Stroke epidemiology: a review of population-based studies of incidence, prevalence, and case-fatality in the late 20th century

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This overview of population-based studies of incidence, prevalence, mortality, and case-fatality of stroke was based on studies from 1990. Incidence (first stroke in an individual's lifetime) and prevalence were computed by age, sex, and stroke type. Age-standardised incidence and prevalence with the corresponding 95% CI were plotted for each study to facilitate comparisons. The review shows that the burden of stroke is high and is likely to increase in future decades as a result of demographic and epidemiological transitions in populations. The main features of stroke epidemiology include modest geographical variation in incidence, prevalence, and case-fatality among the—predominantly white—populations studied so far, and a stabilisation or reversal in the declining secular trends in the pre-1990s rates, especially in older people. However, further research that uses the best possible methods to study the incidence, risk factors, and outcome of stroke are urgently needed in other populations of the world, especially in less developed countries where the risk of stroke is high, lifestyles are changing rapidly, and population restructuring is occurring.

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Panel 1. Eligibility criteria

Studies of stroke incidence, prevalence, mortality, and case-fatality

Complete population-based case ascertainment based on multiple overlapping sources of information (hospitals, outpatient clinics, death certificates)

Standard WHO definition of stroke as "rapidly developed signs of focal (or global) disturbance of cerebral function lasting longer than 24 h (unless interrupted by death), with no apparent nonvascular cause"[19]

Cases of first stroke reported (for incidence studies only)

Data collection over whole years in 1990 or later periods (earlier studies were included only if data for 1990 or a later period of data collection were reported)

No upper age limit for the population studied

Availability of raw numbers sufficient to calculate the rates in question (if not all raw numbers were available in an otherwise eligible publication, a corresponding author of the publication was contacted for missing data)

Prospective study design

Presentation of data in the mid-decade age bands

Studies of time trends in incidence, mortality, and case-fatality

Criteria for comparable studies of stroke incidence suggested by Sudlow and Warlow[20]

- WHO definition of stroke,
- Availability of data on first strokes
- Complete, community-based case-ascertainment
- Prospective study design

Data collection over a period of several years (continuously or periodically for at least one whole calendar year each period) in one and the same catchment area

No upper age limit for the population studied and availability of age-standardised incidence/mortality data for time periods compared

Stroke is a non-communicable disease of increasing socioeconomic importance in ageing populations. According to WHO, stroke was the second commonest cause of mortality worldwide in 1990 and the third commonest cause of mortality in more developed countries;[1] it caused about 4·4 million deaths worldwide.[2] In the most recent estimates made in 1999, the number of deaths due to stroke reached 5·54 million worldwide,[3] with two-thirds of these deaths occurring in less developed countries.[4] Stroke is also a major cause of long-term disability[5] and has potentially enormous emotional and socioeconomic results for patients, their families, and health services. Lifetime costs per patient are estimated at between US$59 800 and US$230 000.[6] By the year 2020, stroke and coronary-artery disease together are expected to be the leading causes of lost healthy life-years.[7]

Stroke mortality data from many countries show that, in general, mortality rates have declined over recent decades most notably in Japan, North America, and western Europe.[1,8] The effects of changes in incidence and improved survival on the downward trend in stroke mortality have not been quantified adequately, chiefly because of the difficulties involved in the accurate measurement of stroke incidence. Data from the WHO Monitoring Trends and Determinants in Cardiovascular Disease (MONICA) stroke project[9] showed a general tendency for mortality and incidence from stroke in people aged 35–64 years to decline. The WHO study also reported large geographical variation in both mortality and case-fatality. Substantial geographical variation in the incidence of stroke was also reported for older people in a review in 1992,[10] although similar between-country age-specific rates for men[11] and little geographical variation in rates were reported in subsequent reviews of population-based studies.[12,13] Most reviews of this topic, despite providing important information, have largely been confined to limited age-groups within a population[10–15] or have included studies with different designs (eg, population-based studies, hospital-based studies, and studies based on official mortality statistic).[15–18] There are few recent reviews on the prevalence of stroke,[17,18] and no reviews have been published on the incidence of subtypes of ischaemic stroke.

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With these limitations in mind, and evidence of changing stroke epidemiology,[11] an updated review is pertinent. This will increase our current knowledge of stroke epidemiology and facilitate health-care planning, prevention, and management of stroke. The aim of this review is, therefore, to analyse published population-based studies of the incidence, prevalence, mortality, and case-fatality of stroke from 1990 onwards, and to review secular trends in incidence and case-fatality.

Methods

Search strategy and selection criteria

Data for this review were identified by searches of Medline (January, 1966, to August, 2002), and from the references of relevant articles. Different subsets of studies were potentially eligible for different parts of this review. The search terms "population-based", "community-based", "community", "epidemiology", "epidemiological", "incidence", "prevalence", "attack rates", "survey", "surveillance", "mortality", "morbidity", "fatality", "case-fatality", "stroke", "isch(a)emic stroke", "intracerebral", "intraparenchymal", "subarachnoid", "h(a)emorrhage", and "trends" were used. Only papers published in English were reviewed.

The eligibility criteria (panel 1;[19,20] except data collection over whole years in 1990 or later and no upper age limit) were largely the "ideal" criteria suggested by Sudlow and Warlow[20] for comparable stroke-incidence studies. There was no time limit for studies of time trends in stroke incidence, mortality, and case-fatality.

In this review, analysis of stroke incidence and case-fatality was confined to first stroke in a lifetime. We excluded stroke-prevalence studies that reported only rates associated with disability or impairment. If several studies were reported from the same population over different time periods, the most recent was used for stroke incidence or prevalence analyses, and all these studies were used in the analysis of trends.

Classification of stroke

Stroke type-specific analyses were confined to those population-based studies where CT, MRI, or autopsy findings were available for at least 70% of stroke cases. Strokes were classified into four major types: ischaemic stroke (if CT or MRI within 30 days of stroke showed infarct or no relevant lesion and/or autopsy showed ischaemic stroke), primary intracerebral haemorrhage (if shown on CT, MRI, or autopsy), subarachnoid haemorrhage (classified by characteristic

Table 1. Characteristics of population-based studies included in the analysis of stroke incidence, mortality and case-fatality (⩾1990)

Study reference	Data collection	Duration (years)	Population	Age range (years)	Total strokes	Incidence for strokes per 1000 person-years (95% CI)	Hospital admission rate (%)	CT/MRI or autopsy rate (%)	Time of CT/MRI after stroke (days)	Types of stroke by age-sex groups, as determined by CT/MRI/autopsy findings*
Melbourne, Australia[22]	1996–97	1	133 816	All	276	2·1 (1·8–2·3)	··	91	28	Age-sex specific rates for IS, PICH, SAH, undetermined
Perth, Australia[23]	1995–96	1	136 095†	All	213†	1·6 (1·4–1·8)†	88	78	..	Age-sex specific rates for IS and IS subtypes, PICH, SAH, undetermined
Frederiksberg, Denmark[24]	1989–90	1	85 611	All	262	3·1 (2·7–3·4)	..	74	..	Total rates for IS, PICH, SAH, undetermined
South London, UK[25]	1995–96	2	234 533	All	612	1·3 (1·2–1· 4)	84	88	30	Total rates for IS, PICH, SAH, undetermined
Espoo-Kauniainen, Finland[26]	1989–91	2	134 804	⩾25†	594	2·2 (2·0–2·4)	86	62	..	Age-sex specific rates for total strokes & SAH
Martinique, French West Indies,[27]	1998–99	1	381 364	All	580	1·6 (1· 5–1·8)	94	93	30	Age-sex specific rates for total strokes, total rates for IS, PICH, SAH, undetermined
Oyabe, Japan[28]	1987–91	4	170 312	⩾25	701	4·1 (3·8–4·4)	41	··	··	Age-sex specific rates for total strokes
Erlangen, Germany[29,30]	1994–98	2	101 450	All	354	1·3 (1·2–1·4)	95	96	3–14	Age-sex specific rates for IS and IS subtypes, PICH, SAH, undetermined
Arcadia, Greece[31]	1993–95	2	80 774	⩾18	555	3·4 (3·1–3·7)	90	82	7	Age-sex specific rates for IS, PICH, SAH, undetermined, total rates for IS subtypes
Belluno, Italy[32]	1992–93	1	211 389	All	474	2·2 (2·0–2·4)	92	90	30	Age-sex specific rates for IS, PICH, SAH, undetermined
L'Aquila, Italy[33]	1994	1	297 838	All	819	2·8 (2·6–2·9)	92	89	7	Age-sex specific rates for IS, PICH, SAH, undetermined
Auckland, New Zealand[34]	1991–92	1	945 369	⩾15†	1305	1·4 (1·3–1·5)	73	41	30	Age-sex-specific rates for total strokes and SAH
Inherred, Norway[35]	1994–96	2	69 295	⩾15	432	3·1 (2·8–3·4)	87	88	21	Age-sex specific rates for IS, PICH, SAH, undetermined
Novosibirsk, Russia[36]	1992	1	158 234	All	366	2·3 (2·1–2·5)	60	46	28	Age-sex specific rates for total strokes
Uzhgorod, west Ukraine[37]	1999–2000	1	125 482	All	352	2·8 (2·5–3·1)	66	41	··	Age-sex specific rates for total strokes

IS=ischaemic stroke; PICH=primary intracerebral haemorrhage; SAH=subarachnoid haemorrhage. *Cerebral angiography or CSF analysis for SAH.†Additional data were provided by corresponding author of the publication.

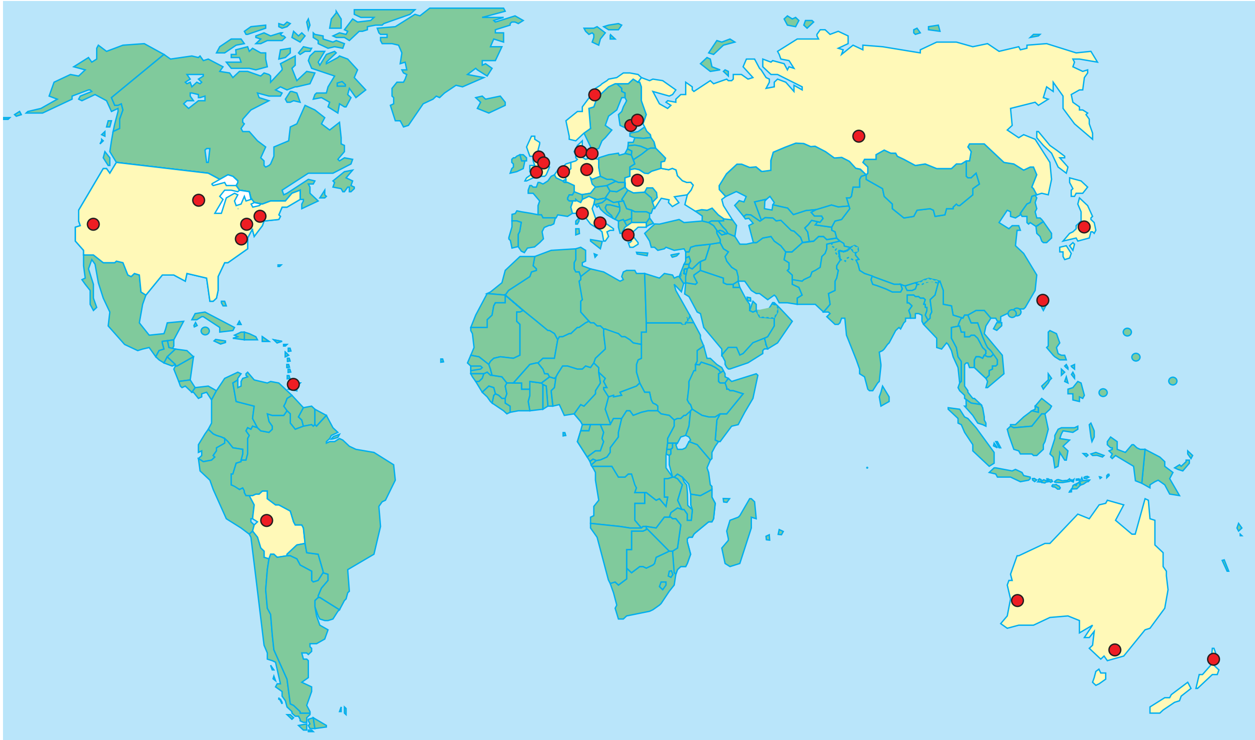

Figure 1. World map showing areas of the selected studies of stroke incidence and prevalence.

findings in CSF analysis and/or autopsy, CT, or cerebral angiography), and undetermined stroke (no CT, MRI, autopsy, cerebral angiography, or [for subarachnoid haemorrhage only] CSF examination was done). These classifications (except for undetermined) are based on standard definitions suggested by Sudlow and Warlow[12] for comparison of pathological stroke types. When possible from the original publication, ischaemic stroke was categorised into four groups: large-artery disease, cardioembolic, small-artery disease (including lacunar strokes), and other (including boundary strokes).

Statistical analysis

The incidence of first stroke was calculated per 1000 person-years. Mortality rates were calculated in the same way, with the numerator consisting of all deaths occurring within 1 month of the onset of a new stroke. Because stroke case-fatalities (proportion of fatal strokes in all first strokes) at 28 days and at 1 month are very similar, these figures were presented under one combined heading "1-month case-fatality rates". The prevalence was expressed as the number of patients with self-reported stroke per 1000 of the population. Incidence (first stroke) and prevalence were computed by age, sex, and stroke type. Age standardisation of incidence and prevalence figures was done by use of the direct method with the Segi 1996 world population[21] as the standard population. Age-standardised incidence for people aged over 55 years, and prevalence for those aged over 65 years were plotted with the corresponding 95% CI for each study to facilitate comparison. These age cut-offs were necessary to ensure that the maximum number of studies were included in the age-standardised comparisons. Larger age ranges would have resulted in exclusion of several studies because they did not provide disaggregated data for younger age-groups. However, the older age-groups included the majority of stroke events in all studies. Only published age-standardised rates were compared to establish time trends in stroke incidence.

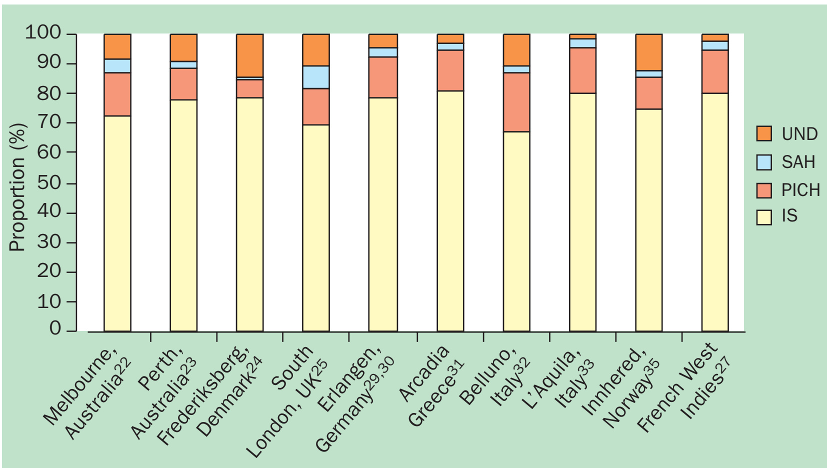

Figure 2. Proportional frequency of stroke types in selected populations. UND=undefined; SAH=subarachnoid haemorrhage; PICH=primary intracerebral haemorrhage; IS=ischaemic stroke.

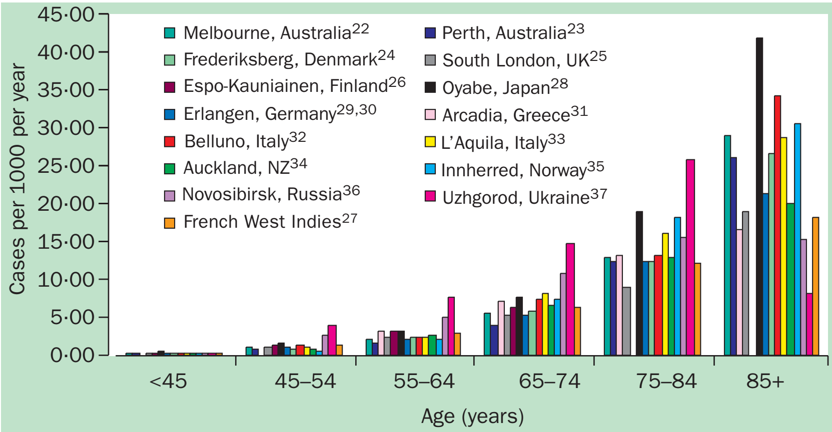

Figure 3. Annual incidence by age per 1000 population of all types of stroke combined in selected studies.

Results

Stroke incidence

15 population-based stroke incidence studies that met our eligibility criteria were identified and included in the analysis (table 1, figure 1).[22–37] These studies covered a population of 3 266 366 people in 13 countries, with 4 398 158 person-years of observation. The frequency of admission to hospital ranged from 41% in Japan to 94·6% in Germany (mean 81%). In five of the 15 studies, the information on timing of CT or MRI after stroke onset was not reported. In three studies, CT or MRI was done within 2 weeks of stroke onset, and in the other seven studies the procedures were done within 30 days. Classification of major stroke types was by CT, MRI, or autopsy in 76% of cases (from 41·0% to 95·5%; in ten of the 15 studies this proportion was over 70%). Mean age at onset—reported in nine studies—was 69·8 years among male patients (from 60·8 years in Uzhgorod, Ukraine,[37] to 75·3 years in Innherred, Norway)[35] and 74·8 years among female patients (from 66·6 in Uzhgorod, Ukraine, to 78·0 in Perth, Australia).[23]

Figure 2 shows the proportional frequency of stroke types in the ten studies (4578 strokes) that provided these data. 67·3–80·5% of strokes were classified as ischaemic stroke, 6·5–19·6% as primary intracerebral haemorrhage, 0·8–7·0% as subarachnoid haemorrhage, and 2·0–14·5% as undefined. Data on ischaemic-stroke subtypes were available for studies from Australia[23] and Germany.[29] Subtype was determined for all ischaemic strokes in one study,[23] but only two-thirds in the other;[29] this discrepancy makes comparison difficult. Large-artery disease constituted 68·0% of the ischaemic strokes in one study and 13·4% in the other, cardioembolism accounted for 17·8% and 26·9%, small-artery disease accounted for 9·7% and 22·6%, subtype was undetermined in 4·6% and 37·1% of cases, respectively.

The age-specific incidence of stroke increased progressively with each decade of life (figure 3).[22–37] For example, the rate of total stroke for those aged less than 45 years ranged from 0·1 to 0·3 per 1000 person-years; for those aged 75–84 years, the range was 12·0–20·0 per 1000 person-years in most studies. The highest age-specific rates occurred in Japan,[28] Russia,[36] and Ukraine.[37]

Age-standardised incidence of total stroke per 1000 person-years for people aged 55 years or more (figure 4) was in the range 4·2–6·5 in 12 of 15 studies, although three studies reported higher values. Age-standardised rates of total stroke in people aged 55 years or more did not differ significantly among study populations, with the exception of Ukraine, Russia, and Japan, where rates were the highest. Fewer studies provided data on stroke type, but age-standardised rates per 1000 person-years ranged from 3·4 to 5·2 for ischaemic stroke, 0·3 to 1·2 for primary intracerebral haemorrhage, and 0·03 to 0·2 for subarachnoid haemorrhage.

Stroke prevalence

Nine prevalence studies that met our eligibility criteria were identified (table 2[38–46] and figure 5).[38–46] Overall, 8788 strokes were reported, with age-specific prevalence increasing with age. The age-standardised prevalence for people aged 65 years or more ranged from 46·1 to 73·3 per 1000 population, but ranged from 58·8 to 92·6 per 1000 population for men, and from 32·2 to 61·2 per 1000 population for women. No strokes were detected among 213 adults aged 20–96 years in Papua New Guinea.[44] The study by Nicoletti and co-workers on prevalence in Bolivia[40] does not feature in figure 5

Table 2. Characteristics of population-based stroke prevalence studies included in the analysis (⩾1990)

Study reference	Data collection	Age range (years)	Number of stroke patients	Observed crude rate/1000 within the screened age-group (95% CI)		
				Men	Women	Total
Auckland, New Zealand[38]	1991–92	⩾15	7491*	10·7	9·7	10·2
Rotterdam, Netherlands[39]	1990–93	⩾55	352	5·0 (4·2–5·8)	4·3 (3·7–4·9)	··
Cordillera, Bolivia[40]	1994	All	16	2·5	1·0	1·7 (0·9–2·5)
Four regions, USA[41]	1989–90	⩾65	246†	6·8	3·2	4·7
Yorkshire, UK[42]	1991	⩾55	415	5·0 (4·3–5·8)‡	4·4 (3·9–5·1)‡	4·7 (4·3–5·2)
Newcastle, UK[43]	1993	⩾45	116	··	··	4·7 (4·6–4·9)
Kitava, Papua New Guinea[44]	1990	20–96	0	0	0	0
Taiwan, China[45]	1994	⩾35	71	6.37	5·53	5·95
L'Aquila, Italy[46]	1992	⩾65	80	9·6 (6·9–12·3)	5·5 (3·6–7·3)	7·3 (5·7–8·8)

*Auckland figures are extrapolations to the entire New Zealand population, as per original publication. †Calculated from the publication cited. ‡No age-specific numbers of stroke or population at risk reported.

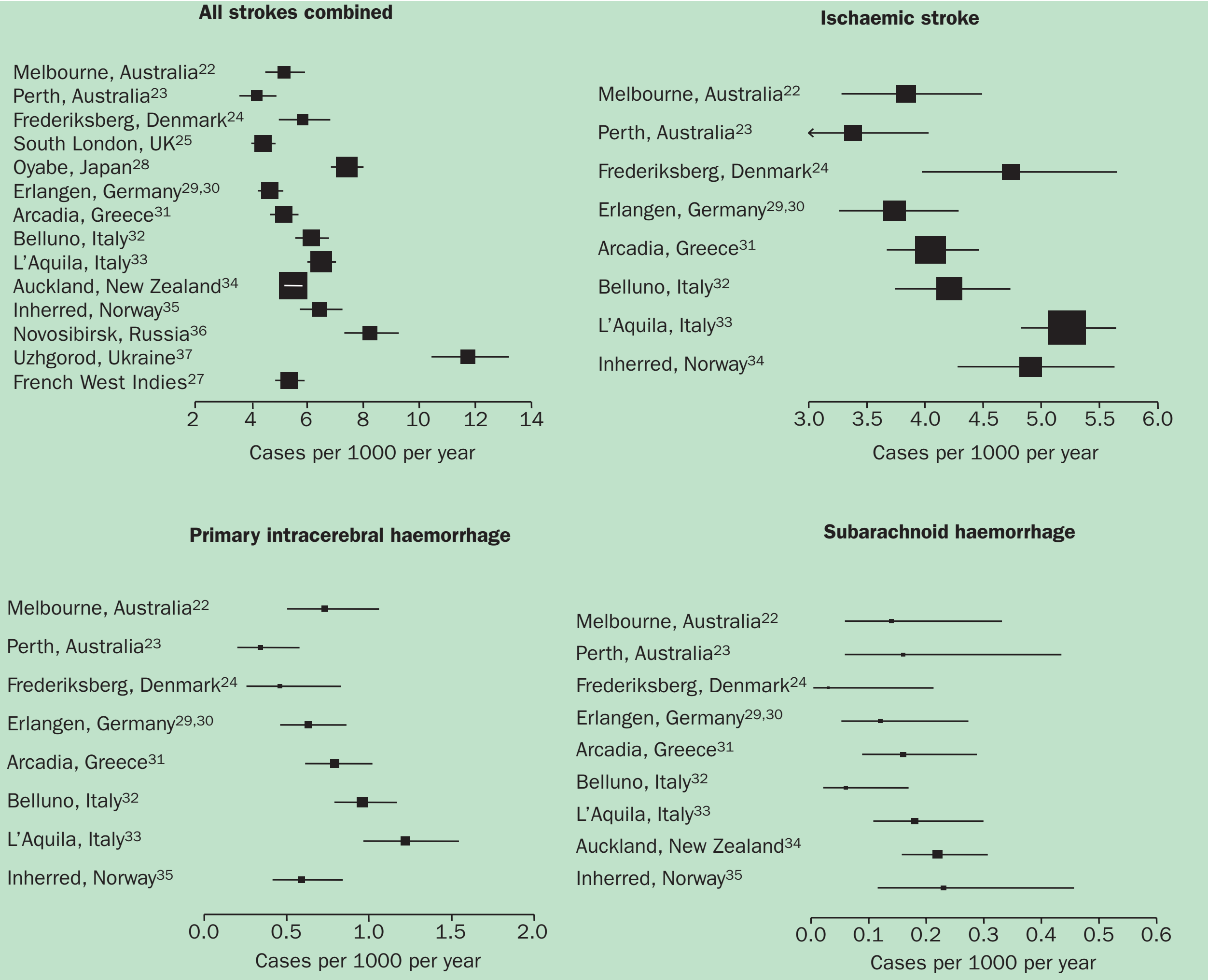

Figure 4. Age-standardised annual incidence per 1000 population of all strokes combined in people aged ⩾55 years. Only studies in which a CT, MRI, or autopsy was done in more than 70% of cases were included in the analyses of stroke types. All stroke-type analyses were based on cases classified by CT, MRI, or autopsy findings for ischaemic stroke and primary intracerebral haemorrhage, or CSF examination and/or cerebral angiography for subarachnoid haemorrhage. The error bars are 95% CIs. Box size is proportional to the number of events contributing to the analysis in each graph.

because there were insufficient age-specific data age-standardised prevalence rates to be calculated. Overall, there was no significant difference in age-standardised prevalence between selected populations in people aged 65 years or more, except in L'Aquila, Italy, and Newcastle, UK, which reported higher prevalences than the other studies. Only three studies[38,42,43] reported frequencies of both total stroke and strokes with associated disability or impairment; the latter varied from 55% of all strokes in New Zealand[38] to 77% of all strokes in Yorkshire, UK.[42] A Spanish study,[47] which is not included in this analysis, had findings in line with those cited so far (crude prevalence in people age 65 years or over was 8·5% in an urban sample [n=340] and 7·1% in a rural sample [n=846])

Stroke case-fatality

In 13 of 15 selected studies that reported either age-specific or total case-fatality within 1 month of stroke onset (figure 6),[22–23,26–37] 1608 (22·9%) of 7021 strokes were fatal. Case-fatality of total strokes varied little between the populations, with the exception of Japan (17%)[23] and Belluno, Italy (33%).[32] Little geographical variation was observed in case-fatality of ischaemic stroke and primary intracerebral haemorrhage, with the exception of studies from Belluno[32] and L'Aquila,[33] Italy. Although case-fatality of subarachnoid haemorrhage showed some geographical variation, we could not assess whether these differences were statistically important because data from individual patients for the calculation of CIs were not available. Age-specific data on stroke case-fatality within 1 month of onset were available in four studies.[23,34,36,37] In these studies, annual mortality rates specific for age and sex increased progressively with age.

Time trends in stroke incidence and mortality and case fatality

Eight population-based studies[23,24,26,28,34,48–50] that assessed secular trends in stroke incidence in a given population were identified (table 3). Overall, these studies yielded 9 121 218 person-years of observation and 13 461 new stroke cases. In

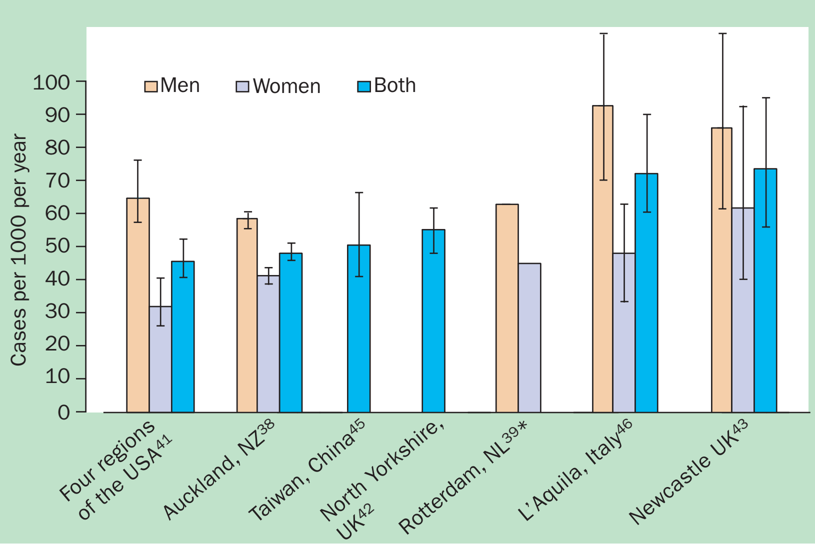

Figure 5. Age-standardised prevalence of stroke per 1000 population in selected studies of people aged ⩾65 years. The error bars are 95% CIs (could not be calculated for the Rotterdam).[38] Studies are arranged in ascending order of prevalence.

five of the eight studies, all age-groups of the population were included in the stroke register, and in three, the study population was restricted to the age range 15 or 25 years and above. The observation period ranged from 7 years to 34 years.

Although the studies covered different periods, several common themes were evident. Most of the studies showed a decline in stroke incidence, through to the late 1970s or early 1980s.[26,28,34,48–50] In several studies, however, this decline seems to have reached a plateau or even reversed in the late 1980s and early 1990s.[26,28,34,49,50] There were exceptions—rates continued to decline in Perth, Australia[23] between 1989–90 and 1995–96, and in men in Japan[28] between 1982–86 and 1987–91. Data from Denmark[24] showed a net increase in incidence, but this study looked at rates over a long period (1972–74 to 1989–90).

Of the few population-based studies that reported time-trend data for stroke mortality, the consistent finding was of a decrease in rates from the 1970s through to the 1990s.[23,26,28,34,35] Four studies recorded declines in case-fatality between the early 1970s and early 1990s,[26,28,34,50] with two reporting no change.[23,49]

Discussion

We have reviewed the epidemiology of stroke predominantly in more developed countries on the basis of well-designed population-based studies. Compared with the two most recent reviews of stroke incidence in various countries published in 1997[12] and 1998,[13] our review included 17 new population-based studies (nine new stroke-incidence studies published since 1990 and eight new studies on secular trends in stroke incidence) and nine stroke-prevalence studies that have not been reviewed previously. In addition, we analysed all population age-groups, reviewed incidence and case-fatality of major stroke types (including ischaemic-stroke subtypes), and calculated age-standardised estimates in the elderly population without an upper age limit. Although there have been more studies conducted in the 1990s since the reviews by Sudlow and Warlow,[12,13] which reviewed the situation for the 1980s, the methods proposed for stroke-incidence studies have not been updated substantially. In particular, few studies with the ability to identify stroke incidence according to defined pathological types have been done. However, unlike the previous review by Sudlow and Warlow,[12] who visited all participating centres and scrutinised and reviewed all original data, we extracted our data largely from published papers. Unfortunately, three recent population-based stroke-incidence studies were excluded from the analysis because they did not meet the inclusion criteria: a study in Sweden[51] was restricted to people aged up to 74 years; a study in Poland[52] did not include subarachnoid haemorrhage and did not provide age-specific rates for other stroke types; and a study in Portugal[53] was published in abstract form only and did not provide the age-specific data required for our analysis. Comparable age-standardised rates could not be calculated for a study in Finland[26] because no rates were given for people aged 75–84 years and 85 years or more in the publication. A study in the West Indies[27] did not provide age-specific data for stroke types. Similarly, several recent stroke-prevalence studies were not included in the analysis because they did not meet our inclusion criteria. For example, a study in Tanzania was restricted to hemiplegic stroke patients with residual impairment or disability only.[54] Data

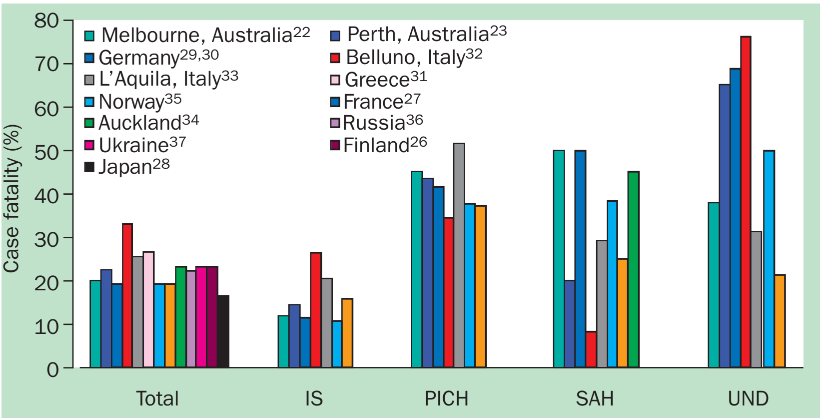

Figure 6. Case-fatality within 1 month of stroke onset by stroke type in selected populations. IS=ischaemic stroke; PICH=primary intracerebral haemorrhage; SAH=subarachnoid haemorrhage; UND=undefined.

Table 3. Characteristics of selected population-based studies on time trends in stroke incidence, mortality and case-fatality

Study reference	Age range	Incident strokes	Person-years	Years included	Changes in stroke incidence	Changes in stroke mortality	Changes in stroke case-fatality
Rochester, MN, USA[49]	All	2521	1 665 257*	1955–79 1970s to 1980s	↓38% ↑19%	Not reported	↔At 1 month and 12 months
Frederiksberg, Denmark[24]	All	927	378 240	1972–74 to 1989–90	↑15%	Not reported	Not reported
Espoo-Kauniainen, Finland[26]	All	1093	769 508	1972–73 to 1978–80 1978–80 to 1989–91	↓28% ↑9%	}↓46%	}↓33%
Oyabe, Japan[28]	⩾25	2068	460 026*	1977–81 to 1982–86 1982–86 to 1987–91 1982–86 to 1987–91	↓25–30% ↓9% in men ↑2% in women	}↓Not reported	}↓26%
Auckland, New Zealand[34]	⩾15	1776	1 774 833	1981–82 to 1991–92	↓9% in men ↑9% in women	}↓Not reported	}↓16%
Copenhagen County, Denmark[48]	⩾25	1206	2 121 600	1982–1991	↓3%	↓2%	Not reported
Novosibirsk, Russia[50]	All	3406	1 683 754*	1982–1988 1988–1992	↓30% ↑8%	Not reported	}↓24%
Perth, Australia[23]	All	464	268 000	1989–90 to 1995–96	↓27%	↓35%	↑5%

↔=no change in rates, ↑=increase in rates, ↓=decrease in rates. *Estimated from the publication cited.

from a study in Calcutta[55] were not presented in the mid-decade age bands, thus preventing calculation of age-adjusted rates comparable with other studies included in our analysis. In a study from Bengal,[56] age-specific data were not reported for people over 61 years of age.

Geographical differences in stroke epidemiology

This overview has shown that the geographical variations in incidence of all strokes combined, age-specific incidence, proportions of stroke types, prevalence, and 1-month case-fatality (panel 2) are, with a few exceptions, small compared with that observed in the MONICA project.[57,58] The high incidence of stroke in Russia and Ukraine can be attributed to well-known social and economic changes that have occurred in these countries over the past decade, including changes in medical care, access to vascular prevention strategies among those at high risk, and the exposure to risk factors. Reasons for the higher stroke incidence in Japan than in other more developed countries are not clear but could be related to genetic and environmental factors. The observed geographical differences in the incidence of ischaemic stroke and primary intracerebral haemorrhage could be the result of the different proportions and timing of CT or MRI investigations in the studies analysed. Recent features in stroke incidence and outcome include a levelling off of previous potential geographical differences in stroke incidence and prevalence and trends towards stabilising or increasing rates, especially in the elderly population. The between-country similarity in rates is not too surprising, given the homogeneity of the populations studied (predominantly white with the exception of the Japanese population) and the restricted period for data collection (from 1990 onwards). In the Oyabe Study, Japan,[28] the proportion of intracerebral haemorrhage in 1987–91 was reported to be higher (16·4%) than the proportions of the 1977–81 period and of other studies included in the analysis. Since no information on the documentation of stroke types by neuroimaging techniques was provided in the publication, no reliable comparisons could be made with other studies. Early total and type-specific stroke case-fatality was also similar between the study populations, with the exception of Japan (low rates) and Italy (high rates). A combination of large-artery disease and cardioembolic strokes constituted the largest proportion of ischaemic strokes, which is in line with results of a population-based stroke-incidence study in Rochester, Minnesota, USA, done in 1985–89.[59]

Stroke prevalence

We identified nine studies of stroke prevalence that met our eligibility criteria and had collected data from 1990 onwards. Studies done before 1990 suggested that the worldwide prevalence of stroke in all age-groups of the population combined varied between four and 20 per 1000 population.[38,49,60–68] In our review, the range of crude prevalence shows far less geographical variation (five to ten per 1000), with the exception of populations in rural Bolivia,[40] in which the prevalence of stroke is as low as 1·7 per 1000, and Papua New Guinea,[44] in which no strokes

Panel 2. Key features of modern stroke epidemiology*

Among areas with population-based studies, the overall age-standardised incidence of stroke in people aged ≥55 years ranged from 4·2 to 11·7 per 1000 person-years. Proportions ranged from 67% to 81% for ischaemic stroke, 7% to 20% for primary intracerebral haemorrhage, 1% to 7% for subarachnoid haemorrhage, and 2% to 15% for undetermined type.

Stroke incidence, prevalence, stroke-subtype structure, 1-month case-fatality, and mortality rates show modest geographical variations, with the exception of Ukraine, Russia, and Japan, where incidence rates are highest, and Italy and the UK where prevalence rates are highest.

The average age of patients affected by stroke is 70 years in men and 75 years in women. More than half of all strokes occur in people over 75 years of age.

The age-standardised prevalence rate of stroke in people aged ⩾65 years ranges from 46 to 72 per 1000 population.

Overall case-fatality within 1 month of stroke onset is about 23% and is higher for intracerebral haemorrhage (42%) and subarachnoid haemorrhage (32%) than for ischaemic stroke (16%).

Overall, there is a trend towards stabilising or increasing stroke incidence, especially in the elderly population.

*Inferences from this study are limited to largely white populations in the more developed countries.

were detected at all. However, the study in Bolivia included only patients with stroke-related disability, and the one in Papua New Guinea screened only 213 patients over 20 years of age, and the refusal rate in the older age-group was 63%. The small variation in age-specific and age-standardised prevalence of stroke across the populations is consistent with the geographical similarity in stroke incidence and case-fatality. Similar results were found in another review of stroke-prevalence studies.[69] The high prevalence of stroke in L'Aquila, Italy, could be related to inclusion of minor strokes in the study.[46] The prevalence of stroke-related disability was reported in only three of the studies analysed,[38,42,43] which suggested that about half to three-quarters of cases had stroke-related disability.

Stroke incidence and case fatality
Our review confirms previous observations of modest geographical variation in the incidence of all types of stroke combined[12,13] and of subarachnoid haemorrhage,[70] but contradicts the conclusions of the MONICA project.[57,58] That project found that there were large geographical differences in the incidence and case-fatality of all strokes and of subarachnoid haemorrhage. Our finding of substantial geographical variations in 1-month case-fatality of subarachnoid haemorrhage is in line with that of the MONICA project.[58] Possible explanations for the observed geographical differences in the case-fatality of subarachnoid haemorrhage include the small number of patients with this subtype, different proportions and timing of CT or MRI investigations, and variations in the management and severity of subarachnoid haemorrhage. Studies analysed in the MONICA project were done in the late 1980s and were restricted to people aged 25–64[58] or 35–64[57] years. Geographical coverage of stroke and the number of countries (13) included in our analyses are also greater than in the MONICA project (11 countries).[57] Compared with recent reviews of stroke incidence,[10–13] our estimates have the advantage of being based on larger numbers of comparable population-based studies done over the past decade (from 1990 onwards) and covering over 3 million people of all ages and over 4 million person-years of observation.

Limitations of this review
The studies of stroke incidence, case-fatality, and prevalence identified in this overview have been largely based on white people in more developed countries. In addition, these studies may not be entirely representative of the countries where they were carried out owing to within-country variations in stroke rates,[22,57,71] including different rates in various ethnic groups.[25,72–74] No population-based stroke studies have been done in less developed countries, except a prevalence study in Bolivia.[40] This lack precludes generalisation of these data to less developed countries where three-quarters of all stroke deaths occur, and where the increase in stroke burden is most likely.[75] In addition, the absence of time-trend studies of stroke incidence in the late 1990s limits our ability to project trends in stroke rates and outcome reliably beyond the year 2000.

Measurement of stroke incidence
Stroke should be studied in a population-wide context because a large proportion of the burden of care for stroke is borne by health services outside the hospital sector and by families of affected patients.[76] Assessment of the need for prevention strategies, health services, and recording of geographical and secular trends, is most sensitively achieved with standardised population-based registers, because analysis limited to hospital cases or varying criteria and definitions can distort results. However, such studies are particularly challenging[20] and, therefore, are less common than other study designs, particularly in less developed countries where resources and the necessary research infrastructure are limited. Since a major challenge is to ensure accurate case-ascertainment, despite the exclusion of over half of all strokes, many population-based stroke registers are limited to people under the age of 75 years. Tilling and co-workers[77] used advanced capture-recapture methods to check for completeness of case ascertainment in the south London stroke register. They found that several demographic and stroke severity variables were associated with case identification, and that a capture-recapture model without covariates underestimated the age-standardised incidence rates by as much as 12%. To our knowledge this approach was not used in the other studies included in this review, so the age-standardised rates reported may be underestimates.

Only limited data for contemporary health planning can be extracted from stroke-incidence studies before 1990, because the studies were either outdated, incomplete, or failed to distinguish reliably the stroke types. There is also evidence of inaccuracy of official stroke-mortality statistics.[57,78–85] High-quality population-based stroke-incidence studies provide accurate data on the occurrence of an individual's first stroke, which are important for risk estimates and for comparison between populations. Information on the occurrence of recurrent stroke is invaluable for estimates of the totality of the burden of stroke in a community, for health-care planning, and as an indicator of the effectiveness of programmes for the prevention of secondary stroke. Increasing demand for more specific planning of stroke care (eg, accurate resource allocation for carrying out carotid endarterectomy, antithrombotic treatment, aneurysm surgery) need more detailed information, not just on the major stroke types but also on ischaemic stroke subtypes.

Population-based studies
Criteria by which the quality of population-based studies of stroke could be judged were published by Malmgren and colleagues[86] in 1987, and later updated by Bonita[87] in 1995, and Sudlow and Warlow[20] in 1996. These remain relevant for all incidence studies, at least in more developed countries that have the ability to verify the diagnosis by CT or MRI in at least 80% of cases and classify ischaemic stroke into subtypes. Other considerations are that a large sample size is needed to ensure sufficient number of incident strokes per year, and that age-specific data for first and recurrent stroke in the oldest age-groups (⩾85 years) are presented.

Less developed countries

The above-mentioned criteria are not practical for stroke studies undertaken in less developed countries, where most strokes occur and resources are limited. To address the problem of accurate and comparable data in these countries, an approach to increase the detail in the data collected for stroke surveillance has recently been proposed by the WHO.[75] This flexible and sustainable system includes three steps: standard data acquisition (recording of hospital admission for stroke), expanded population coverage (calculation of mortality rates by use of death certificates or verbal autopsy), and comprehensive population-based study (reports of non-fatal events used to calculate incidence and case-fatality). These steps could provide vital basic epidemiological estimates of the burden of stroke in many countries around the world.

Measurement of stroke prevalence

Prevalence of stroke can be estimated by cross-sectional surveys, cohort studies, or by indirect calculations from incidence studies that have followed up cases at uniform times after stroke onset.[38,69] International comparisons of stroke prevalence are fraught with difficulties[38] due to the low rates of stroke in some countries, wide between-country variations in the population age structure, and few prevalence studies with people in the oldest age-groups who are at the greatest risk of the disease. Further difficulties include measurement bias, poor verification of stroke types, and resource expenses. Although the prevalence of stroke-related disability is important for health-care planning,[38,68] these estimates may be unreliable because of overlapping disabilities caused by disorders that accompany stroke in many older patients.[13] Suggested criteria for stroke-prevalence studies include the use of the WHO definition of stroke, and a population-based study design of a large, well-defined, and stable population (the choice of study design may vary, for example a door-to-door survey may be the design of choice for an elderly population with restricted mobility). Data should be presented by sex in standard age bands for cases aged 85 years and older, self-reported stroke and medically confirmed stroke should be reported with 95% CI for prevalence data.

Assessment of the time trends of stroke

In five of the eight studies on the time trends of stroke incidence, there was a decrease in stroke incidence to the mid-1980s, and an increase in rates in the late 1980s or early 1990s; these changes were most noticeable in elderly people. Even in Japan, a country with the largest decrease in stroke incidence in 1977–86, there was an increase in stroke incidence in women and in people aged over 85 years.[28] Although no changes in overall stroke incidence were observed in Auckland, New Zealand for the period 1981–92, there was an increase in rates in women.[34] The only study that showed a decrease in stroke incidence in the mid-1990s from the late 1980s was the study in Perth, Australia.[23] Variations in competing risks (exposures) for diseases across countries might explain the different secular trends in incidence. The changing pattern of stroke incidence over time can be attributed to several factors: changing patterns of exposure to or control of risk factors for stroke (including socioeconomic and environmental factors); changing completeness of case ascertainment (eg, better identification of minor strokes from neuroimaging and diagnostic awareness); birth-cohort or period-cohort effects (eg, changes in fetal or early childhood health many years ago); or all of these factors.

Most studies have found a decrease or no change in early stroke case-fatality over the past 20–30 years. Official stroke mortality data from over 25 countries[8,88] showed that, in general, these numbers have declined for several decades, most notably in Japan, North America, and western Europe. In many more developed countries stroke mortality has been falling since the early 1950s, but the rate of this decline has decreased recently.[89–91] The contributions of changes in incidence and improved survival to the downward trends in stroke mortality have not been quantified adequately, chiefly because of the difficulties involved in the accurate measurement of stroke incidence.[20,76] Several studies have suggested that declining case-fatality is a major contributor to the declining stroke mortality,[92] but these data were not population based.[93–95] Such data for stroke mortality and case-fatality are scarce, so assessment of whether the trends in stroke incidence are associated with similar trends in stroke mortality is not possible. Only two studies[23,48] have found such a correlation. Interestingly, the fall in stroke incidence and mortality was associated with no change in stroke case-fatality in one study[23] and an increase in case-fatality in another.[48] The most likely explanation for the commonly observed recent increase in stroke incidence is rapid ageing of the population. Whether the observed continuous decrease in the incidence and mortality rates from myocardial infarction[96–105] contributed to the changing pattern of stroke incidence remains to be studied. Even less is known about stroke time trends in less developed countries.

Untangling the puzzle of trends in the effects of stroke is a matter of pressing importance. Stroke is a leading cause of disability, and the elderly—the most stroke-prone age-group—constitute the fastest-growing segment of the population. Data on trends in the cause-specific incidence of stroke provide important local feedback on public-health measures, although patterns of case-fatality and outcome bear a closer relation to acute treatment and rehabilitation. Both data sets are required for effective planning of services in scope and scale, as they will inevitably come under increasing pressure from restructuring of populations and adverse lifestyle changes.

Future research perspectives

Despite the numerous epidemiological studies done to date, there remain many unresolved issues.

Most stroke deaths already occur in less developed countries and the proportion could increase. More stroke data on these regions, obtained by the "best possible" stroke studies (such as a WHO stepwise surveillance system), will contribute to a greater understanding of stroke epidemiology and appropriate measures for health-care planning and prevention strategies.

An important issue is the explanation for changes over time in stroke incidence (of first and recurrent stroke) and worldwide and nationwide mortality rates. It would indicate how much emphasis should be placed on secondary stroke prevention compared with primary prevention. In this respect, the need for high-quality comparable stroke studies in different parts of the world, including studies in less developed countries and of various ethnic or racial groups, cannot be overestimated. These studies would also allow more meaningful estimates of the worldwide burden of stroke.

Monitoring of the secular trends in incidence and outcomes (natural history) of stroke in the same populations, together with measurement of the contribution of changes in stroke risk factors, would help to develop models to predict future trends in stroke incidence and outcomes, to find the best strategies for its control, and to monitor the progress of prevention and management programmes.

Identification of differences and similarities of stroke incidence in different populations and its changes over time can also improve our knowledge of stroke aetiology. An acceptable alternative to continuous monitoring of such time trends, which is expensive and not practicable in most populations, is to do population-based incidence studies in the same population once every decade. Monitoring of the prevalence of stroke risk factors in the same populations can be achieved through risk-factor surveillance systems, which could be implemented for major risk factors and then for disease events.[106]

There is a need for more studies of stroke prevalence in different parts of the world. In this respect, a door-to-door survey may be the design of choice. This method is simple, efficient, and can be implemented in many different settings around the world. A consensus on the measurements that best reflect a prevalence of stroke-related disability should be developed to facilitate better health-care planning.

Given the ageing population, particular attention should be given to covering all age-groups, including people over 85 years old, the fastest-growing group.

Further attention should be given to verification of stroke types, including ischaemic stroke subtypes, because management and prevention strategies for different stroke types vary. Improvement in the quality of routinely available stroke mortality data is also important.

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Authors' contributions

VLF and CMML did the literature search and extracted the data. CMML and DAB designed the tables. DAB did the statistical analyses. VLF wrote the first draft and all authors subsequently helped to write the article.

Conflict of interest

We have no conflict of interest.

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