Observe progress • Provides printed instructions, clear • To show the difference in risk with modifying risk factors • Very clear, numbers-based prediction • Monitor risk changes • Interpretation is straightforward to patients

Theme 2: long term implications of PeventS

Sub-theme	Supporting quotes
Enriched discussion during patient consultation	• Stimulate preventive discussion • Good tool to enable discussion • Provide materials to enrich discussion with patients during consultation • Reinforces usual health message • Cover certain elements that may be missed during regular interactions
Enhancing acceptability, motivation and compliance of prevention recommendations and patient-doctor connect	• Much more acceptable by patients if there is a calculation of stroke risk • A clear documentation of risk to convince doubtful patient • Patients will feel that doctor is more attentive • To increase trust for the examination • Motivation to patient and clinician that can see the progress or risk reduction • It has the ability to engage patients input to improving their own score • Enhancing compliance, connect and acceptability • More knowledge, more willingness and more active to practice • Motivate people and patients to involve actively for health promotion and prevention of stroke more • Motivation for a patient to change their risk factors profile • Additional education for patients and family. I believe likely to encourage them to take more active role in their care • Empowering the patient to manage their risk factors, educating the patient to monitor • It is individual risk which might be more motivating to some • Will enhance stroke risk factor control
Strong potential to reduce stroke/TIA	• Strong potential to reduce stroke/TIA • Potential for great impact in reducing incidence of stroke at community and population level • Decreased morbidity • People's lives less at risk
Incorporating primary prevention in everyday practice	• Better focus on prevention • Provides comprehensive information on primary stroke prevention

	• Pre-emptive stroke/CVD prevention in high risk and even in low-risk individuals • Prevention measures will be a part of everyday practice. Standardised approach to prevention measures • Identifying at risk patients, and having a mechanism to follow-up management • Implementing this tool to everyone might indeed systematize the process (re patient individual prevention strategies • Prevention activities in everyday practice • Support of prevention activities
improved quality of life	• Quality of life improvement • Improved quality of life

Appendix Table 8. Barriers to implementing and use of PreventS into daily routine care

Theme 1: App design and output	
Sub-theme	**Supporting quotes**
Ease of use	- Need to print (email would be better) - Need to print a lot of pages - The present output is not in any real order and the change in risk expected if an area is addressed is a bit "buried' in the text - There is too much text, difficult to read - Lot to read with recommendations
Concerns around data security	- Some patients may be afraid of data safety - Patient privacy needs to be insured - The only point can be keeping the patient's privacy and confidential information safe - Security - Data security issues - Patients less keen to share their data
Internet availability and accessibility	- Difficulty for Internet connection for some places - Patients without Internet/smartphone access - Internet and compatibility issue - Internet access problems - Internet connection - Internet cost - Internet connection availability - Limited or no Internet access - Internet not working
Theme 1: Practitioner restrictions	
Sub-theme	**Supporting quotes**
Deficit of time, deficit of time, deficit of time	- The recommendations may be too time consuming for clinicians to go through and edit them as text - Dr time - Extra time - Lack of clinicians′ time - Lack of time - Time - Additional time for risk assessment results will be needed - Additional time will be needed not only for assessment but for result's discussion. If patient visit is not about any cardiovascular issues, then risk assessment could look a bit unreasonable - Deficit of time, Deficit of time, Deficit of time - Engaging clinicians to devote a small amount of time to consider the aims, process, implementation, and potential benefits of the PreventS - Filling form may take time - Lack of time - Time!

	• Time is needed not only to make assessment but also to discuss the results
	• Time
	• Time
	• Requires physician to input the data
	• Time constrains
	• Time constraints at ward rounds and clinics
	• Time consuming,
	• time for discussion with patient
	• time of the health professional,
	• Time taken to complete and use web-app
	• Time
Difficulties integrating into current healthcare system	• Accessibility by all staff involved in stroke care • Integration into current healthcare systems • Integration with existing hospital systems • Not interfacing well with existing patient management systems
Requirements for ethical approval	• Ethics approval • Needs to be approved by national board of health • If data are stored it would need approval as well • Resistance from the Ministry of Health to using external software
Changing conditions in practice	• Routine implementation • Changing practicing behaviour of clinicians • Objections from the supervisor
Practitioner knowledge and acceptance	• Low knowledge of health professionals about necessity of risk assessment of potentially low risk patients • Need to education of doctors • Lack of interest in patients/physicians • The patients and health professionals are sceptic about patient's ability to achieve control on risk factors • Patient acceptance, clinician acceptance

Theme 1: Patient limitations

Sub-theme	Supporting quotes
Technological requirements and proficiency limits app usability	• Some elderly or disabled patients might encounter technical issues while using app • Need for electronic device, so a challenge for elderly, visually challenged, less educated • Poor skills in the use of electronics in older age • Some aged may need more time to get used to the system. • Need adequate electronic devices to do it • Need computer to access • Less tech savvy patients
Lack of interest or motivation	• Patient/family interest • Lack of patients′ motivation • Patient's lack of motivation • Lack of interest • Ignorance • Some of the baselines on the graphs might make them a bit daunting to clients. This could reduce motivation for change.

	• Patients who lack self-motivation • Lack of interest in patients/physicians • The patients and health professionals are sceptic about patient's ability to achieve control on risk factors • Patient acceptance, clinician acceptance • Motivation, and interest
Patient literacy	• Not all patients are literate • Patient's school ed education • Need to reduce professional medical terms as less as possible. • I personally feel that the advice generated by PreventS is too complex for patients to understand. There are a lot of difficult words that patients would not know what they mean, such as absolute x relative, whole grains, fibre, subarachnoid haemorrhage etc. • Ease of understanding for countries with poor health literacy • Illiteracy • Education level • Education of patients • Level of understanding of the risk factor concept (as opposed to cause)
Language barriers	• Validation for other languages • Language - can be translated to local language • Not translated into local language • May require multiple languages

Theme 1: Perspectives on the Stroke Riskometer algorithm	
Sub-theme	**Supporting quotes**
Current perceived shortcomings	• Some questions need to be adopted for specific country context (e.g., concept of alcohol drinks may be confusing for Eastern European countries, which measure alcohol in grams or millilitres) • Need to consider the difference of stroke risk factors among different ethnicities. • Stop smoking >12 mths treated as risk factor • The definition of risk factors or some items is not clearly defined • Some risk factors are not covered - dyslipidaemia and use of anti-thrombotic • There is no direct link between estimated risk and how much it will decrease if stopping/reducing the exposure • 2.5 hours of exercise/week as the ideal seems pretty low • Some types of dementia (e.g., FTD) do not have the vascular risk factors • Memory loss and dementia overlap? • No question in history of hypertension? • Sex - what if a pt. prefers to be identified as neither female nor male? • Patients would also struggle to understand the current graphs Traffic lights system would be much easier to understand • The graphs need editing - its two dots and doesn't add much. I don't know what would be better, but the current version needs revision visually • Graphs with points on axes looks not good • I'm not sure I agree with all the wording in the letter that is generated. For example, I put in someone who was male and drank 1 alcoholic drink per day (the box was 1-2), and this came up as excessive drinking. It would probably be good to check this out. Same for past smoking (more than 12 months ago) • If current BP is lower than the recommended BP assigned the information that comes is that BP is "high BP" • There is not any pre-diabetic status or glucose intolerance. • Smoking Passive/second-hand smoking increases the chances of having a stroke by almost 80%. ?? (30-40%?) • Environmental factors like air pollution could be asked. For refugees, war environment may be important related to the air pollution • Lack of "positive feedback" besides risks calculation. As an example, if a patient stops smoking, recommendations about quit- smoking remain. The same is true if the patient stopped a year ago • I was able to see that sometimes recommendations on elevated blood pressure are issued when this is not a problem • Some items need more clarity to fill precisely
Recommendations for change	• Ethnicity - maybe amend Chinese to be East Asian and Indian to be South Asian? • Heart disease to also add peripheral vascular disease? as it may be missed if the '?' is not moused over

	• Perhaps some of the responses my benefit from re-wording e.g., 'history of diabetes' 'yes, more than 12 months ago' may be better 'yes, for more than 12 months', etc. • In the initial data section, there are a few items where 'no or unknown' is a single response. I wonder if for some of these an absolute "no" is possible, for example someone might have NO history of diabetes (with frequent blood tests to back this up) and this would be different from someone being "unknown" (though this may just reflect how things are coding into the risk formula) • No additional risk case text report should look different. BP 120 is usually treated as normal • questions assessing alcohol, diet and tobacco use could be Appendix with demonstration cards containing pictures of standard drinks for different alcoholic beverages, pictures of portions of vegetables and fruits and pictures of tobacco products • Question on Memory Loss: Is this related to mild cognitive deficit? It could be useful to add the additional question as "Does this complaint effect your Daily activity? • May try to give comparisons such as if the subject quits smoking, to what degree the risk will be reduced

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