Analysis of Canadian Population With Potential Geographic Access to Intravenous Thrombolysis for Acute Ischemic Stroke

Phillip A. Scott, MD; Chris J. Temovsky, HBSc; Kate Lawrence, MBBS, MPH, MFPHM; Edward Gudaitis, MBA; Mark J. Lowell, MD

Background and Purpose—We sought to identify the Canadian population with potential access to intravenous tissue plasminogen activator within 3 hours of onset of acute ischemic stroke.

Methods—Assuming that 60 minutes is needed for stroke recognition, emergency room evaluation, and administration of tissue plasminogen activator, 120 minutes remain for transport, using a 3-hour treatment window. Ambulance databases were analyzed for transport times of 60, 90, and 120 minutes and were found to correspond to transport distances of 32, 64, and 105 kilometers (20, 40, and 65 miles), respectively. Using Geographical Information System (GIS) software, these radii were overlaid on thematic maps of Canadian hospitals identified as having a third- or fourth-generation CT and with a neurologist and an emergency physician on staff. Analysis was then performed on complete Canadian census data from 1991 and the interim 1996 census count.

Results—67.3%, 78.2%, and 85.3% of the total Canadian population were within 32, 64, and 105 kilometers, respectively, of an identified hospital. For individuals ≥65 years of age, 64.4%, 77.0%, and 85.7% were within the respective radii. Complete analysis by age, ethnic origin, and gender are detailed.

Conclusions—In the model described, a substantial percentage of the Canadian population has geographic access to a hospital potentially capable of delivering intravenous thrombolysis for acute ischemic stroke. GIS analysis can identify both population groups and rural areas with limited access to thrombolytic stroke treatment. A coordinated emergency medical service response for stroke is advocated to maximize coverage, as a 60-minute delay in emergency room arrival eliminated 5.1 million people from potential treatment. (Stroke. 1998;29:2304-2310.)

Key Words: epidemiology ■ geography ■ stroke, acute

The NINDS rt-PA Stroke Study demonstrated improved neurological outcome in patients with acute ischemic stroke when tissue plasminogen activator (rtPA) was administered intravenously within 3 hours of symptom onset in carefully selected patients. Treatment was beneficial regardless of the patient’s gender, age, ethnic background, or presumed etiology of stroke. The American Heart Association has issued recommendations supporting its use in appropriate patients when treatment can be delivered within 3 hours. Treatment cannot be recommended, however, unless the diagnosis of ischemic stroke is established by a physician with expertise in the diagnosis of stroke and the CT scan of the brain is assessed by physicians with expertise in interpreting this imaging study. The American Heart Association further recommends that thrombolytic therapy should not be given unless emergency ancillary care and facilities to handle bleeding complications are readily available. These are defined as the availability of an intensive or acute stroke care unit during the initial 24 hours following treatment. Similar recommendations have been put forward by the American Academy of Neurology.

These guidelines create reasonable minimal qualifications for hospitals that deliver thrombolytic therapy in acute stroke. The 180-minute treatment window places geographic limits on the distance a patient can be located from a treatment center at the time of stroke onset and still have access to emergency thrombolysis.

It is recognized that meeting the criteria to receive rtPA in acute stroke is a difficult prospect. In the NINDS study, only 3.6% of >17 000 patients evaluated were eligible for treatment. The median time of hospital arrival in various studies has ranged from 84 minutes in those using 911 as their first medical contact to >24 hours. Failure to meet the time criteria is the most common cause for exclusion from thrombolytic therapy.
The essential time elements of emergency stroke care that must occur prior to thrombolytic treatment include the following: (1) patient recognition of a medical emergency; (2) delivery of the patient to an appropriate facility for stroke care, a function of the efficiency of the transport system used and the distance the patient must travel; and (3) the time required for emergency department evaluation, laboratory studies, CT scanning, and rtPA administration.

Public and professional education efforts focus on reducing the time associated with all of the above elements. No stroke educational campaign or other intervention, however, can affect where the patient is located at the time of stroke onset. The distance a patient must travel to reach a hospital with stroke treatment capability is the limiting factor in thrombolytic stroke therapy after the other time elements have been optimized to their minimums. In countries with large rural regions with limited hospital access, this distance will determine individual access to acute thrombolytic stroke treatment.

The combination of finite facilities meeting the outlined qualifications for rtPA use with a limited transport time creates a definable “service area” for the delivery of rtPA in stroke patients for an entire health system. The population of these service areas can be modeled and evaluated using Geographic Information System (GIS) analysis, which combines digital population data with cartographic information. GIS software creates computer-generated thematic maps based on spatial information and databases using geographical parameters. Although this concept originated in the late 1960s, it is only recently that the technology and data have become available for general use.

The objective of this project was to create the above model and then apply it to the 1991/1996 Canadian census data to identify (1) the population with potential access to rtPA treatment for acute ischemic stroke, based on varying time assumptions; (2) the characteristics of that population with respect to age, gender, and ethnic origin; and (3) the geographic regions with limited coverage. This information could direct the delivery of public and professional education for maximum patient benefit by targeting efforts at specific areas with access to stroke centers. It would also identify geographic regions without access to such specialization and allow the creation of a priority list for the development of stroke treatment centers on the basis of the total population in the region and their stroke risk factors.

Canada was selected for analysis on the basis of the availability of digital cartographic and census data, the presence of large rural regions with potentially limited medical access, and the need for maximum resource utilization in a system of universal health coverage. Although thrombolytic therapy in acute stroke is not currently approved in Canada, it remains under evaluation, and such an analysis may serve as a model for developing stroke delivery systems.

Subjects and Methods

Model Assumptions

Hospital Identification

The minimum requirements for hospitals delivering intravenous rtPA in acute ischemic stroke were arbitrarily defined as the presence of: (1) a third or fourth generation CT scanner on site, (2) a neurologist on staff and (3) a specialist in emergency medicine on staff.

203 hospitals were identified with a suitable CT scanner by cross-referencing the Canadian Coordinating Office for Health Technology Assessment (CCOHTA) selected technology list for CT scanning with current listings from GE Medical Systems Canada (Reference 7 and GE Medical Systems Canada, unpublished data, 1997). These 203 hospitals were then cross-referenced with the Canadian Medical Directory (1997 Edition), listing all Canadian physicians and their places of practice by specialty, and the Canadian Association of Emergency Physicians membership list (Reference 8 and Canadian Association of Emergency Physicians, unpublished data, 1997). One hundred thirty-four of these hospitals were identified with at least 1 emergency physician on staff, and 110 of the 203 hospitals had at least 1 neurologist on staff. All 110 hospitals with a neurologist also had an emergency physician, yielding the final list of 110 hospitals used in the analysis. These 110 hospitals all had intensive care units available.

Hospital Service Area Calculation

The following assumptions were made to establish the distance around each hospital for population analysis: (1) the maximum allowable time-to-thrombolysis for stroke patients is 180 minutes, (2) the optimum time required for emergency department evaluation, head CT scan, required laboratory studies and thrombolytic initiation is 60 minutes, and (3) different prehospital transport systems are comparable in their speed of patient delivery to a given hospital.

The first assumption is based on animal stroke models and the NINDS rt-PA Stroke Study.19 The second reflects the consensus recommendations of the Hospital Acute Stroke Care NINDS Task Force (A.J. Furlan, Cleveland Clinic Foundation, unpublished data, 1996). The third assumption allows a uniform treatment of various ambulance systems for model consistency. This establishes a total time available for patient recognition and transport of up to 120 minutes (180 minutes total time available less 60 minutes utilized in patient evaluation and treatment). For ground ambulance transport this 120 minutes is assumed to represent the total time available for one-way transport as ambulances are commonly dispersed throughout communities to reduce response time. For air medical (helicopter) transport this is assumed to represent the time available for round-trip transport as helicopters are typically centrally based at the dispatching hospital.

Analysis of southeastern Michigan local ground ambulance data found a maximum one-way transport distance of 32 km was associated with a transport time of 60 minutes. This included ambulance dispatch, ambulance travel to receiving hospital time (Huron Valley Ambulance, Ann Arbor, Mich, unpublished data, 1997). Longer one-way ground transport times were atypical, often nonemergency (scheduled), and outside the local service area. This distance and time data corresponds closely to those reported in other emergency medical services (EMS) systems.10 Retrospective analysis of 1992 to 1996 University of Michigan Survival Flight helicopter transport data (unpublished data, 1996) demonstrated that a round-trip distance of 64 km (32 km 1 way), 128 km (64 km 1 way), and 210 km (105 km 1 way) corresponded to transport times of 60, 90, and 120 minutes, respectively.

By combining the aboveground and helicopter transport time data, we established an EMS service area radius of 32, 64, and 105 km for analysis around centers capable of delivering thrombolytic therapy in acute stroke. These distances corresponded to transport times of 60, 90, and 120 minutes, respectively. Previously published reports evaluating total prehospital transport time compared with distance traveled support these assumptions. Of note, only a minor incremental decrease in time-to-arrival (mean, 10 minutes; standardized for distance) was identified by Nicholl et al11 when air transport was compared with ground transport. Although air ambulance transport is a faster “en...
route" method of transport, this advantage is often lost in short transfers due to delays in obtaining authorization for liftoff, landing site availability, engine warm-up/cool-down, and weather restrictions. In Canada, the use of ground ambulances for trauma-patient transfers of ≥60 km (approximate distance to trauma center) has been advocated. In the model, areas without helicopter ambulance availability were assumed to have similar ground ambulance transport times over the above distances.

**GIS Analysis**

ArcView 3.0, a commercially available GIS platform produced by Environmental Systems Research Institute, Inc (ESRI), served as the project software. The various data elements used in the model were imported and assigned geographic coordinates (latitude and longitude) in a process known as “geocoding.” Geocoding began with importing Canadian political boundaries for each province/territory from commercially available ESRI boundary data to form the base layer for geographic analysis.

The next layer overlaid included digital population data from the 1991 Canadian 2A and 2B census (the last complete census) and the interim count from the 1996 census update. These were obtained from Statistics Canada and added to ArcView by enumeration area (EA) centroid location.

EAs are the smallest geographic areas for which complete census data are available, and 1 census representative canvasses each. EAs are designed to be as compact as possible to minimize travel and optimize census representative work; therefore, EAs

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**Figure 1.** Canadian hospitals identified with stroke treatment capability with overlay of model geographic coverage area. Yellow areas indicate identified hospital capable of delivering intravenous rtPA in stroke; blue, the EAs within 32 km of the hospital; green, the EAs within 64 km of the hospital; and red, the EAs within 105 km of the hospital.
typically follow easily recognizable physical features, such as road networks and rivers. EAs form the building blocks of larger census areas, such as census tracts, subdivisions, and Federal Electoral Districts. For the 1991 count there were 45,749 individual EAs, each covering between 125 and 375 dwellings and their aggregate census information. Each EA has an associated “centroid,” a geographic coordinate that is a representative central location for the covered area. These centroids are located at either the center of gravity or the assumed largest concentration of dwellings; hence, these are not centroids in the mathematical sense. The population data for each EA is assigned to its respective centroid for mapping. Census variables analyzed include those related to known ischemic stroke risk factors (age, gender, ethnic background) and potential modifiers of ease of access to medical facilities (education and income).

The final layer added to ArcView were those hospitals identified above as capable of delivering rtPA for stroke. The list of hospitals was forwarded to Statistics Canada, where each street address was converted into longitudinal and latitudinal coordinates for importing into ArcView. After building the above data sets, ArcView allows extraction of census data from the EAs within specific areas around the identified hospitals. The radius of this area is taken from the model described above. An equidistant azimuthal map projection, designed to preserve both distance and direction, and all significant digits from the geocoding sources were utilized.

Results

One hundred ten Canadian hospitals were identified as capable of delivering intravenous rtPA for acute ischemic stroke and plotted using the methodology described above. Geographic analysis for population characteristics around these centers was then completed using service area radii of 32, 64, and 105 km. Figure 1 identifies these covered areas for all of Canada.

The Table identifies the results of the GIS analysis for total population, gender, and individuals >65 years of age by their respective access to a potential stroke treatment center using the varying distances described in the model.

Figure 2 compares access by age (by 5-year age groups) to the access of the total population. The variation by age group was found to be small. Individuals between 20 and 24 years of age were noted to have the highest percentage (71.5%) of their total population within 32 km of a potential treatment center, and those $\leq 65$ years with the least (63.8%). Similar variations were found at the 64- and 105-km distances.

Figure 3 compares access to a potential treatment center by single ethnic origin, as reported in the 1991 2B census data. The following groups are identified as having >50% of their total group population with access to a potential stroke treatment center when evaluated at 32 km: Swedish, Finnish, and those of Aboriginal origin. Individuals of Aboriginal origin had the smallest population with geographic access, with only 27%, 34%, and 40% located within 32 km, 64 km, and 105 km, respectively, of a potential center. Twelve groups were identified with >90% of their population located within 32 km of a potential center, with individuals of Black, Chinese, Greek, and Korean origin having the greatest total percentage access.

### Table

<table>
<thead>
<tr>
<th>Census Category</th>
<th>32 km/20 miles (60 min)</th>
<th>64 km/40 miles (90 min)</th>
<th>105 km/65 miles (120 min)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>%</td>
<td>No.</td>
<td>%</td>
<td>No.</td>
</tr>
<tr>
<td>1991 total population</td>
<td>18,364,035</td>
<td>67.3</td>
<td>21,343,790</td>
<td>78.2</td>
</tr>
<tr>
<td>1996 total population</td>
<td>19,625,021</td>
<td>68.0</td>
<td>22,755,200</td>
<td>78.9</td>
</tr>
<tr>
<td>1991 male population</td>
<td>8,960,645</td>
<td>66.8</td>
<td>10,463,915</td>
<td>77.8</td>
</tr>
<tr>
<td>1991 female population</td>
<td>9,383,570</td>
<td>67.8</td>
<td>10,880,200</td>
<td>78.6</td>
</tr>
<tr>
<td>1991 population &gt;65 y</td>
<td>1,868,305</td>
<td>64.4</td>
<td>2,232,335</td>
<td>77.0</td>
</tr>
</tbody>
</table>
Increased access was found for those with higher levels of schooling, with only 58.6% of individuals who had completed <9 years of education with access at 32 km compared with 82.2 percent of those completing a university degree (Figure 4). Likewise, the higher a family’s total income the greater their access to a potential stroke treatment center. Fifty-four percent of families with total incomes of less than Can $20 000 were within 32 km of a potential center, whereas 70.3% of families with incomes over Can $50 000 had access.

**Discussion**

In the model, a significant percentage of the Canadian population has geographic access to a hospital with potential stroke treatment capability. Over 67% of the total population lives within a 32-km radius (60 minutes) of an identified center. Seventy-eight percent and 85% of the population live within 64 and 105 km, respectively, representing transport times of 90 and 120 minutes. While these numbers are encouraging, they highlight the effect of delays in delivering a time-dependent therapy. Failure of rapid recognition of stroke onset combined with prehospital transportation, emergency room, and CT delays all serve to reduce the service area of a given hospital. Sixty minutes of lost time in a national acute stroke care delivery system as modeled results in a 21% relative reduction (17.9% absolute) in the population with access to thrombolysis for acute stroke. Delays of this modest magnitude would effectively deny thrombolytic treatment to a population exceeding 5.1 million individuals. To fully realize the available geographic access, a clear organization of the delivery of acute stroke care is needed.
In establishing the hospitals for use in the model, the presence of a neurologist on staff had the largest impact on hospital inclusion after the CT criteria was met. Of the 203 hospitals with appropriate CT scanners, 93 (46%) were excluded from analysis for lack of neurology coverage.

Considerable overlap was identified in the service area of many hospitals, as illustrated in Figure 1. This emphasizes the urban/suburban location of many hospitals but also suggests that a prehospital transport system could be designed to minimize the number of facilities required for 24-hour-per-day, 365-day-per-year stroke treatment coverage within a given province. Elements of such a system would mirror those in use for trauma patients and focus on early patient recognition and EMS activation, early EMS identification of stroke and preferential delivery of the patient to the closest stroke treatment facility as appropriate.

GIS analysis allows determination of treatment access by population subgroup, enabling identification of particular groups with limited access. Our analysis found that the percentage of individuals over 65 years of age, a population at increased risk for ischemic stroke, did not vary significantly from the total population with geographic access. No significant access differences existed when the population was evaluated by 5-year age groups or gender.

Of ethnic groups analyzed, individuals identifying themselves as Aboriginal, Norwegian, Swedish, and Finnish had the least access with greater than 30% of their total populations located over 105 km from a potential treatment center. Of those, Aboriginal Canadians had the worst access with 60 percent of their population without access. A trend of increasing access with increased level of schooling and total family income was also noted.

These variances again reflect primarily on the location of the identified population group with respect to urban and suburban facilities. Review of the location of the identified hospitals in Figure 1 demonstrates concentrations of facilities along the St. Lawrence Seaway, Pacific and Atlantic Ocean communities, and large interior cities. Thus, population subgroups located in rural regions have limited access. In the model, large rural regions, including all of the Yukon and Northwest Territory, are completely without access along with northern regions of the Provinces of Ontario, Quebec and Manitoba.

Limitations of the analysis include those associated with the model assumptions, the raw data and the software utilized. Within the model assumptions the time available for thrombolysis may increase as data associated with ongoing thrombolytic and neuroprotective trials becomes available. The attainment of a 1-hour emergency room evaluation and treatment time, while advocated, has yet to be demonstrated consistently in the community. The model specifically assumes prehospital transport times associated with a given distance which may not reflect local EMS response times or availability. It is recognized that not all hospitals have access to helicopter EMS transport, however, the distances as assigned are reasonably covered in the allocated time by non-EMS personnel traveling via ground.

Limitations of the raw data include failure to identify hospitals with treatment capability and errors associated with the census data itself. The hospital lists were completed using the most recent available data, however, these may not reflect the rapid changes in the Canadian health care system particularly with respect to hospital mergers and closures. The census data as reported was considered the “gold standard” for available population data. For a complete discussion of each the reader is referred to the appropriate Statistics Canada source.

Finally, there are those limitations associated with the use of GIS software, as a digital map is at best only an approximation of the ground truth. Inaccuracy in a spatial variable enters from multiple sources, including: (1) temporal changes, eg, movement in population or political boundaries with time, (2) loss of information on map projection which distorts area, distance, shape or direction and (3) digitization error, eg, number of significant digits used in latitude/longitudinal plotting. An acknowledged limitation of the GIS service area analysis is that the population was evaluated using a linear radius around a given point (hospital). This fails to incorporate local transportation variables, such as traffic patterns, bridges, and ferries, which would alter the access time, and therefore distance, available to the patient.

In summary, substantial percentages of the Canadian population have geographic access to a hospital potentially capable of delivering thrombolytic therapy. Groups identified as having limited access are located in rural regions remote from urban and suburban facilities. The effect of time delays in stroke care significantly reduce the population that can be serviced by existing facilities, and therefore potentially increase the public health costs of ischemic stroke. To maximize the available resources in delivering acute stroke care, a clear identification of stroke treatment hospitals and a coordinated EMS response are advocated. Finally, GIS analysis offers the ability to rapidly model patient access to specialized therapies, including the use of rtPA in stroke.

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