Hypertension in stroke survivors and associations with national premature stroke mortality: data for 2·5 million participants from multinational screening campaigns

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Summary

Background Blood pressure control has a pivotal role in reducing the incidence and recurrence of stroke. May Measurement Month (MMM), which was initiated in 2017 by the International Society of Hypertension, is the largest global blood pressure screening campaign. We aim to compare MMM participants with and without a previous history of stroke and to investigate associations between national-level estimates of blood pressure management from MMM and premature stroke mortality.

Methods In this annual, global, cross-sectional survey, more than 2·5 million volunteers (≥18 years) from 92 countries were screened in May, 2017, and May, 2018. Three seated blood pressure readings and demographic, lifestyle, and cardiovascular disease data were collected. Associations between risk factors and stroke history were analysed with mixed-effects logistic regression, and associations between national-level estimates of blood pressure management and premature stroke mortality based on Global Burden of Disease data were investigated with linear regression.

Findings 2 222 399 (88·4%) of 2 515 365 participants had recorded data on a history of stroke, of whom 62 639 (2·8%) reported a previous stroke. Participants with a history of stroke had higher rates of hypertension (77·0% *vs* 32·9%, p<0·0001) and of treated (90·2% *vs* 57·0%, p<0·0001) and controlled (55·9% *vs* 32·4%, p<0·0001) hypertension than those without a history of stroke. A third of participants with a history of stroke had either untreated hypertension or treated but uncontrolled hypertension (blood pressure ≥140/90 mm Hg). Strong positive associations were found between national premature stroke mortality and mean systolic blood pressure (84·3 [95% CI 38·8 to 129·9] years of life lost [YLL] per 100 000 people per mm Hg increase) and the percentage of participants with raised blood pressure (49·1 [22·6 to 75·6] YLL per 100 000 people per 1% increase). Strong negative associations were found between national premature stroke mortality and the percentage of participants with hypertension on treatment (–21·0 [–33·0 to –8·9] YLL per 100 000 people per 1% increase) and with controlled blood pressure (–31·6 [–43·8 to –19·4] YLL per 100 000 people per 1% increase).

Interpretation Blood pressure control remains suboptimal worldwide among people with a history of stroke. National estimates of blood pressure management reflect national premature stroke mortality sufficiently to prompt policy makers to promote blood pressure screening and management.

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See **Comment** page e1076

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Introduction

In 2019, stroke was the second largest cause of death worldwide and the third leading cause of premature mortality.[1] Globally, there were 12 million incident strokes in 2019 and a further 100 million people had a previous history of stroke.[1] These values represented a 71% increase in the incident cases and an 82% increase in the prevalent cases reported annually in the 1990s.[1] The global burden of stroke is expected to continue to increase and cause more than 7 million annual deaths by 2030.[2] Economic costs associated with stroke are substantial, with direct annual medical costs to patients in the USA predicted to reach US$184 billion by 2030 unless more effective preventive and therapeutic measures are instigated.[3]

Years of life lost as a result of stroke is highest in low-income countries and lowest in high-income countries.[1] However, to date, data on non-fatal stroke from low-income and middle-income countries are scarce.[4,5] The INTERSTROKE study[6] established the contribution of ten potentially modifiable risk factors that provide 90% of the population attributable risk of stroke. Of these, hypertension was the largest contributor, accounting for 48% of the population attributable risk, with stroke risk almost three times higher in people with hypertension than in those without.[6,7]

Worldwide, between 1975 and 2015, the number of people with hypertension increased from 590 million to more than 1·1 billion, two-thirds of whom live in

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Research in context

Evidence before this study

We searched PubMed for articles related to blood pressure control among stroke survivors published in any language between Jan 1, 2010, and Aug 1, 2021, using the search terms "stroke", "risk factors", "stroke survivors", "post-stroke", "blood pressure", "hypertension", "control", "antihypertensive treatment/medication", "Global Burden of Disease", "global", "worldwide", "African countries", "European countries", "Asia", "smoking", "overweight", "obesity", "alcohol", "diabetes", "myocardial infarction", "age", and "sex". Combinations of the above terms were also searched. We screened more than 500 articles and found studies, including the Global Burden of Disease studies from 2016 and 2017, suggesting that hypertension is the most important risk factor for stroke, but data on stroke survivors and coverage of age range was poor. We also found studies that described suboptimal control of blood pressure in at least half of stroke survivors in several countries with small samples, whereas we found no research in a global context nor large-scale studies in low-income settings. Little is known about the control of blood pressure in people with a previous history of stroke worldwide.

Added value of this study

Our study used data from 92 countries collected in 2017 and 2018 as part of May Measurement Month (MMM), the largest standardised, contemporary, global blood pressure screening programme. Despite using opportunistic screening in many of the countries involved, these MMM data are the largest source of population blood pressure data available and contain data on more than 60 000 stroke survivors. By analysing individual-level data from more than 2 million participants, we show that those with a previous history of stroke were much more likely than those without to have hypertension (77% *vs* 33%) and, among stroke survivors, a third had untreated or inadequately treated raised blood pressure (≥140/90 mm Hg). After aggregating MMM data to the national level, parameters of blood pressure management were strongly and significantly associated with national premature stroke mortality rates, highlighting the crucial effect of blood pressure control on stroke mortality.

Implications of all the available evidence

Our results show consistently poor blood pressure control among stroke survivors worldwide. Interventions tailored to the local context, including enhanced blood pressure screening facilities, are urgently needed to enable more effective blood pressure control. The strong associations between age-standardised measures of blood pressure management at the national level and premature stroke mortality could, in the absence of data arising from large, nationally representative samples, provide an impetus to policy makers to promote enhanced blood pressure screening and improved management of hypertension.

low-income and middle-income countries.[8] Blood pressure control has a pivotal role in reducing the incidence[6,7] and recurrence[9] of stroke. Although a few studies, mostly in high-income countries, have found at least half of stroke survivors to have increased blood pressure,[10–13] little is known about the current status of blood pressure control in stroke survivors in most of the world.

The May Measurement Month (MMM) campaign is an annual, multinational, cross-sectional study, initiated in 2017 by the International Society of Hypertension, to raise awareness of the importance of blood pressure measurement. During the 2017 and 2018 campaigns,[14,15] more than 2·7 million adults in 95 countries had their blood pressure screened. The MMM dataset is one of the largest sources of opportunistic data on blood pressure and related cardiovascular disease, arising from countries across the range of national income settings worldwide.

For MMM see https://maymeasure.org

The first aim of this study was to compare cardiovascular risk factors, including the detection, management, and control of blood pressure, in MMM participants with and without a history of stroke. The second aim was to evaluate whether blood pressure and parameters of hypertension management at a national level based on MMM data were associated with national premature stroke mortality based on data from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD).

Methods

Study design

The MMM campaign is an annual, global, cross-sectional survey of blood pressure that uses a single, standardised protocol and questionnaire across countries from seven UN geographical regions.[16] Detailed descriptions of the methods used for setting up sites and promoting the campaign are available in previous MMM global reports[14,15] and on the MMM website but local promotion included celebrity and government endorsement through media and social media. Self-referred participants 18 years or older were screened opportunistically using convenience sampling from May 1 to June 30, 2017, and from May 1 to June 30, 2018. Almost half (48·5%) of participants were screened in health-care settings such as hospitals and pharmacies, 39·5% in indoor or outdoor public places such as supermarkets, education institutes, and playing fields, and 10·1% in workplaces.[14,15]

Three seated blood pressure readings were collected at 1-min intervals and a questionnaire was completed for each participant. Details of blood pressure measurement are reported in previous MMM global reports.[14,15] Measurements were made by volunteers trained in standardised techniques through video recordings hosted on the MMM website and through face-to-face, on-site training. Blood pressure devices varied between sites, but 88·1% of readings were measured with Omron devices. The questionnaire included questions on demographic information, lifestyle risk factors, and cardiovascular comorbidities (ie, stroke, myocardial infarction, and diabetes). Height and weight were measured, or estimated if equipment was unavailable. The questionnaire differed slightly between 2018 and 2017 (appendix pp 3–4); in 2018 a question regarding previous diagnosis of hypertension was added to enable awareness of hypertension to be evaluated. Alcohol consumption was treated as a binary variable ("never/rarely/1–3 times per month" or "at least once per week") in both 2017 and 2018 for consistency.

Data collected at screening sites were either entered into a web-based or mobile app available in six languages, or recorded on paper before being electronically transcribed. The data were collated centrally, cleaned, and analysed, except for data on 190 955 participants from India who were screened in 2017, which were analysed locally for regulatory reasons and are not included in this analysis. Data cleaning rules and protocols for 2017 and 2018 remained consistent throughout all sites.[14,15] Ethics approvals for the study were obtained where required by national investigators in each country. Informed oral consent was obtained from all participants.

Raised blood pressure was defined as a systolic blood pressure of at least 140 mm Hg, a diastolic blood pressure of at least 90 mm Hg, or both, on the basis of the mean of the second and third blood pressure readings. Hypertension was defined as a raised blood pressure or the taking of antihypertensive medication. Uncontrolled blood pressure was defined as raised blood pressure in participants who were taking antihypertensive medication. Body-mass index (BMI) was calculated as recorded weight (kg)/height^2 (m). Participants were categorised into four BMI groups (underweight, healthy weight, overweight, or obese) according to WHO categories.[17]

Statistical analysis

Data were analysed using Stata version 15 IC. Three countries with insufficient data, defined as fewer than 50 participants, were excluded from the analysis, after which 92 countries remained. Descriptive statistics for participant characteristics are based on observed data. To reduce any bias from missing blood pressure readings, multiple imputation using chained equations was conducted to derive the missing mean of the second and third blood pressure readings, based on the assumption that the blood pressure readings were missing at random, using the approach developed previously for MMM.[15] Two imputation models were applied and the results combined (appendix pp 5–6). The first imputation model was applied for participants for whom information on age, sex, ethnicity, and use of antihypertensive medication was complete. All variables included in the analysis models were incorporated in the imputation model, including the three systolic and three diastolic blood pressure readings, the mean of the second and third blood pressure readings, and an interaction between age and sex. For the 733 893 participants for whom records of age, sex, ethnicity, or antihypertensive medication were missing, a second imputation model was used, imputing on the basis of the recorded blood pressure readings alone (appendix pp 5–6). 25 sets of imputed data were generated, corresponding to the approximate proportion of participants for whom one or more blood pressure readings were missing. Hypertension parameters were standardised for age and sex on the basis of the WHO single age standard population, assuming an equal male-to-female ratio.[18]

See Online for appendix

We used mixed-effects logistic regression to estimate the odds ratios for different cardiovascular risk factors given a history of stroke, accounting for clustering within country using a random intercept model and assuming equal slopes. We selected variables for inclusion in the model using a theoretical approach, based on suspected confounders, but requiring a statistically significant association with both outcome and exposure. We constructed a basic multivariable model adjusted for age and sex alone and a fully adjusted model incorporating all potential confounders that were significantly associated with outcome and exposure from univariable models, except for myocardial infarction, which was excluded owing to multicollinearity with stroke. The fully adjusted model included age, sex, use of antihypertensive medication, smoking, alcohol intake, diabetes, and BMI category.

To analyse the odds of a participant having raised blood pressure given a history of stroke, we applied univariable and multivariable mixed-effects logistic regression using a random intercept model for country and assuming equal slopes. Models were stratified by use of antihypertensive medication as a potential effect modifier. Two separate multivariable models were analysed: a basic model adjusted for age and sex alone, and a fully adjusted model that included age, sex, smoking, alcohol intake, diabetes, and BMI category.

We analysed the associations between national mean blood pressure levels and parameters of hypertension management from MMM and premature stroke mortality using national-level estimates of premature stroke mortality extracted from GBD data.[19] We used age-standardised estimates of premature mortality, measured in years of life lost per 100 000 people, standardised according to the world population age standard from GBD 2017 data.[20] Results from MMM were aggregated to the national level, and linear regression was used to examine the associations between GBD national premature stroke mortality and the following national MMM parameters: mean systolic blood pressure, the proportion of all participants with raised blood pressure, the proportion of all participants with hypertension, the proportion of participants with hypertension taking antihypertensive

	Previous stroke (n=62 639)	No previous stroke (n=2 159 760)	p value*
Sex			
Male	33 910 (54·5%)	978 585 (45·7%)	<0·0001
Female	28 294 (45·5%)	1 164 674 (54·3%)	<0·0001
Age (years)	51·1 (17·4)	45·0 (16·8)	<0·0001
Age categories			
<40 years	16 441 (28·6%)	843 404 (41·7%)	<0·0001
40–59 years	20 567 (35·7%)	724 325 (35·8%)	<0·0001
60–79 years	17 878 (31·1%)	411 754 (20·3%)	<0·0001
≥80 years	2645 (4·6%)	43 678 (2·2%)	<0·0001
Diabetes	23 630 (38·8%)	153 009 (7·4%)	<0·0001
Myocardial infarction	36 743 (59·5%)	57 830 (2·7%)	<0·0001
Current smoker	31 718 (50·9%)	245 826 (11·4%)	<0·0001
Alcohol consumption (at least once per week)	5798 (10·0%)	127 751 (6·4%)	<0·0001
BMI, kg/m²	25·0 (4·9)	24·4 (4·5)	<0·0001
BMI categories			
Underweight	4146 (7·1%)	127 921 (6·4%)	<0·0001
Healthy weight	26 406 (45·6%)	1 078 360 (54·0%)	<0·0001
Overweight	18 575 (32·1%)	580 426 (29·0%)	<0·0001
Obese	8788 (15·2%)	212 182 (10·6%)	<0·0001

Data are n (%) or mean (SD). Percentages given for each variable exclude participants for whom data were missing. For table with all denominators included, see appendix (p 7). BMI=body-mass index. *p values are for the difference between estimates in participants with and without a previous stroke (calculated from χ^2 tests for categorical variables or *t* tests for continuous variables).

Table 1: **Characteristics of 2 222 399 study participants with and without a history of stroke**

medication, the proportion of participants taking antihypertensive medication with controlled blood pressure, and the proportion of all participants with hypertension who had controlled blood pressure.

Both univariable and multivariable linear regression models were constructed, with further adjustment for the national-level proportion of males and the proportions of participants with diabetes, who were current smokers, who consumed alcohol at least once per week, and who were overweight or obese. To remain consistent with the age standardisation used by GBD, each parameter was standardised according to the same GBD weights using 5-year age groups.[20] Countries with fewer than 50 participants using antihypertensive medication were excluded for the models that evaluated medication use. If data regarding the use of antihypertensive medication was missing, we assumed that these participants were not taking such medication when calculating national-level estimates. To assess the effect of this assumption, sensitivity analyses were conducted under two alternatives, assuming all participants for whom medication records were missing were either taking medication or excluded from the analysis.

Role of the funding source

The funders of the MMM campaigns in 2017 and 2018 had no role in study design, data collection, data analysis, data interpretation, or writing of the report, although several past or present officers of the International Society of Hypertension are coauthors.

Results

Data were available for 2 515 365 participants from 92 countries. Of these, data on a history of stroke were recorded for 2 222 399 participants, of whom 896 432 were screened in 2017 and 1 325 967 were screened in 2018. Participants ranged in age from 18 years to 99 years with a mean of 45·1 years (SD 16·9). Females accounted for 53·7% of participants, males comprised 45·6%, and the remaining participants (less than 0·8%) were recorded as “other” or the data were missing. Of the 2 222 399 respondents, 62 639 (2·8%) reported a history of stroke.

Of participants with a history of stroke, 33 910 (54·5%) were male and 28 294 (45·5%) were female (p<0·0001; table 1). The mean age of participants with a history of stroke was 6 years older than those without (51·1 years *vs* 45·0 years, p<0·0001). Age-adjusted proportions of participants with a previous stroke were higher in males than in females (3·1% *vs* 2·2%, p<0·0001). In participants with a history of stroke, the proportions reporting diabetes, a previous myocardial infarction, current smoking, and consuming alcohol at least once per week were higher than in participants without a history of stroke (all p<0·0001). Participants with a history of stroke were also more likely to be underweight, overweight, or obese than those without (p<0·0001). Characteristics by country are given in the appendix (pp 8–13).

Among 1 764 601 (79·4%) participants for whom all three blood pressure readings and data on stroke history were recorded, mean systolic and diastolic blood pressure decreased from the first to the third readings (appendix p 13). The reduction was larger in participants with a previous stroke (4·1 mm Hg systolic; 3·2 mm Hg diastolic) than in participants without (2·9 mm Hg systolic; 1·8 mm Hg diastolic). Basing a definition of hypertension on each single reading, the absolute proportion of participants with hypertension reduced from 80·6% using the first reading to 78·7% using the third reading in participants with a previous stroke and from 38·3% to 34·2% in participants without. The lowest proportion of participants with hypertension was calculated from the mean of the second and third readings in both those with (78·6%) and without (33·3%) a history of stroke.

After multiple imputation for missing blood pressure readings for 686 147 participants with one or two missing readings, the mean of the second and third blood pressure readings was 129·5/79·6 mm Hg in those with a history of stroke and 123·0/77·9 mm Hg in those without a history of stroke (p<0·0001). Participants with a history of stroke who were not taking antihypertensive medication had significantly higher mean systolic and diastolic blood pressures than those without a history of stroke who were not taking antihypertensive medication

	Crude values			Standardised for age and sex		
	Previous stroke	No previous stroke	p value*	Previous stroke	No previous stroke	p value*
Mean systolic/diastolic pressure, mm Hg	129·5/79·6	123·0/77·9	<0·0001†	124·4/77·8	124·0/78·4	0·059/<0·001
Stratified mean systolic/diastolic pressure, mm Hg						
Not on antihypertensive medication	124·3/78·4	120·3/77·0	<0·0001†	122·0/77·6	122·6/78·0	0·047/0·089
On antihypertensive medication	131·8/80·1	134·2/82·1	<0·0001†	125·8/78·1	131·2/82·1	<0·0001†
Proportion of all participants with raised blood pressure	33·9%	22·2%	<0·0001	24·7%	23·2%	0·020
Proportion of all participants with hypertension	77·0%	32·9%	<0·0001	70·1%	33·6%	<0·0001
Proportion of participants with hypertension on medication	90·2%	57·0%	<0·0001	89·7%	54·0%	<0·0001
Proportion of participants on medication with controlled blood pressure	62·0%	56·8%	<0·0001	72·9%	61·4%	<0·0001
Proportion of participants with hypertension with controlled blood pressure	55·9%	32·4%	<0·0001	64·8%	31·1%	<0·0001

Estimates are based on the mean of the second and third blood pressure readings, after multiple imputation. Raised blood pressure was defined as blood pressure ≥140/90 mm Hg. Hypertension was defined as blood pressure ≥140/90 mm Hg or on antihypertensive treatment. Controlled blood pressure was defined as on antihypertensive treatment with blood pressure <140/90 mm Hg. *p values are for the difference between estimates in participants with and without a previous stroke (calculated from χ^2 tests for categorical variables or *t* tests for continuous variables). †p<0·0001 for both systolic and diastolic blood pressure values.

Table 2: **Blood pressure readings and parameters of hypertension management for 2 222 399 study participants with and without a history of stroke**

(table 2). By contrast, of participants taking antihypertensive medication, those with a previous stroke had significantly lower mean blood pressures than those without (table 2). However, after standardisation for age and sex, the mean blood pressures of participants with and without a history of stroke in individuals not taking antihypertensive medication were similar. The proportion of participants with hypertension and the rates of treatment and control of hypertension were higher in those with a previous stroke, before and after standardisation for age and sex (all p<0·0001). In participants for whom hypertension awareness was recorded, awareness was significantly higher in the 32 960 participants with a previous stroke than in those without (93·8% *vs* 57·2%, p<0·0001). Sensitivity analyses showed that estimates were not substantially affected by assumptions regarding missing data on medication use (appendix p 14).

Associations of comorbidities and risk factors with a history of stroke were examined using univariable and multivariable mixed-effects logistic regression (figure 1). After adjustment for age and sex alone, participants with a history of stroke had 5·9 times (95% CI 5·8–6·0, p<0·0001) increased odds of having diabetes and 9·9 times (9·7–10·1, p<0·0001) increased odds of being current smokers than those without a previous stroke—associations which, although attenuated, remained significant after full adjustment. Significant modification of this effect by age was also observed, with the odds of current smoking in participants with a history of stroke being significantly higher in the 18–39-year age group than in other age groups after full adjustment (appendix p 15).

Participants with a history of stroke were more likely than those without to consume alcohol at least once per week and to be underweight, overweight, or obese after adjustment for age and sex. However, in the fully adjusted model, participants with a history of stroke were at a lower risk of being overweight (odds ratio 0·89 [95% CI 0·87–0·91], p<0·0001) or obese (0·92 [0·89–0·95], p<0·0001) than those with no recorded history of stroke.

Overall, the odds of having raised blood pressure were 1·72 times (95% CI 1·69–1·75, p<0·0001) higher in participants with a previous stroke than in participants without. However, the use of antihypertensive medication modified this effect. The unadjusted odds of raised blood pressure in participants with a previous stroke compared with those without was higher for participants not taking medication, but not in those taking medication (appendix p 16). After adjustment for age and sex, the strength of this association was reduced in participants not taking medication and, after full adjustment, only a small but significant increase in the odds of raised blood pressure remained. However, in participants taking medication, full adjustment had only a small effect on the association with raised blood pressure: the odds of raised blood pressure in participants with a previous stroke was 9·3% lower than in those without.

At the national level, several significant associations were seen between estimates of premature stroke mortality and mean systolic blood pressure, the percentage of participants with raised blood pressure, and other parameters of hypertension management in both univariable and multivariable models (table 3, figure 2, and appendix pp 17–18). In univariable models, premature stroke mortality increased, on average, by 84·3 (95% CI 38·8–129·9) years of life lost per 100 000 people for each 1 mm Hg increase in the mean systolic blood pressure of participants in each country (p<0·0001; table 3). Premature stroke mortality also increased significantly for each 1% increase in the percentage of participants with raised blood pressure (p<0·0001; table 3). Similarly, national parameters of hypertension treatment and control were strongly associated with national estimates of premature stroke mortality, such that higher percentages of participants with hypertension on treatment and higher percentages of participants with controlled blood pressure were associated with lower rates of premature stroke death. However, no significant association was found between national premature stroke mortality rates and estimates of the percentage of participants with hypertension in each country. Multivariable adjustment for sex, alcohol intake, smoking, diabetes, and the proportion of participants who were overweight or obese did not significantly alter the strength of these associations (table 3).

The proportion of the variance (R^2) explained by each of the univariable models ranged from 0% for the proportion of participants with hypertension to 24% for the proportion of participants with controlled hypertension. In multivariable models, R^2 values ranged from 31% to 44% (table 3). Sensitivity analyses indicated that assumptions regarding medication missingness did not affect the direction or the strength of these associations (appendix p 17).

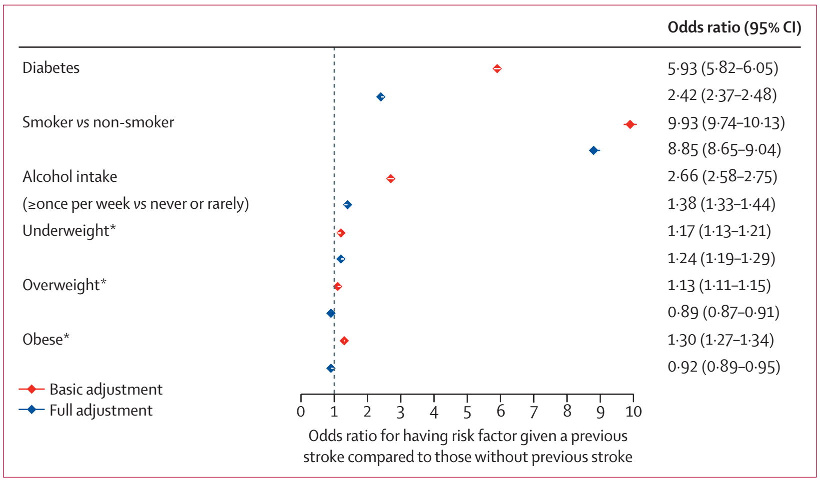

Figure 1: **Forest plot of adjusted odds ratios for cardiovascular risk factors given a history of stroke from basic and fully adjusted mixed-effects logistic regression models**
Basic adjustment=adjusted for age and sex. Full adjustment=adjusted for age, sex, use of antihypertensive medication, diabetes, smoking, alcohol intake, and body-mass index (BMI) categories. *BMI categories analysed as binary outcomes compared with healthy weight as the reference group.

Discussion

In this study of more than 2·2 million adults with recorded data on stroke history and whose blood pressure was recorded in one of two consecutive MMM campaigns[14,15] in 92 countries, 62 639 (2·8%) reported a history of stroke. Participants who reported a history of stroke were 6 years older on average than those who did not, and age-adjusted proportions of stroke were higher in men than in women.

Participants with a history of stroke were significantly more likely at the time of blood pressure screening to have diabetes, smoke, consume alcohol regularly, and be underweight, associations that remained after adjustment for confounders. Given the cross-sectional nature of the MMM campaign, the temporal sequence of the association between stroke and subsequent risk factors seen in figure 1 cannot be established. However, given the established strong predictive links between diabetes and smoking and subsequent stroke,[6,21] these findings are likely to largely reflect the carryover of pre-stroke propensity for stroke and the persistence of lifestyle habits. The small positive association between being overweight or obese and having a history of stroke is consistent with the recent findings from the FAST-MAG trial, which reported that being overweight or obese after stroke was associated with better survival.[22] However, this apparent association disappeared after adjustment in our study.

Stroke survivors were significantly more likely to have hypertension than participants without a history of stroke (77% *vs* 33%), which was largely unaffected by accounting for differences in age and sex (table 2). However, among

	Univariable linear regression			Multivariable linear regression		
	Mean change in premature stroke mortality per unit increase (95% CI)*	p value	R^2	Mean change in premature stroke mortality per unit increase (95% CI)*	p value	R^2
Mean systolic blood pressure, mm Hg	84·3 (38·8 to 129·9)	<0·0001	0·138	85·1 (46·2 to 124·0)	<0·0001	0·441
Proportion of all participants with raised blood pressure	49·1 (22·6 to 75·6)	<0·0001	0·138	37·8 (14·6 to 61·0)	0·002	0·385
Proportion of all participants with hypertension	9·0 (−16·5 to 34·5)	0·484	0·006	13·3 (−8·4 to 35·0)	0·227	0·311
Proportion of participants with hypertension on medication	−21·0 (−33·0 to −8·9)	0·001	0·140	−20·4 (−34·0 to −6·8)	0·004	0·373
Proportion of participants on medication with controlled blood pressure	−31·4 (−46·6 to −16·2)	<0·0001	0·186	−26·3 (−40·5 to −12·1)	<0·0001	0·409
Proportion of participants with hypertension with controlled blood pressure	−31·6 (−43·8 to −19·4)	<0·0001	0·237	−29·9 (−43·6 to −16·3)	<0·0001	0·441

Multivariable models adjusted for age-standardised proportions of male participants, current smokers, consuming alcohol at least once per week, diabetes, and the proportion who are overweight or obese. *Data are the mean (95% CI) change in premature stroke mortality (years of life lost per 100 000 people) per 1 mm Hg increase in mean systolic blood pressure or per 1% increase in proportion of participants.

Table 3: **Associations between age-standardised premature stroke mortality from the Global Burden of Disease and age-standardised blood pressures and parameters of hypertension management from May Measurement Month from univariable and multivariable linear regression models**

participants who were classified as hypertensive, those with a previous stroke were more likely to be on antihypertensive treatment, and have lower mean blood pressures, and have controlled blood pressure than those without a previous stroke (table 2).

Crude mean blood pressures in participants who were not treated for hypertension were significantly higher in those with a previous stroke than in those without, although only a small difference was apparent after standardisation for age and sex. Taken together, these findings suggest that participants with a previous stroke were more likely than those without to be on antihypertensive medication, and more likely to achieve stricter blood pressure control. Higher treatment rates in those with a previous stroke could be due to a greater likelihood of medical investigation and therefore higher diagnosis rates in participants with a history of stroke than in the general population, whereas stricter control could relate to both patient and clinician factors. Nevertheless, almost 40% of participants with a history of stroke who were on antihypertensive treatment did not have blood pressures controlled to less than 140/90 mm Hg (table 2), which is currently viewed as a conservative, suboptimal target.[23,24] In total, a third of those with a previous stroke had either untreated or inadequately treated blood pressure.

The significant associations between national blood pressure levels and markers of hypertension management and the associated proportions of the variance in premature stroke mortality are notable given the opportunistic convenience sampling used in the MMM campaigns. Only the national proportions of participants classed as having hypertension were not significantly associated with premature stroke mortality. This finding could, in part, reflect that a third of the population classed as having hypertension had normalised blood pressures (table 2). In univariable analyses, the other five parameters contributed between 14% and 24% of the variance in national premature stroke mortality, with proportions of controlled blood pressure among all participants with hypertension detected being the biggest independent contributor to the variance (figure 2, table 3).

A limitation of the GBD data is the absence of primary data for some countries and causes of death, and the use of modelling approaches, such as Bayesian meta-regression, to impute data from neighbouring countries.[1,25] Modelling will inevitably incorporate some inaccurate estimates and comparative studies have shown differences in estimates compared with other data sources.[26,27] Consequently, the already high estimated proportions of the stroke mortality variance arising from the MMM blood pressure parameters probably represent underestimates. That MMM only involved convenience sampling through opportunistic screening, rather than including representative samples of the countries included, could be considered a limitation of the associations observed between MMM-based measures

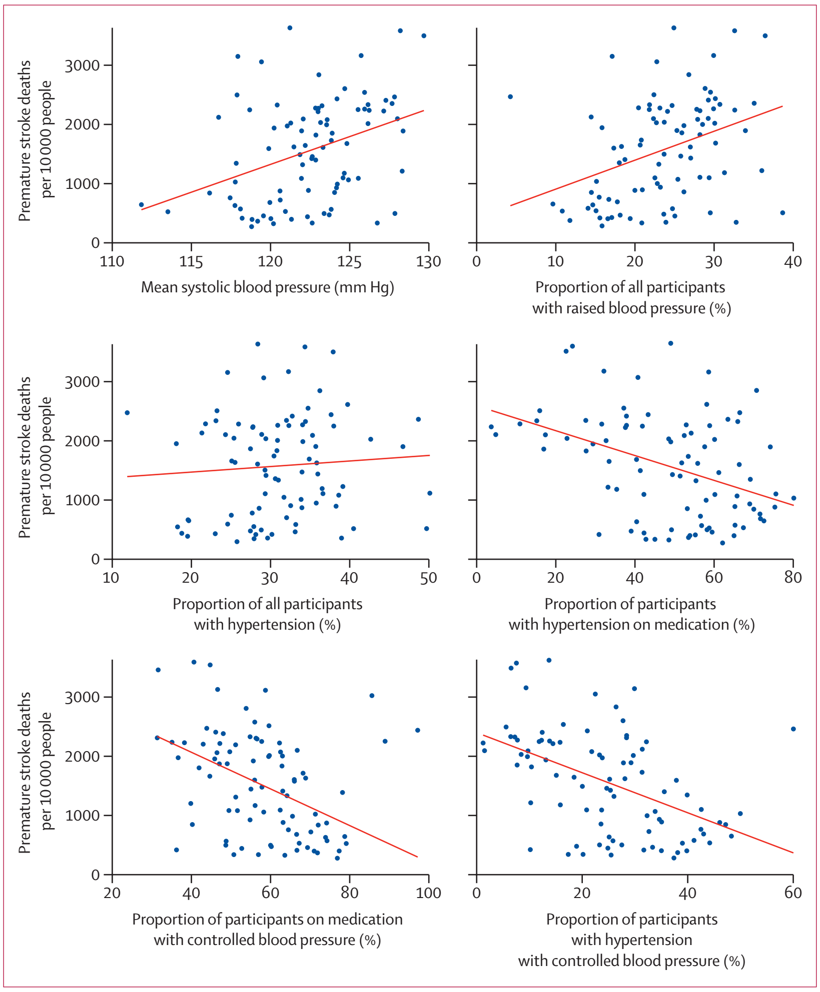

Figure 2: **Scatter plots and predicted regression lines of national age-standardised premature stroke mortality from the Global Burden of Disease and age-standardised blood pressures and parameters of hypertension management from May Measurement Month from univariable linear regression models**

of blood pressure management and national stroke mortality. However, the use of non-representative samples would probably dilute the true associations between measures of blood pressure control and stroke mortality at a national level. Meanwhile, in many of the countries involved with the MMM campaigns, systematic screening is not available and MMM represents the most comprehensive contemporary blood pressure data available.[14,15] Consequently, pending the availability of representative data, and given the strong associations between raised blood pressure and subsequent premature mortality due to stroke, MMM data should help to persuade policy makers of the need for improved blood pressure screening and management in their countries—one of the objectives of the MMM campaign.

Other limitations of these analyses are that MMM data include only non-fatal strokes, stratification by stroke type (ischaemic or haemorrhagic) was not possible, and other details of stroke causes and management were not available. Furthermore, data on stroke were self-reported and the duration since the reported stroke event was not recorded, which could affect the associations with subsequent risk factors. In common with all surveys of blood pressure carried out on a single occasion, the blood pressure data collected in the MMM campaigns are likely to overestimate rates of hypertension and uncontrolled blood pressure. Most clinical hypertension guidelines recommend that hypertension is diagnosed on the basis of repeated recordings measured on at least two evaluation visits, in an attempt to reduce the effect of acclimatisation to measurement and the white-coat effect. Missing data on the use of antihypertensive medication has the potential to confound the relationships between stroke, cardiovascular risk factors, and blood pressure, but sensitivity analyses showed that different assumptions regarding the missingness did not materially affect the results.

The key strengths of these analyses are that the data are derived from the largest standardised contemporary blood pressure screening campaign synchronised across 2 years in 92 countries and include a large number of contemporary prevalent stroke cases across a wide age range. Blood pressures were measured using standardised techniques and other data were collected in the same questionnaire following a common protocol.

In conclusion, blood pressure among stroke survivors is not adequately treated, with a third of those in our study having untreated or undertreated blood pressure. Furthermore, the MMM-based measures of blood pressure management at a national level correlated with premature stroke death sufficiently to allow policy makers to promote more efficient blood pressure screening and management.

Contributors

TB and NRP conceived the study. QL, TY, SC, TB, and NRP developed the methodology. QL, TY, PY, SC, and TB had access to and verified the data, and conducted the analyses. All authors contributed to the interpretation of the results. QL, TY, TB, and NRP wrote the draft of the manuscript, and all authors contributed to the critical revision of the manuscript and approved the final version. The first two and last two authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests

GS reports lecture and consulting fees from AstraZeneca, Menarini, Microlife, Omron, and Servier; research study payments to his institution from Braun, InBody, Maisense, and Microlife; and honoraria for lectures and presentations from AstraZeneca, Boehringer, Menarini, Novartis, and Servier; all outside the submitted work. All other authors declare no competing interests.

Data sharing

Anonymised participant data from MMM are available for research purposes subject to approval by the May Measurement Month Management Board with a Data Use Agreement in place. Further details on applying for data access are available at https://www.maymeasure.org or by email to the corresponding author.

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