Stroke

CLINICAL AND POPULATION SCIENCES

Attributable Costs of Stroke in Ontario, Canada and Their Variation by Stroke Type and Social Determinants of Health

Manav V. Vyas, MBBS; Jiming Fang, PhD; Claire de Oliveira, PhD; Peter C. Austin, PhD; Amy Y.X. Yu, MD; Moira K. Kapral, MD

BACKGROUND: Estimates of attributable costs of stroke are scarce, as most prior studies do not account for the baseline health care costs in people at risk of stroke. We estimated the attributable costs of stroke in a universal health care setting and their variation across stroke types and several social determinants of health.

METHODS: We undertook a population-based administrative database-derived matched retrospective cohort study in Ontario, Canada. Community-dwelling adults aged ≥40 years with a stroke between 2003 and 2018 were matched (1:1) on demographics and comorbidities with controls without stroke. Using a difference-in-differences approach, we estimated the mean 1-year direct health care costs attributable to stroke from a public health care payer perspective, accounting for censoring with a weighted available sample estimator. We described health sector–specific costs and reported variation across stroke type and social determinants of health.

RESULTS: The mean 1-year attributable costs of stroke were Canadian dollars 33 522 (95% CI, $33 231–$33 813), with higher costs for intracerebral hemorrhage ($40 244; $39 193–$41 294) than ischemic stroke ($32 547; $32 252–$32 843). Most of these costs were incurred in acute care hospitals ($15 693) and rehabilitation facilities ($7215). Compared with all patients with stroke, the mean attributable costs were higher among immigrants ($40 554; $39 316–$41 793), those aged <65 years ($35 175; $34 533–$35 818), and those residing in low-income neighborhoods ($34 687; $34 054–$35 320) and lower among rural residents ($29 047; $28 362–$29 731).

CONCLUSIONS: Our findings of high attributable costs of stroke, especially in immigrants, younger patients, and residents of low-income neighborhoods, can be used to evaluate potential health care cost savings associated with different primary stroke prevention strategies.

GRAPHIC ABSTRACT: A graphic abstract is available for this article.

Key Words: adult ■ demography ■ ischemic stroke ■ social determinants of health ■ stroke

Stroke is among the leading causes of death and disability worldwide.[1,2] It is estimated that the cost of stroke care in Europe amounted to 27 billion euros in 2017, whereas it was about 45.5 billion dollars in the United States in 2016, with generally higher costs for intracerebral hemorrhage (ICH) than ischemic stroke.[3,4] In Canada, the total average direct and indirect annual costs of ischemic stroke were estimated at $95 580 per stroke (inflation adjusted to 2021 in Canadian dollars [CADs]) in a single-center study,[5] whereas the total average direct health care costs in the year poststroke were $53 001 using a population-based sample in Ontario, with higher costs for ICH than ischemic stroke[6] and with variation by sex[6] and neighborhood socioeconomic status.[7]

These previous studies do not account for the baseline health care costs of people who are at risk of stroke, which

Correspondence to: Manav V. Vyas, MBBS, St. Michael's Hospital-Unity Health Toronto, 6th Floor, Bond Wing, 30 Bond St, Toronto, Ontario M5B 1W8, Canada. Email manav.vyas@mail.utoronto.ca

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Nonstandard Abbreviations and Acronyms

CAD	Canadian dollar
ED	emergency department
ICH	intracerebral hemorrhage

may be higher than those of the average population due to the prevalence of vascular risk factors. These baseline costs can be accounted for by calculating attributable costs of stroke, which are the costs that can be avoided by preventing the incident event.[8] Understanding population attributable costs of stroke is relevant because these estimate the direct savings of avoiding a stroke, which in turn can help determine the cost-effectiveness of primary stroke preventive strategies from a health care system perspective.

Our objective was to calculate the attributable costs of all publicly funded medical care in patients with stroke using patient-level medical costs in Ontario, Canada. We further compared costs by stroke subtype (ischemic stroke and ICH) and across social determinants of health, including age (≥65 versus <65 years), sex, neighborhood-level income, immigration status, and rural or urban residence. We hypothesized that attributable costs of stroke would be lower than previously estimated direct costs of stroke. Further, we hypothesized that ICH would have higher costs than ischemic stroke and that the costs would vary across different social determinants of health.

METHODS

We used administrative health databases available at ICES, an independent, nonprofit research institute in Toronto, Ontario. Multiple administrative health databases were linked using unique encoded identifiers and analyzed at ICES (details of databases used in Table S1). Use of these data was authorized under section 45 of the Ontario Personal Health Information Protection Act, which does not require review by a research ethics board. Study data are held securely in a coded form at ICES, with data sharing agreements prohibiting ICES from making the data set publicly available (www.ices.on.ca/DAS).

Setting

All Ontario residents have access to publicly funded health care programs under the provincial health plan, which covers costs related to hospital fees, drug costs included under the public provincial drug plan, surgical procedures, physician fees, rehabilitation costs, and long-term care home costs. This plan covers over 98% of Ontario residents, except for seasonal migrants, temporary residents, and those living on federal reserves.

Data Sources and Cohort Creation

We used a population-based cohort of all community-dwelling adults aged 40 to 105 years on January 1, 2003, without prior stroke (with a 23-year look back window), residing in Ontario. The cohort was derived from the Registered Persons Database, a population registry that identifies all provincial residents, and using unique coded identifiers, it was linked to the Canadian Institute for Health Information Discharge Abstract Database to identify hospitalizations for stroke and the Canadian Institute for Health Information National Ambulatory Care Reporting System database to identify emergency department (ED) visits for stroke. By law in Ontario, all hospitalizations and ED visits must be recorded in these Canadian Institute for Health Information databases, ensuring complete ascertainment of events that result in presentation to a hospital (details in Table S1 and Figure S1). The Registered Persons Database provided information on age, sex, and any deaths occurring during the study period, and the Canadian Institute for Health Information databases provided information on comorbid conditions. We further linked this cohort to the physician claims database, which includes information on all physician visits or services; the inpatient rehabilitation database, which includes duration of stay and services provided during inpatient rehabilitation; the home care database, which includes information on services provided as part of home care; the long-term care database, which includes information on long-term care residence; the Immigration, Refugees and Citizenship Canada Permanent Resident database, which includes data on immigration status; and the census-linked postal code files, which includes data on neighborhood-level income and rural residence. We included only those eligible for provincial health insurance 1 year before the index date to calculate costs in the year before the index events. We excluded individuals residing in long-term term care homes at the index date because their care needs may differ from those of community-dwelling adults.[9] We identified people with an index stroke event defined as a hospitalization or ED visit with the most responsible or main diagnosis of ischemic stroke (*International Statistical Classification of Diseases and Related Health Problems, Tenth Revision*, codes H34.1, I63.x, and I64.x) or ICH (*International Statistical Classification of Diseases and Related Health Problems, Tenth Revision*, code I61.x), between January 1, 2003, and March 31, 2018. This definition has high sensitivity and specificity.[10] If an individual had an ED visit leading to hospitalization, we included the date of hospitalization as the index date (Table S2). We only included the first event as the index event in individuals with multiple events during the study period, and data on recurrent strokes during the follow-up period were used for the purposes of calculating costs. To account for baseline health care costs, we matched each patient with stroke (exposed) to another person without stroke from the general population (control). We performed a 1:1 hard match on the following key variables: age (within 1 year), and age <65 and ≥65 years, sex, neighborhood-level income quintile, rural residence, immigration status, Charlson comorbidity index, and specific comorbidities (hypertension, diabetes, high cholesterol, congestive heart failure, atrial fibrillation, chronic obstructive pulmonary disease, asthma, and dementia; see Table S1 for definitions). These comorbidities were identified in the exposed and controls using similar look back windows from the cohort start date. Controls were required to have at least 1 health care contact during the case ascertainment window. We censored controls if they developed stroke. We calculated a lag time (ie, time from the beginning of the study accrual period, January 1, 2003) to the index date of stroke and reviewed the distribution of these times. For each control, we randomly assigned a lag time based on the distribution of lag times of exposed such that index date for the exposed and the controls were close to each other.

Social Determinants of Health

We were interested in identifying health care costs within strata defined by different social determinants of health. We focused on age, sex, immigration status (those born outside of Canada and arriving in 1985 or later defined as immigrants), neighborhood-level income (expressed as quintiles), and rural residence (living in dissemination areas with population <10 000 people).

Population Attributable Costs

We calculated direct costs of health care incurred by the government-funded health system as a result of patient encounters with the health care system. All direct patient-level health care costs borne by the public third-party payer, the Ontario Ministry of Health and Long-Term Care, were estimated using a costing algorithm, which uses a bottom-up/micro-costing approach to cost services at the patient level. Given Ontario's public health insurance system, private marketplace providers rarely set prices; therefore, costs/amounts paid by the third-party payer were used. Where individual unit costs were unavailable (eg, long-term care), a top-down approach, which allocates aggregate costs to individual visits or cases/episodes of care, was used. Costs captured by the algorithm account for over 90% of all government-paid health care services. Further details on the costing methodology can be found elsewhere.[11] We inflated health care costs to 2021 CADs, where 1 CAD=0.76 US dollar (June 26, 2023).[12] Costs were obtained by tracking health care encounters of the exposed and controls in the year before the index date and the year after the index date.

To obtain attributable costs, we used a difference-in-differences approach.[13] The first difference is the difference in the mean health care costs in the year before and the year after among the exposed (people with stroke) and the second difference is the difference in the mean health care costs in the year before and after the index date among controls. The difference of these differences provides the population attributable costs of stroke (Figure 1). This method provides net attributable costs of stroke, such that if we were to prevent 1 stroke, the cost savings would be of this amount.

We performed various analyses to address our research questions. First, we estimated cumulative costs using a phase-based method[14] using the following 3 phases poststroke: acute (daily costs for first 7 days), subacute (weekly costs from 7 to 90 days), and chronic (monthly costs from 91 to 365 days), which were selected based on understanding of typical phases of stroke care. We presented the cumulative costs among cases and controls using cumulative costs curves. We also presented these costs across different health sectors. Second, we presented the survival probability from the index date up to 1 year using the Kaplan-Meier curves in cases and controls. Cases and controls were matched on various predictors of poststroke mortality, and so we did not need further adjustment of covariates.[15] We accounted for censoring due to loss to follow-up using 4 different estimators: available sample estimator, complete-case estimator, weighted complete-case estimator, and weighted available sample estimator. These estimators have been previously proposed and evaluated, and each uses a different methodology to account for right censoring when estimating costs.[16] We reported the population attributable costs of stroke using a weighted available sample estimator.[16] Third, we evaluated the attributable costs of stroke across stroke types (ischemic stroke versus ICH) and different social determinants of health. Because

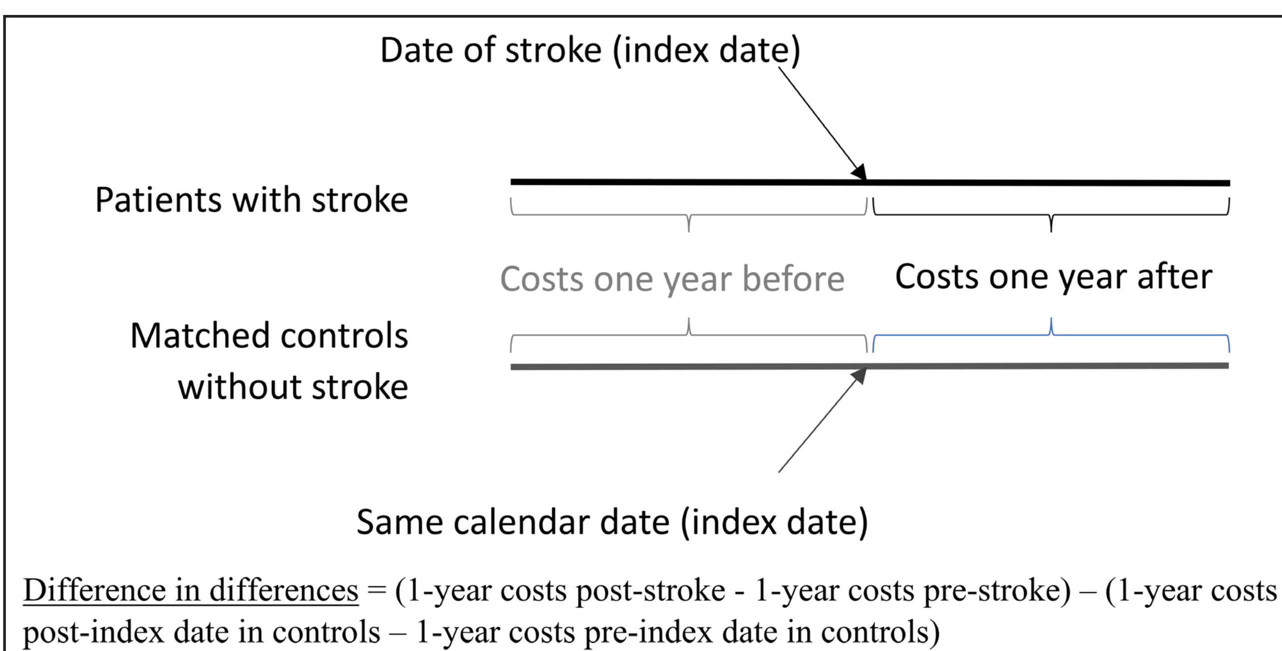

Figure 1. Difference-in-differences method to calculate attributable costs of stroke.
Patients with stroke are matched 1:1 with controls without stroke on the following characteristics: age, sex, people >66 years of age, rural vs urban residence, neighborhood-level income quintiles, immigration status, Charlson comorbidity index, and comorbidities (hypertension, diabetes, dyslipidemia, atrial fibrillation, chronic obstructive pulmonary disease, congestive heart failure, asthma, and dementia).

costs are presented relative to a matched control, matched on key characteristics, we report only unadjusted estimates of the costs. Finally, for descriptive purposes, we performed an ad hoc sensitivity analysis to estimate the direct health care costs in the subset of patients with acute ischemic stroke who received thrombolysis between 2012 and 2018 but did not calculate attributable costs as we did not have matched controls.

Because the costs are right skewed, all costs were reported using the mean along with 95% CIs and median and the 95th percentile of attributable costs. Only <0.1% people had missing data for neighborhood-level income (there were no missing data otherwise) and missing neighborhood-level income was entered as a separate category when matching. All analyses were performed using SAS, version 9.4.

RESULTS

Our cohort population included 4 536 248 individuals of whom 185 372 had a stroke during the ascertainment period (Figure S1). People who had a stroke were older and had more comorbid conditions than those without stroke (Table). We were able to match 185 271 cases of stroke with 185 271 controls such that the baseline differences in the covariates of interest were absent after the matching process (Table).

The mean health care costs in the year pre-index date were \$12 521 in the exposed and \$12 705 in the controls, whereas the mean costs in the year post-index date were \$46 899 in the exposed and \$13 561 in the controls. Using the difference-in-differences method, the mean 1-year attributable costs of stroke were \$33 522 (95% CI, \$33 231–\$33 813). The median 1-year attributable costs of stroke were \$17 261 and \$108 653 in the 95th percentile. Given the low rates of right censoring in our cohort (<0.5% in cases and controls), the mean attributable costs of stroke after accounting for right censoring among cases and controls using the weighted available sample estimator did not change significantly, \$33 418 (\$33 128–\$33 709), with no change in the estimates across the 4 estimators.

The 1-year mortality in cases (patients with stroke) was significantly higher than in controls (26.8% versus 6.9%; $P<0.001$; Figure 2). There was a marked increase in cumulative costs in patients with stroke compared with

Table. Baseline Characteristics of the Cohort Before and After Matching Exposed (People With Stroke) and Controls (People Without Stroke)

	Before matching			After matching		
	No stroke	Stroke	Std diff	No stroke	Stroke	Std diff
Characteristics	n=4 350 876	n=185 372		n=185 271	n=185 271	
Female, n (%)	2 293 603 (52.7)	92 587 (49.9)	0.06	92 537 (49.9)	92 537 (49.9)	0.00
Mean age (SD), y	61.69 (11.58)	74.40 (11.77)	1.09	74.27 (11.64)	74.40 (11.76)	0.01
People >66 y, n (%)	1 581 442 (36.3)	144 282 (77.8)	0.92	144 198 (77.8)	144 198 (77.8)	0.00
Residing in rural Ontario, n (%)	588 865 (13.5)	26 858 (14.5)	0.03	26 775 (14.5)	26 775 (14.5)	0.00
Neighborhood-level income quintiles, n (%)						
First (lowest)	783 647 (18.0)	42 504 (22.9)	0.12	42 478 (22.9)	42 478 (22.9)	0.00
Second	863 591 (19.8)	40 124 (21.6)	0.04	40 116 (21.7)	40 116 (21.7)	0.00
Third	864 024 (19.9)	36 213 (19.5)	0.01	36 191 (19.5)	36 191 (19.5)	0.00
Fourth	891 039 (20.5)	34 057 (18.4)	0.05	34 041 (18.4)	34 041 (18.4)	0.00
Fifth (highest)	948 575 (21.8)	32 474 (17.5)	0.11	32 445 (17.5)	32 445 (17.5)	0.00
Immigrant, n (%)	440 204 (10.1)	12 310 (6.6)	0.13	12 224 (6.6)	12 224 (6.6)	0.00
Charlson comorbidity index, n (%)						
0	2 331 969 (53.6)	4940 (2.7)	1.37	4931 (2.7)	4938 (2.7)	0.00
1	925 333 (21.3)	38 104 (20.6)	0.02	40 141 (21.7)	38 097 (20.6)	0.03
2	493 968 (11.4)	33 003 (17.8)	0.18	31 393 (16.9)	32 993 (17.8)	0.02
≥3	517 075 (11.9)	109 277 (59.0)	1.13	108 754 (58.7)	109 196 (58.9)	0.01
Comorbidities, n (%)						
Hypertension	1 933 114 (44.4)	148 719 (80.2)	0.80	149 661 (80.8)	148 628 (80.2)	0.01
Diabetes	730 405 (16.8)	62 468 (33.7)	0.40	59 333 (32.0)	62 435 (33.7)	0.04
Dyslipidemia	179 280 (4.1)	19 228 (10.4)	0.24	16 794 (9.1)	19 218 (10.4)	0.04
Atrial fibrillation	161 008 (3.7)	32 558 (17.6)	0.46	29 016 (15.7)	32 513 (17.5)	0.05
COPD	210 709 (4.8)	25 147 (13.6)	0.31	22 757 (12.3)	25 135 (13.6)	0.04
CHF	167 203 (3.8)	34 518 (18.6)	0.48	31 196 (16.8)	34 481 (18.6)	0.05
Asthma	339 701 (7.8)	17 052 (9.2)	0.05	14 335 (7.7)	17 047 (9.2)	0.05
Dementia	103 108 (2.4)	23 045 (12.4)	0.39	20 464 (11.0)	23 032 (12.4)	0.04

CHF indicates congestive heart failure; COPD, chronic obstructive pulmonary disease; and Std diff, standardized difference.

the controls in the first 90 days (from $2239 to $29 192; Figure 2; Figure S2). As expected, mean attributable costs of inpatient acute care ($15 872; $15 639–$16 051) and inpatient rehabilitation services ($7215; $7140–$7291) were the main drivers of attributable costs, whereas costs associated with long-term care ($1215; $1165–$1265), home care ($892; $858–$926), and ED care ($589; $554–$624) contributed less to the attributable costs of stroke in the first year (Figure 3; Figures S3 through S5).

The mean attributable costs of ICH were higher ($40 244; S39 193–$41 294) than for ischemic stroke ($32 547; $32 252–$32 843; Figure 4). Compared with costs for all patients with stroke ($33 522), the mean 1-year attributable costs of stroke were higher among immigrants ($40 554; $39 316–$41 793), those aged <65 years ($35 175; $34 533–$35 818), and those residing in the lowest neighborhood-level income quintile ($34 687; $34 054–$35 320) and were lower among rural residents ($29 047; $28 362–$29 731) and female patients ($32 857; $32 455–$33 259; Figure 4; Table S3). The variations in the attributable costs across social determinants were driven by the variation where the costs were incurred: higher inpatient acute care costs among immigrants and those residing in low-income neighborhoods and lower inpatient rehabilitation costs among those residing in rural Ontario and female patients (Figure 4). Finally, the mean 1-year direct (not attributable) health care costs in patients with acute ischemic stroke who received thrombolysis (n=7211) were estimated to be $53 541 ($52 228–$54 854).

DISCUSSION

Using data on over 180 000 community-dwelling patients with first-ever strokes, and accounting for baseline health care costs in people at risk for stroke, we found that the mean 1-year attributable costs of stroke were $33 522 CAD. With ≈60 000 strokes annually in Canada,[17] and assuming the same mean costs across all Canadians with stroke, the total annual attributable costs of stroke would be 2 billion CADs in the first year after stroke or ≈0.8% of the total health spending in 2021 (0.1% of Canada's gross domestic product).

A systematic review of studies evaluating stroke-related costs found that most studies did not account for mortality poststroke.[18] A prior study in Canada found that the mean direct costs of stroke in the first year after stroke were higher in those alive at 1 year than those who died within the first year.[6] This is important because cumulative costs are no longer incurred after death. However, costs stratified by survival status are difficult to interpret when thinking of the cost-benefit analyses of an intervention aimed at improving survival or preventing the index event. Our study overcomes these limitations by using a phase-based costing method to account for high poststroke mortality, and we showed that attributable costs were the highest in the first 90 days from stroke onset. Further, we showed that due to low rates of right censoring when using health administrative data, attributable costs of stroke do not change significantly by using weight-based estimators. Our finding of higher attributable costs of ICH compared with ischemic stroke is similar to previously published literature, likely explained by an increased need for intensive care unit care and other life-sustaining interventions such as mechanical ventilation or neurosurgical procedures.[19,20] We also found that the biggest driver of stroke-related costs was acute inpatient care, where costs are higher for ICH than ischemic stroke.[21]

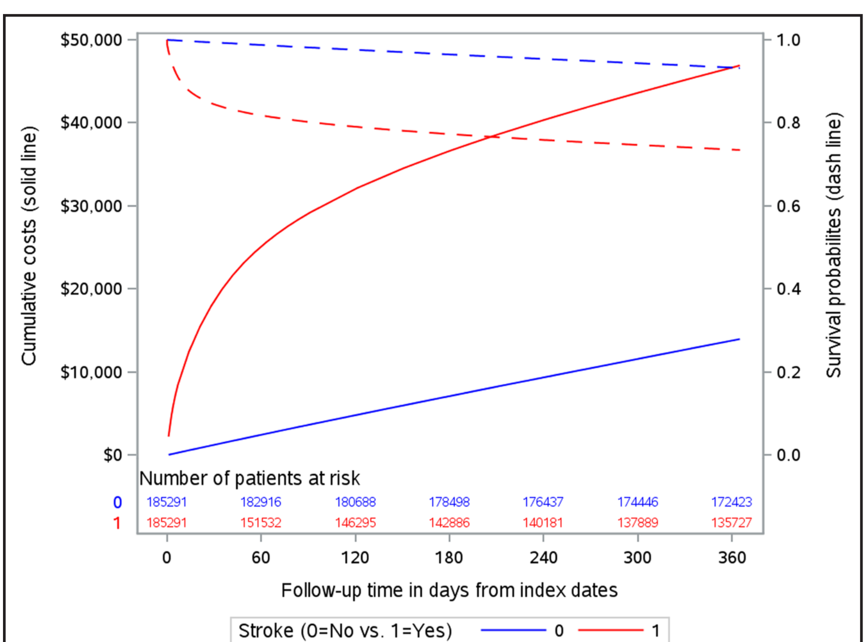

Figure 2. One-year cumulative direct health care costs and 1-year overall survival in cases, that is, people with stroke (red) and controls, that is, those without stroke (blue) in Ontario, Canada.

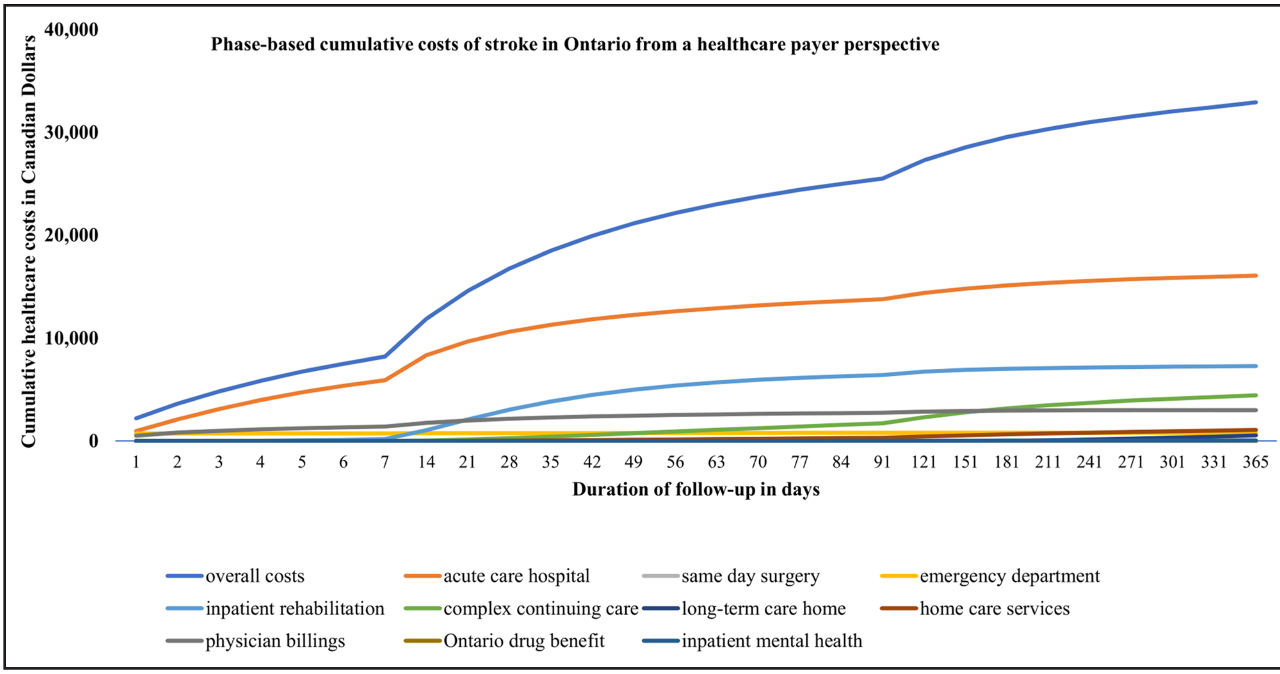

Figure 3. Distribution of 1-year cumulative attributable costs of stroke across 3 different phases as a result of various health sector encounters.

Cumulative costs calculated using phase-based system of accumulating costs: daily costs for days 0 to 7: weekly costs for days 8 to 90; and monthly costs for days 91 to 365.

Compared with the overall population, the attributable costs of stroke varied based on sex, age at the time of stroke, immigration status, neighborhood-level income, and rural residence. In a recent study in the United States, social determinants measured at a county level such as racial and ethnic segregation and poverty and income inequality were important contributing factors for higher costs associated with cardiovascular disease.[22] In 1 prior study on sex differences in direct health care costs of stroke, higher unadjusted costs of stroke were found in female compared with male patients; however, these were lower after adjusting for comorbidities.[6] A systematic review on poststroke care costs across different health segments found inpatient rehabilitation to be the

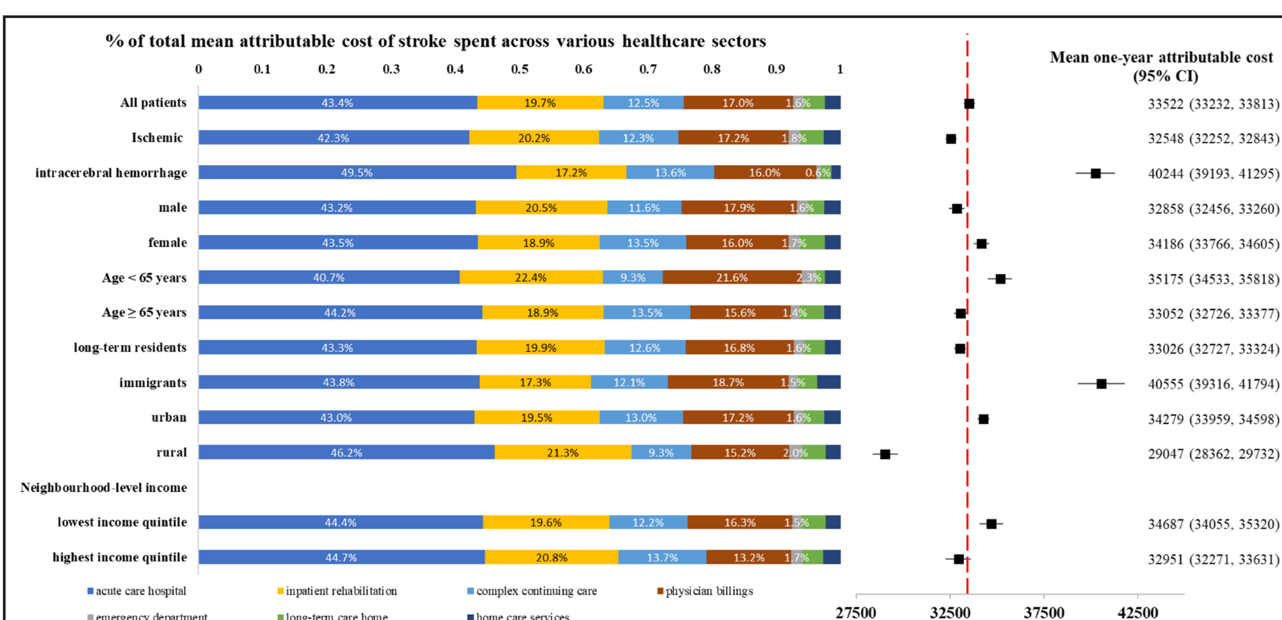

Figure 4. Variation in the mean 1-year attributable cost of stroke (red dotted line for overall mean cost) in Ontario, Canada, across different social determinants of health.

main driver of costs,[21] and sex differences in the receipt of inpatient rehabilitation are not well-known.[23] Thus, it may be important to further investigate sex differences in the duration and type of rehabilitation poststroke. Compared with nonimmigrants, immigrants are younger at the time of the stroke and more likely to receive life-sustaining treatments, which may be associated with the observed higher acute inpatient care and complex continuing care costs in the year after stroke in immigrants.[24] In Ontario and other jurisdictions, residing in rural areas has been associated with lower rates of endovascular therapy for ischemic stroke and poststroke rehabilitation, which has in turn been associated with worse outcomes and greater mortality, potentially lowering the overall costs.[25–27] Thus, from a health equity perspective, it is important to ensure access to life-saving hyperacute stroke therapies for those in rural residence. Lastly, prior work in Ontario has not found differences in acute stroke care, length of acute care hospital stay, or discharge destination based on area-level socioeconomic status,[28] but those residing in the most materially deprived neighborhoods were found to have higher stroke costs compared with those in the least deprived neighborhoods,[7] suggesting a need for further work to understand these differences in costs.

Direct comparisons of costs across these social determinants require cautious interpretation because stroke type, stroke severity, and outcomes (mortality and disability) after stroke may vary with age, sex, rural residence, socioeconomic status, and other factors.[24,29,30] However, comparisons to costs in the overall population are reasonable because disease-specific factors such as stroke type and severity could be considered in the causal pathways through which these social determinants may influence risk of stroke and stroke care.[31,32] Also, lower attributable costs have been associated with poorer access to care and outcomes in New Zealand,[27] and future studies should explore similar association in other settings. From a health system perspective, understanding the attributable costs of stroke and their variations based on social determinants can help make a case to implement potentially expensive, yet successful, preventive integrated care programs for all.[33,34] While we report on the variation in costs across specific social determinants of health, future work using intersectional quantitative approaches is required to understand how these determinants intersect and influence care and costs.

Certain limitations merit discussion. Our definitions of incident stroke were based on hospitalizations or ED visits and could miss minor strokes. We also excluded subarachnoid hemorrhage and transient ischemic attacks, as well as recurrent stroke events, which will lead to underestimation of the total burden of stroke at a population level.[35] Long-term care home residents were excluded, which limits the generalizability of our findings to people who have a stroke when they are living in the community. The costs presented here are based on service fees set by Ontario's provincial insurance plan and may not reflect the costs incurred in other countries or jurisdictions. We could not evaluate differences in costs of subgroups of patients based on stroke severity or receipt of hyperacute treatments, as our data sources did not have information on stroke severity or on indications for revascularization. While patients with stroke and stroke-free controls were matched on key comorbidities, residual differences may exist between those with and without stroke. This study focuses on costs from the public health care payer perspective and does not include patient or family out-of-pocket expenses that can occur due to medication use (in those who are not <65 years of age and not on disability), certain outpatient rehabilitation services, or caregiver supports, either through paid support workers or unpaid family caregiving[36]; the costs also do not account for lost productivity among stroke survivors.[37] Lastly, we did not have information on other social determinants of health such as ethnicity or homelessness

CONCLUSIONS

The health care costs attributable to stroke are high, even after accounting for baseline health care costs and poststroke mortality. These costs are primarily incurred in acute inpatient hospitals and rehabilitation facilities and vary by sex, immigration status, neighborhood-level income, and rural versus urban residence. Reducing stroke incidence through optimal stroke preventive care offers the best hope for substantial cost savings.[38]

ARTICLE INFORMATION

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Affiliations

Division of Neurology, Department of Medicine (M.V.V., A.Y.X.Y.), Institute of Health Policy, Management and Evaluation, Dalla Lana School of Public Health (M.V.V., C.d.O., P.C.A., A.Y.X.Y., M.K.K.), and Division of General Internal Medicine, Department of Medicine (M.K.K.), University of Toronto, Canada. Health Economics, Centre for Addictions and Mental Health, Toronto, Canada (C.d.O.). Division of Neurology, Li Ka Shing Knowledge Institute, St. Michael's Hospital-Unity Health Toronto, Canada (M.V.V.). ICES, Toronto, Canada (M.V.V., J.F., C.d.O., P.C.A., A.Y.X.Y., M.K.K.). Sunnybrook Research Institute, Sunnybrook Health Sciences Centre, Toronto, Canada (A.Y.X.Y.).

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Supplemental Material

Figures S1–S5
Tables S1–S3

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