Previous research has found decreased mortality rates among hospitals/providers that treat high volumes of patients for specific surgical and medical conditions. This relationship is often considered as a proxy measure of quality and evidence to support regionalization of a particular procedure or medical condition. The degree of association between hospital volume with outcomes among patients with ischemic stroke (IS) volume and 30-day mortality to inform regionalization planning.

Methods and Results—Using a population-based hospital discharge administrative database (2005/2006 to 2011/2012), average annual IS patient volumes were calculated for 162 Ontario acute hospitals. Hospitals were ranked and classified as small (<126), medium (126–202), and large (>202). Hierarchical multivariable logistic regression was used to estimate the odds of death within 7 and 30 days to account for the homogeneity in outcomes for patients treated at the same hospital. Overall, 73,368 patients were hospitalized for IS, and 30-day mortality was 15.3%. The mean (±SD) of annual hospitalizations for IS was 29 (31) for small-volume hospitals, 156 (20) for medium-volume hospitals, and 300 (78) for high-volume hospitals. High-volume hospitals admitted younger patients (mean [±SD] age, 73.0 [13.9] years) compared with medium- and small-volume hospitals (74.0 [13.2] and 75.5 [12.5] years, respectively; P<0.0001). Patients at small-volume hospitals were more likely than patients at high-volume hospitals to die at 30 days after an acute IS (adjusted odds ratio, 1.37; 95% confidence interval, 1.14–1.65).

Conclusions—Hospital IS volume is associated with 30-day mortality in Ontario. Patients admitted to hospitals with annual IS volumes <126 annually are more likely to die within 30 days than patients admitted to hospitals that see on average 300 patients annually. This finding supports centralizing care in stroke-specialized hospitals. (Circ Cardiovasc Qual Outcomes. 2015;8:S141-S147. DOI: 10.1161/CIRCOUTCOMES.115.002079.)

Key Words: epidemiology ■ health services research ■ hospitals ■ outcome assessment (health care) ■ stroke volume

Does the Volume of Ischemic Stroke Admissions Relate to Clinical Outcomes in the Ontario Stroke System?

Ruth E. Hall, MSc, PhD; Jiming Fang, PhD; Kathryn Hodwitz, BA; Gustavo Saposnik, MD, MSc; Mark T. Bayley, MD

Background—Better outcomes have been found among hospitals treating higher volumes of patients for specific surgical and medical conditions. We examined hospital ischemic stroke (IS) volume and 30-day mortality to inform regionalization planning.

Methods and Results—Using a population-based hospital discharge administrative database (2005/2006 to 2011/2012), average annual IS patient volumes were calculated for 162 Ontario acute hospitals. Hospitals were ranked and classified as small (<126), medium (126–202), and large (>202). Hierarchical multivariable logistic regression was used to estimate the odds of death within 7 and 30 days to account for the homogeneity in outcomes for patients treated at the same hospital. Overall, 73,368 patients were hospitalized for IS, and 30-day mortality was 15.3%. The mean (±SD) of annual hospitalizations for IS was 29 (31) for small-volume hospitals, 156 (20) for medium-volume hospitals, and 300 (78) for high-volume hospitals. High-volume hospitals admitted younger patients (mean [±SD] age, 73.0 [13.9] years) compared with medium- and small-volume hospitals (74.0 [13.2] and 75.5 [12.5] years, respectively; P<0.0001). Patients at small-volume hospitals were more likely than patients at high-volume hospitals to die at 30 days after an acute IS (adjusted odds ratio, 1.37; 95% confidence interval, 1.14–1.65).

Conclusions—Hospital IS volume is associated with 30-day mortality in Ontario. Patients admitted to hospitals with annual IS volumes <126 annually are more likely to die within 30 days than patients admitted to hospitals that see on average 300 patients annually. This finding supports centralizing care in stroke-specialized hospitals. (Circ Cardiovasc Qual Outcomes. 2015;8:S141-S147. DOI: 10.1161/CIRCOUTCOMES.115.002079.)

Key Words: epidemiology ■ health services research ■ hospitals ■ outcome assessment (health care) ■ stroke volume

Previous research has found decreased mortality rates among hospitals/providers that treat high volumes of patients for specific surgical and medical conditions. This relationship is often considered as a proxy measure of quality and evidence to support regionalization of a particular procedure or medical condition. The degree of association between mortality and volume varies substantially by condition and procedure,1 and although this relationship has been examined for many surgical procedures, studies in medical conditions, such as congestive heart failure, myocardial infarction, pneumonia, cancer,2–4 and stroke, are limited.5–10

Our objective was to examine the relationship of hospital volume with outcomes among patients with ischemic stroke (IS) to inform regional stroke care planning given the increasing concern for the growing costs of medical care and the need to establish stroke units. Stroke units are complex, requiring several key features, including a dedicated multidisciplinary team with expertise in stroke care, and are associated with lower mortality and disability after an acute stroke.11 Maintaining clinical expertise, defined as the proficiency and judgment that clinicians acquire through clinical experience and clinical practice, requires regular engagement in care of this specialized population.12 Therefore, we hypothesized that to sustain this stroke infrastructure and expertise, higher hospital patient volumes are required and be associated with better outcomes.

Methods

Data Sources and Sample

The Canadian Institute for Health Information (CIHI) Discharge Abstract Database (DAD) housed at the Institute for Clinical Evaluative Sciences was used to identify all adult IS separations (>18 years) at 162 acute hospitals in the province of Ontario between April 1, 2005, and March 31, 2012. We excluded in-hospital strokes and elective admissions. A secondary analysis was conducted excluding hospitals with IS volumes <15 per year.
WHAT IS KNOWN

- Hospital volume–outcome relationships among many surgical and cardiac populations have found higher volumes to be associated with better outcomes.
- Better patient outcomes and quality of care have been associated with higher volumes.

WHAT THE STUDY ADDS

- This study uses more contemporary data targeting stroke outcomes from a publicly funded health system less subject to funder preferences.
- We have shown patients admitted to hospital admitting <126 patients with ischemic stroke per year are more likely to die than patients seen at high-volume hospitals.
- Volume thresholds were established for a regionalization strategy for stroke care.

Patients with IS were identified if the most responsible diagnosis code was International Classification of Diseases 10th version (ICD-10-CA) I63, (excluding I63.6), I64, or H34.1. We took the first IS event for each individual in each fiscal year. We linked patient records to the Ontario Registered Persons Database using an encrypted health card number to identify all-cause mortality at 7 and 30 days from admission. All hospitals in Ontario are required to submit data into the CIHI-DAD. CIHI performs routine data quality checks for most mandatory data fields, and records with errors are sent back to hospitals for correction and routinely used for health services research in Ontario.13,14 The Registered Persons Database was used to identify death at 7 and 30 days from the index IS admission.

Risk factors and comorbidities were identified in the CIHI-DAD based on the acute IS diagnosis. The CIHI-DAD has ≤25 diagnostic code fields, not all are required to be entered and fields and are also used to capture postadmission conditions; however, we did not include those that arose during the hospitalization given the DAD has a diagnosis type identifier to differentiate between pre-existing conditions and those that occurred during admission.11 The ICD-10-CA codes for risk factors and comorbidities are found in Appendix I in the Data Supplement.

Ethics

This study was approved by the Institute for Clinical Evaluative Sciences and the Sunnybrook Health Sciences Center Research Ethics Board and done without the subjects giving informed consent because Institute for Clinical Evaluative Sciences is named as a prescribed entity under provincial privacy legislation.

Statistical Analysis

The average annual IS volume was determined for each hospital by dividing the total number of patients with IS discharged during the 7-year study period. Hospitals were ranked based on average annual IS volumes and stratified into terciles with approximately one third of patients in each tercile. Hospitals were classified as small (<126 patients with IS per year), medium (126–202 cases per year), or high (>202 patients with IS per year) volume to describe the association between hospital IS volume and all-cause mortality at 7 and 30 days.

Differences in baseline characteristics were examined across terciles using 1-way ANOVA for continuous variables and χ² tests for categorical variables. We used a modified version of Get With the Guidelines IS 30-day mortality model10 and included year, patient age status, stroke center, and teaching status of the hospital to calculate each facility’s risk-adjusted 7-day and 30-day IS mortality rates.

Adjusted odds ratios (ORs) of terciles were estimated using hierarchical multivariable logistic regression to account for the homogeneity in outcomes for patients treated at the same hospital with each hospital having its own intercept. The association between mortality and hospital volumes was expressed as the OR and 95% confidence interval.

Analysis of optimal cut-off points or volume threshold was done by plotting the receiver operating characteristic curve and finding the maximal Youden index13 for each corresponding point. We also visually inspected the risk-adjusted mortality rates across all hospitals for natural breakpoints. SAS version 9.2 was used for all analyses.

Results

Acute care hospitals in Ontario discharged 73,368 patients with IS between April 1, 2005, and March 31, 2012. The overall 7- and 30-day mortality rates were 7.6% and 15.3%, respectively. The average annual patients with IS in each tercile are shown in Table 1. In the lowest tercile, hospitals saw an average of 29 patients with IS per year ranging from 1 to 120 patients; in the medium-volume tercile, an average of 155 patients ranging from 126 to 202 cases per year, and in the highest tercile, hospitals admitted on average 300 cases per year. The numbers of hospitals in each tercile were 125, 25, and 12, respectively. The average annual IS patient volume across the 162 centers ranged from 1 to 469 patients per year. Of the 162 hospitals in Ontario, 28 (17.3%) are designated stroke centers and of the 28 designated stroke centers, 8 (28.5%) are considered small-volume hospitals (<126 patients with IS). Designated stroke centers are facilities with written stroke protocols (eg, transport and triage), neuroimaging capacity, deliver thrombolytic therapy, clinicians with stroke expertise, and linkages to rehabilitation and secondary prevention clinics with 9 having neurosurgical facilities and interventional radiology. Of the 12 high-volume hospitals, all but one is a designated stroke center and more likely teaching hospitals compared with medium or small hospitals.

Patient characteristics across hospital volume categories are presented in Table 2. The small- and medium-volume hospitals had fewer patients arriving by ambulance compared with the highest volume hospitals (61.4%, 64.6%, versus 70.3%; P<0.0001). Similarly, the smaller and medium volume hospitals had a higher proportion of patients aged ≥75 years compared with the high-volume hospitals (60.6% and 55.9% versus 53.6%; P<0.0001). The patients admitted to high-volume hospitals were more likely to have atrial fibrillation, hypertension, carotid disease, and hyperlipidemia (P<0.0001).

Overall, the 7-day and 30-day risk-adjusted mortality rates for the 7-year period were 7.6% and 15.3%, respectively. Patients cared for in small-volume hospitals have 32% and 27% higher 7- and 30-day mortality rates, respectively, relative to patients cared for in a high-volume hospital. There was no statistically significant difference in 7-day and 30-day mortality rates between medium- and high-volume hospitals. Observed 7-day and 30-day mortality rates decreased as hospital IS volume increased 9.0%, 7.1%, and 6.8% and 17.5%, 14.8%, and 13.8%, respectively, (P=0.0001 and 0.0001).

The risk-adjusted OR for 7 and 30-day mortality rates for each hospital volume tercile is shown in Table 3. There was a statistically significant difference in risk-adjusted mortality between small-volume hospitals and high-volume hospitals,
and no statistically significant difference between medium- and high-volume hospitals for both 7- and 30-day mortality rates. Patients admitted to small-volume hospitals had 47% and 37% higher odds of death at 7 and 30 days after an acute stroke compared with patients admitted to high-volume hospitals. The secondary analysis excluding hospitals with <15 IS discharges per year revealed consistent results and, not unexpectedly, an attenuated volume effect. To further describe the outcome–volume relationship, we examined the average annual hospital IS volume and 30-day risk-adjusted

Table 1. Hospital Characteristics by Hospital Volume

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Small Volume</th>
<th>Medium Volume</th>
<th>High Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of hospitals</td>
<td>162</td>
<td>125</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>% of hospital</td>
<td>100</td>
<td>77.1</td>
<td>15.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Mean volume±SD</td>
<td>69.0±87.0</td>
<td>29.3±30.7</td>
<td>156.3±20.1</td>
<td>299.7±77.9</td>
</tr>
<tr>
<td>Median volume (IQR)</td>
<td>28 (10–102)</td>
<td>15 (8–42)</td>
<td>155 (143–165)</td>
<td>290 (236–357)</td>
</tr>
<tr>
<td>Minimum</td>
<td>1</td>
<td>1</td>
<td>126</td>
<td>206</td>
</tr>
<tr>
<td>Maximum</td>
<td>469</td>
<td>120</td>
<td>202</td>
<td>469</td>
</tr>
<tr>
<td>Designation (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional stroke center*</td>
<td>9 (6)</td>
<td>0 (0)</td>
<td>2 (8)</td>
<td>7 (58)</td>
</tr>
<tr>
<td>District stroke center†</td>
<td>19 (12)</td>
<td>8 (6)</td>
<td>7 (28)</td>
<td>4 (33)</td>
</tr>
<tr>
<td>Nondesignated center‡</td>
<td>134 (83)</td>
<td>117 (94)</td>
<td>16 (64)</td>
<td>1 (8)</td>
</tr>
<tr>
<td>Teaching hospital§</td>
<td>15 (9.3)</td>
<td>5 (4)</td>
<td>4 (16)</td>
<td>6 (50)</td>
</tr>
</tbody>
</table>

*A facility that meets all the requirements of a district stroke center and has neurosurgical facilities and interventional radiology.
†A facility with written stroke protocols (eg, transport and triage, thrombolytic therapy, and neuroimaging), clinicians with stroke expertise, and linkages to rehabilitation and secondary prevention.
‡An acute care hospital that does not fit the definition of district or regional stroke center.
§University-affiliated facilities; members of the Council of Academic Hospitals of Ontario.

Table 2. Characteristics of Patients With Ischemic Stroke by Hospital Volume

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Small Volume</th>
<th>Medium Volume</th>
<th>High Volume</th>
<th>χ² P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>73,368</td>
<td>24,321</td>
<td>25,094</td>
<td>23,953</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Women, %</td>
<td>50.4</td>
<td>51.6</td>
<td>50.9</td>
<td>48.6</td>
<td></td>
</tr>
<tr>
<td>Age groups, y, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>18–49</td>
<td>5.3</td>
<td>3.8</td>
<td>5.4</td>
<td>6.6</td>
<td></td>
</tr>
<tr>
<td>50–64</td>
<td>17.1</td>
<td>15.0</td>
<td>17.4</td>
<td>18.8</td>
<td></td>
</tr>
<tr>
<td>65–74</td>
<td>20.9</td>
<td>20.6</td>
<td>21.2</td>
<td>21.0</td>
<td></td>
</tr>
<tr>
<td>75+</td>
<td>56.7</td>
<td>60.6</td>
<td>55.9</td>
<td>53.6</td>
<td></td>
</tr>
<tr>
<td>Risk factors, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>19.3</td>
<td>17.1</td>
<td>18.4</td>
<td>22.6</td>
<td></td>
</tr>
<tr>
<td>Past history of stroke/TIA</td>
<td>2.4</td>
<td>1.4</td>
<td>2.7</td>
<td>3.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Past history of CAD</td>
<td>13.8</td>
<td>12.8</td>
<td>13.8</td>
<td>14.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Past history of carotid disease</td>
<td>3.3</td>
<td>2.4</td>
<td>3.2</td>
<td>4.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>26.3</td>
<td>25.2</td>
<td>27.6</td>
<td>25.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>2.0</td>
<td>2.2</td>
<td>1.7</td>
<td>2.1</td>
<td>0.0012</td>
</tr>
<tr>
<td>Hypertension</td>
<td>49.3</td>
<td>44.2</td>
<td>48.8</td>
<td>54.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Hyperlipidemia</td>
<td>9.3</td>
<td>6.7</td>
<td>8.0</td>
<td>13.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Comorbid conditions, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CHF</td>
<td>2.4</td>
<td>2.2</td>
<td>2.5</td>
<td>2.6</td>
<td>0.0447</td>
</tr>
<tr>
<td>Cancer</td>
<td>1.3</td>
<td>1.2</td>
<td>1.4</td>
<td>1.5</td>
<td>0.0439</td>
</tr>
<tr>
<td>Renal disease</td>
<td>3.4</td>
<td>2.8</td>
<td>3.9</td>
<td>3.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Liver disease</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1572</td>
</tr>
<tr>
<td>Arrival by ambulance</td>
<td>65.4</td>
<td>61.4</td>
<td>64.6</td>
<td>70.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>7-d mortality</td>
<td>7.6</td>
<td>9.0</td>
<td>7.1</td>
<td>6.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>30-d mortality</td>
<td>15.3</td>
<td>17.5</td>
<td>14.8</td>
<td>13.8</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

CAD indicates coronary artery disease; CHF, congestive heart failure; and TIA, transient ischemic attack.
mortality rate for all 123 hospitals in the Figure. The 30-day risk-adjusted mortality rate varied from 0% to 56.1%. Of the 28 designated stroke centers, only 1 had 30-day risk-adjusted mortality rate significantly higher than the provincial average of 15.4% and is considered a small-volume hospital.

Analysis to explore potential volume thresholds revealed 2 potential points. The Figure illustrates a natural volume threshold that seems to be an annual IS volume of 165 given that the risk-adjusted 30-day mortality rates of all hospitals at or beyond 165 were at or below the provincial rate. Second, a receiver operating characteristic plot revealed that sensitivity, specificity, and the corresponding Youden index (>0.55) were maximized at an IS volume of 100.

Table 4 reports the number of deaths potentially avoided if patients treated at small-volume hospitals were referred to higher volume facilities using an average of the medium- and high-volume risk-adjusted mortality rates. Eight hundred and seventy-five deaths could potentially be avoided if patients seen at small-volume hospitals were referred to hospitals that admitted at least 126 patients with IS annually. This strategy would affect ≈42% of all admitted patients with IS per year to be cared for in 37 hospitals given an OR of 1 assigned to medium-volume hospitals.

### Discussion

We found that a higher mean IS hospital volume was associated with better outcomes measured by 7- and 30-day mortality rates. To our knowledge, this is one of the largest studies examining the relationship between hospital stroke patient volume with >73,000 patients with IS admitted to 162 hospitals for a 7-year period. In particular, patients admitted to hospitals that see on average <30 patients with IS per year were more likely than patients admitted to hospitals that see an average of 300 IS patients per year to die at 7 and 30 days after an acute IS (adjusted OR [95% confidence interval], 1.47 [1.13–1.91] and 1.37 [1.14–1.65], respectively). These associations remained in a secondary analysis excluding hospitals with <15 annual IS admissions per year. There is no significant difference in mortality rates between hospitals that see on average 156 patients with IS per year compared with hospitals that see 300 patients with IS per year. This could be explained by higher likelihood of admission to designated stroke centers where there are stroke protocols, resources, and expertise developed by regularly caring for patients with stroke although this does not entirely explain the findings for the whole group of hospitals. In fact, when we included an interaction term in the model, the volume–outcome relationship remained the same (P=0.21). Examining this association was important in the context of an upcoming change in the funding policy for Ontario acute hospitals that seeks to incentivize best practice stroke care. This work supports the recommendations for enhancing regionalized care to define volumes for designated stroke centers and provides estimates of potential avoided deaths. Our work identified 100 IS admissions and 165 IS admissions as break points associated with lower mortality rates.

The association between patient volume and outcomes has been reviewed in both the surgical and medical literature, demonstrating that higher volumes are associated with better outcomes. Outcome typically reported is mortality, and the magnitude of the association varies by condition and volume categories selected. Other studies that have examined hospital stroke volume and outcome relationship have shown no benefit in mortality across volume categories; however, most of these studies had few small-volume hospitals, and those considered small had volumes <250. Ogbu et al found similar results to our study when hospital quartiles were categorized as small volume being considered <50 patients, and a previous Canadian study found that only the highest volume quartile shows significantly lower mortality rates compared with the lowest quartile. The inconsistent results across countries suggest that the effect of patient volumes on outcomes may differ in each country and dependent on volume categories selected. Our findings support the centralization of stroke.
services into designated stroke centers where optimal clinical outcomes may be achieved when such services are provided in institutions with high institutional volumes (≥165 patients with IS per year) and well-established processes of care. It has been postulated that institutional characteristics such as high volume, experienced support staff, order sets, and protocols onsite may reduce the risk of adverse outcomes. A second possibility is that technological advances, including more widespread use of neuroimaging, tPA, and stroke unit care, have led to improvements in outcomes that may have minimized the difference between medium- and high-volume facilities on outcomes.

Several important differences exist between the American and Canadian healthcare settings that may affect the IS volume–outcome relationship. The US model has been characterized as a multipayer healthcare system with many hospitals and limited regionalization of stroke care. Determining the relationship between volume and outcomes in the US system may be obscured by other factors, such as ambulance preferences, socioeconomic differences, and insurance status. In contrast, Canada has a publicly funded healthcare system in which all patients face no financial barrier to seeking hospital care and hospitals face no financial gain from treating patients provides insights into the importance of expertise. Furthermore, in Ontario, a regionalized stroke system was established in 2001 and full implementation in 2005. Ontario with >13 million people is the most populous province in Canada and is divided

Table 4. Effects of a Volume-Based Referral Strategy on 30-Day Mortality

<table>
<thead>
<tr>
<th>Hospital Volume</th>
<th>&lt;126</th>
<th>126–202</th>
<th>&gt;202</th>
<th>Total No. of Potential Avoidable Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of hospitals</td>
<td>125</td>
<td>25</td>
<td>12</td>
<td>875</td>
</tr>
<tr>
<td>Total no. of patients</td>
<td>24321</td>
<td>25094</td>
<td>23953</td>
<td></td>
</tr>
<tr>
<td>30-day mortality, %</td>
<td>17.5</td>
<td>14.8</td>
<td>13.8</td>
<td></td>
</tr>
<tr>
<td>30-day risk-adjusted mortality, %</td>
<td>16.8</td>
<td>13.7</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td>No. deaths avoided†</td>
<td>875</td>
<td>...</td>
<td>...</td>
<td>875</td>
</tr>
</tbody>
</table>

*Adjusted for age, sex, ambulance arrival, atrial fibrillation, poststroke/transient ischemic attack, coronary artery disease or percutaneous coronary intervention or coronary artery bypass graft, carotid disease or carotid endarterectomy or carotid artery stenting, diabetes mellitus, hypertension, peripheral vascular disease, hyperlipidemia, patient emergency department triage status, hospital teaching status, stroke center, and year.

†By referring patients from small-volume hospitals to medium and highest volume hospitals.
into 11 stroke regions, and within each region, there are ambu-
lance bypass protocols and repatriation agreements between
the designated stroke centers and the non-designated hospitals.
Thus, redirecting patients is occurring in Ontario. However,
work is needed to achieve further redirecting of patients to hos-
pitals to build and sustain stroke unit care. A strategy to move
patients from small-volume hospitals to medium- and high-
volume hospitals is reasonable given ≥3500 patients with IS
per year across 37 hospitals is more realistic than redirecting
to the 12 high-volume hospitals, which would see an additional
300 patients with IS per year, doubling the current patient vol-
ume. All but 8 of 28 designated stroke centers have average
annual IS volumes ≥126 patients. Furthermore, stroke center
care was found to be independently associated with lower
mortality rate (adjusted OR [95% confidence interval], 0.83
[0.73–0.95]). However, transferring patients may not translate
the outcomes of patients now at smaller hospitals to the out-
comes reported at large hospitals because the delay in getting
to larger hospitals may offset some of the benefit observed for
larger hospitals. In Ontario, there are few communities with
travel distances >4.5 hours from any of these designated stroke
centers or hospitals with access to stroke expertise through
telemedicine. This suggests that given how Ontario’s popu-
lation is distributed redirecting to designated stroke centers with
expertise or access to expertise in stroke care is feasible.

Several limitations of this study must be acknowledged.
The analysis was performed using administrative data, and
therefore, it did not include detailed clinical and stroke sever-
ity patient characteristics. Risk-adjustment was based solely
on ICD-10 coding, and the c indices for mortality in our mod-
els (0.74, 0.74) are less than those reported using detailed
clinical databases (0.86–0.85).15,21 The risk factors and
comorbidities were identified from the acute IS admission,
and although the administrative inpatient hospital database
(DAD) has ≤25 diagnostic code fields, not all are required to
be entered. These fields are also used to capture postadmis-
sion conditions; however, we did not include those that arose
during the hospitalization given the DAD has a diagnosis type
identifier to differentiate between pre-existing conditions and
those that occurred during admission.22 In this analysis, the
only outcome that is evaluated was mortality. It is possible
that hospital volume may be related to the incidence of other
complications, including pneumonia, vascular complications
and bleeding, and longer length of stay. This should be the
subject of future research.

Conclusions
Similar to procedure-based volume–outcome relationships,
there does seem to be an association between acute hospital
stroke volume and 7 and 30-day mortality among patients
with IS in Ontario where stroke care has been regionalized
with 28 designated stroke centers most of which have annual
IS patient volumes ≥126. Hospitals that have average annual
IS volumes <126 per year have 37% higher odds of death at 30
days after an acute IS than hospitals that see on average
300 patients with IS per year. These results may be used to
inform stroke care planning where stroke care is regionalized
to redirect patients to hospitals where there is capacity to care
for more patients. Having sufficient patient volumes facilitates
a sustainable interprofessional staff with expertise in stroke care
and stroke unit care.

Acknowledgments
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Disclosures
None.

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**SUPPLEMENTAL MATERIAL**

**Appendix 1:** International Classification of Diseases, Tenth Revision, Canadian (ICD-10-CA) diagnostic codes used to identify risk factors and comorbidities among admitted acute ischemic stroke patients.

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>ICD-10-CA Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial Fibrillation</td>
<td>I48</td>
</tr>
<tr>
<td>Past History of Stroke/TIA</td>
<td>I60, I61, I63, I64, H341, G45</td>
</tr>
<tr>
<td>Past History of CAD*</td>
<td>I20, I21, I22, I23, I24, I25</td>
</tr>
<tr>
<td>Past History of Carotid Disease</td>
<td>I652</td>
</tr>
<tr>
<td>Peripheral Vascular Disease</td>
<td>I70, I71, I731, I738, I739, I771, I790, I792, K551, K558, K559, Z958, Z959</td>
</tr>
<tr>
<td>Hypertension</td>
<td>I10, I11, I12, I13, I15</td>
</tr>
<tr>
<td>Hyperlipidemia</td>
<td>E78</td>
</tr>
</tbody>
</table>

**Comorbid Conditions (%)**

<p>| C00-C26, C30-C34, C37-C41, C43, C45-C58, C60-C76, |</p>
<table>
<thead>
<tr>
<th>Condition</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cancer</td>
<td>C81-C85, C88, C90-C97, C77-C80</td>
</tr>
<tr>
<td></td>
<td>N032-N037, N052-N057, N18, N19, N250, Z490-Z492,</td>
</tr>
<tr>
<td></td>
<td>Z940, Z992</td>
</tr>
<tr>
<td>Renal Disease</td>
<td>B18, K700-K703, K709, K713-K715, K717, K73, K74,</td>
</tr>
<tr>
<td></td>
<td>K760, K762-K764, K768, K769, Z944, I850, I859, I864,</td>
</tr>
<tr>
<td>Liver Disease</td>
<td>I982, K704, K711, K721, K729, K765, K766, K767</td>
</tr>
</tbody>
</table>

* CAD = Coronary Artery Disease, CHF = Congestive Heart Failure