GEOSPATIAL ANALYSIS TO EXPLORE ACCESS TO HYPERACUTE STROKE SERVICES ACROSS CANADA

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ABSTRACT:

BACKGROUND: Treatment for stroke is time sensitive. Canada's vast geography creates challenges for ensuring prompt transport to hospital. We sought to determine the proportion of people across various provinces in Canada for whom hyperacute emergency stroke services are accessible within evidence-based time targets via transport by emergency medical services (EMS).

METHODS: We calculated "drive time polygons" on a map of Canada that delineated the area around stroke centers and EMS stations to which one can drive in 3.5 to 6 hours for the 8 provinces with available data. We calculated the proportional area of each forward sorting postal code zone contained within a drive-time polygon. We applied this ratio to the 2011 Canadian Census population of the FSA to estimate the population that can reach a stroke center in designated time.

RESULTS: Among the 8 provinces with known EMS center locations, 48%-97% of the population by province live within a drive time of 4.5 hours and 53-97% of the population live within 6 hours by road EMS. Assuming 5-hour total travel time by EMS from base to patient and patient to hospital by road, 85-100% of the population has access to a current or proposed endovascular site.

CONCLUSION: Most Canadians live within six hours' road access to a stroke center. Geospatial mapping could be used to inform decisions for additional sites and identify gaps in service accessibility. Coordinated systems of care and ambulance bypass agreements must continue to evolve to ensure maximal access to time-sensitive emergency stroke services.

INTRODUCTION:

Stroke is an acute neurological emergency with major public health impact. (1) Hyperacute treatment for stroke is evolving rapidly, with implications for service delivery and for equitable access to evolving standards of care. About 85% of strokes in North America are ischemic. The primary treatment of acute ischemic stroke is administration of intravenous alteplase (rtPA) (2) but outcome is highly associated with speed of access, measured by onset-to-treatment (OTT) time. (3,4) A majority of stroke patients do not receive treatment because they present too late or have medical contraindications to treatment. Stroke centers and dedicated stroke teams can continually improve the quality of treatment offered to patients who arrive within evidence-based time windows to warrant treatment. Implementation of a comprehensive system of stroke care has increased the role of Emergency Medical Services (EMS) for stroke patient transport.

Early identification of stroke, and protocols to enable rapid transport via EMS, have resulted in reduced onset to treatment times, reduced inter-facility transfer delays, and increased rates of thrombolysis administration for acute ischemic stroke.(5,6,7) The recent establishment of endovascular therapy for ischemic stroke patients places even greater demands on systems of care, with fewer centres able to support 24/7 neuro-intervention. Every minute delay in reperfusion results in a loss of 1.9 million neurons (8). With endovascular therapy, the odds of benefit reduce with every hour of delay from onset to arterial puncture(9). Given the need for rapid treatment, geographically dispersed populations may not be able to benefit from either alteplase or endovascular thrombectomy.

Canada's vast geography creates challenges for ensuring prompt transport to hospital. To inform ongoing system planning and improvement efforts towards optimal stroke services delivery, we sought to determine the proportion of people across several provinces for whom hyperacute stroke services are currently accessible by EMS.

METHODS:

The population with access to stroke centers in sufficient time for treatment was estimated by province using the 2011 Canadian population census. The area within which residents can be reached by an ambulance (traveling by road) and then driven to a stroke hospital was compared with the population in those regions (based on forward-sorting postal codes, i.e., the areas defined by the first three digits of a postal code) to determine the portion of residents that can reach a hospital between 3.5 and 6 hours of contacting emergency services. (Figure 1)

We used geospatial analyses with Geographic Information Systems (GIS) technology (10,11,12) to generate Drive-Time Polygons. The addresses of hospitals with comprehensive and advanced stroke centers and the addresses of Emergency Medical Service (EMS) centers were geocoded to assign geographic coordinates (latitude and longitude). These addresses were available for 8 provinces (EMS locations for Nova Scotia and Quebec not available); therefore, the analysis was limited to these regions. Once geocoded, Drive Time Polygons were calculated for each hospital and EMS station using the ArcGIS Online World Routing Service algorithm. This algorithm delineates the spatial extent to which one can drive from a starting point within a given duration, assuming average drive times per road segment. While this algorithm assumes average civilian drive times, emergency vehicles generally drive faster, resulting in larger drive-time polygons. This assumption results in an underestimation of the population with sufficient access to stroke centers.

Drive-Time Polygons were calculated with the simplified assumption that at least half of the journey to the hospital would be spent by an ambulance traveling to a patient location and half by the ambulance traveling from the patient location to the stroke center. Drive-time polygons were thus calculated at 1.75, 2.25, 2.5, and 3 hours (i.e., half of 3.5, 4.5, 5, and 6 hours' total drive time) around each stroke center and EMS station. The actual travel duration (in addition to driving times) would be increased by the on-site time incurred by EMS personnel (median range of 16 to 24 minutes across provinces) (1). Thus the 3.5-hour drive time is potentially closer to 3 hours and 45 minutes when the on-site time is included. Drive-time polygons were then spatially intersected with the forward-sorting postal codes to identify the regions within

which residents were in access to both a stroke center and EMS drive-time polygon (the "serviced region"). This method assumes that road ambulance is the only method by which residents can travel to a stroke center.

Forward-sorting postal codes with associated 2011 populations provided by Statistics Canada were used to estimate the population inside and outside the serviced region. The ratio of the serviced area to the forward-sorting postal code area multiplied by the population within the associated forward-sorting postal code represents the portion of residents with access to a stroke center within the associated duration. The populations within the serviced regions were summed for each province to calculate the provincial totals. This method assumes that residents suffer from a stroke at home (or at a location within their home forward sorting postal code).

Further analyses were conducted to examine access to acute endovascular therapy for large vessel ischemic stroke, a newer therapy that is only available in a limited number of comprehensive stroke centers with the necessary equipment and professional expertise to perform the procedure and care for the patient afterwards. This procedure can be offered to eligible stroke patients who can get to hospital within 5 hours of stroke onset (13).

RESULTS:

We included 456 EMS locations and 637 hospitals and calculated the Drive-Time Polygons on a map of 8 of the 10 provinces in Canada with available data. Among the 8 provinces, Alberta with 229 EMS locations and 96 hospitals, and Ontario with 82 EMS locations and 165 hospitals had the largest numbers of EMS locations and hospitals. As an example of a smaller province, PEI had just 4 hospitals and 6 EMS locations. Hospital administrative data shows that 69% of admitted stroke cases in Canada are transported to hospital emergency departments by EMS in Canada. (Table 1)

Among the 8 provinces studied in this cross-sectional snap-shot, an estimated 79% of the population has predicted access to hyperacute stroke services either via EMS or self-drive. This

represents the maximum proportion of the population who could benefit from time-sensitive therapies. As an example by province, among the population of Alberta (3,645,081) 89%, 92% and 93% of population of Alberta lived within 3.5, 4.5 and 6 hours' drive from a stroke center via EMS. (Figure 2) Further, 94%, 98% and 99% of population of Alberta lived within 3.5, 4.5 and 6 hours of self-drive (i.e., without EMS) from a stroke center. The mean percentage of Alberta population within the services area is 92%. In Ontario 96%, 97% and 97% of population lived within 3.5, 4.5 and 6 hours' drive from a stroke center via EMS. Whereas, 98%, 100% and 100% of population lived within 3.5, 4.5 and 6 hours of self-drive from a stroke center. (Table 2) Other provinces showed similar results.

Only 44% and 41% of population of Saskatchewan and Newfoundland and Labrador provinces lived within 3.5 hours drive from stroke center via EMS. It increased to 47% and 52% for 4.5 hours' drive and 53% and 84% respectively for 6 hours' drive. Within Saskatchewan, 59%, 93% and 93% of population lived within 3.5, 4.5 and 6 hours of self-drive from a stroke center. These data reflects the larger proportion of the populations of these provinces living in rural and remote areas where EMS and stroke-enabled hospital access is geographically challenging.(Figure 3)

A sub-analysis was conducted to understand access to recently implemented acute endovascular treatment across Canada. A major Canadian clinical trial on endovascular care (ESCAPE) included 11 sites, and an additional 10 sites have implemented this treatment or are in planning stages. Assuming a 5-hour travel time by EMS from base to patient and then from patient to hospital, 76% of the country's population has access to a site that participated in ESCAPE, 78% of the country's population has access to a proposed additional endovascular site and 92% of the country's population has access overall to a current or proposed endovascular site (Table 3).

DISCUSSION:

In our study, among the 8 provinces included, a high proportion of the population has potential access to acute stroke treatment with intravenous alteplase, and 85% to 99% with access to acute endovascular therapy in provinces where this is available. However, there is significant

variability. With private transport (a one-way trip), 86% to 100% of the population, varying by province) lives within a 4.5 hours' drive of a stroke center. With EMS (to home and then to hospital), between 48% and 96% live within 4.5 hours and 53% to 97% of the populations live within 6 hours by road EMS.

In Canada, 69% of admitted stroke patients are transported by EMS, yet the Canadian Stroke Best Practice Recommendations have established a target for EMS transport at 80%.(13) From the North Carolina Stroke Care Collaborative registry, it was noted that arrival by EMS (versus private transport) was associated with faster access to brain imaging and faster interpretation of these images (14) Canada's vast geography, challenging landscapes and climate makes it almost impossible to get all patients to hospital in early enough time frames to allow even fast door to treatment times to occur. People living in rural and remote locations in general have challenges accessing emergency medical services for urgent conditions. Similar patterns of access limitations to what we observed in this study have been seen in acute coronary syndrome access and in trauma care.(15)

The ESCAPE trial delivered rapid endovascular therapy to stroke patients with proximal intracranial occlusion on the basis of imaging at 11 sites in Canada improving clinical outcome and reducing mortality. (16) The significant difference between the trial and the current analysis is that the proposed sites cover the large population centers of Vancouver and Winnipeg. One pan-Canadian study similarly used geospatial tools to estimate the proportion of population with 60, 90 and 120-minute access to a hospital with the minimum requirements to treat stroke (a 3rd or 4th generation CT scanner, a neurologist and an emergency physician on staff). Based on 1991 and 1996 census counts, 67.3% of Canadians lived within 60 minutes of such a center, 78.2% within 90 minutes and 85.3% within 120 minutes. (17) Another study in Ontario found that access to hospitals with specialized services (including interventional cardiology centers) varied by geography, with rural areas having significantly less access. Overall, 40.5% of the population had access to a hospital with specialized services within 30 minutes, 72.2% had access within one hour and 96.5% had access within 4 hours. (18) One study in Alberta used geospatial tools to estimate the change in proportion of the population

with access to a stroke center after the province increased the number of such centers (between 2002 and 2010). This study found that the proportion of Albertans with geographic access by ground transport within 15 minutes increased from 47.5% to 53.8%, and those with access within 75 minutes increased from 84.6% to 93.9%. (19)

This approach can be useful to inform capacity planning – e.g. extending transport windows from 4 to 6 hours makes a bigger difference in increasing access to acute stroke treatments in Newfoundland and Labrador than in Saskatchewan. By plotting potential sites, decision-makers can objectively determine which locations would have greater population reach. This information, in turn, would need to be combined with hospital capability to care for stroke patients following acute treatment, resources (human and equipment), expertise and anticipated annual volumes to justify location selection.

The use of geospatial tools to estimate access to stroke services is relatively new application. These analyses depend on accurate road data and speed of travel by ambulances. One study in Calgary demonstrated that actual time to center as recorded by EMS was consistently higher than predicted by the geospatial tools, usually by between 10 and 20 minutes. Again, the error was not randomly distributed, with areas outside the city having the highest underestimates. By adjusting model assumptions to correct for this underestimate, this author estimates that access within 60 minutes to invasive cardiac services is available for 56.3% of the population, with a low of 13.5% in New Brunswick to a high of 62.7 in Ontario. (20) A similar study from Alberta found that travel time predicted with geospatial tools was approximately 70% of actual EMS time, with the greatest discrepancies occurring during the winter months and peak morning and afternoon rush hour, reflecting real-time conditions (poor weather, traffic) not often accounted for in a GIS. (19) Simple assumption of the population being equally distributed around a forward-sorting postal code will bias the results in rural areas. Instead, it is expected that a population will be heavily distributed around the road network. This bias is higher in lower-population areas, thus limiting the error. We assume that an ambulance is dispatched immediately after a stroke occurs, travels at an average road speed, and EMS spends no time at the patient residence. This will lead to errors associated with the ambulance speed compared

to the average road speed (expected to be higher), errors associated with estimating traffic (the true travel time might be higher or lower than the road averages applied given time of day and traffic disruptions), and errors associated with ignoring delays at the patient site (notably, delays associated with travel within large buildings). Some provinces and hospitals have access to air ambulance and we did not consider this possibility in our analysis. These estimates also assume that patients or witnesses will contact Ems as soon as stroke symptoms begin. Canadian stroke quality monitoring data reveals significant delays in first contact with EMS or first presentation to an emergency department by private transport [1]. These delays in contact may result in reduced numbers of patients arriving in specified time windows, even if they reside within a 6 hour drive time. Finally, provinces with a greater rural population may be underestimated because local private EMS providers could not be identified.

In conclusion, our study reports on the predicted access of the Canadian population to stroke centers that provide time-sensitive acute treatments. The majority of Canadians live within six hours' road access to a stroke center. Coordinated systems of care and ambulance bypass agreements must continue to evolve to ensure maximal access to hyperacute services. The public need to be aware of the signs of stroke and contact EMS without delay to maximize eliegibility for these time-sensitive treatments. Geospatial analysis may help estimate coverage for specific stroke services (e.g. intra-arterial clot retrieval), and other medical or surgical emergencies. This methodology could be broadly applied in healthcare to inform decisions for resource allocation to maximize population access, and to identify gaps in service accessibility across a range of health conditions and across geographic regions globally.

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Table 1: The percentage of admitted stroke cases transported by emergency medical services in Canada^

CAN!	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NL
69% 25312/36704	67% 4704/7002	75% 3219/4306	64% 1072/1679	65% 1098/1689	69% 12464/17939	*	62% 832/1352	73% 1069/1465	64% 174/272	68% 610/881

*** data on EMS transport not collected or reported in Quebec at time of analysis.**

! Overall values for Canada do not include data from Quebec

^ Parts of this material are based on data and information provided by the Canadian Institute for Health Information. However, the analyses, conclusions, opinions and statements expressed herein are those of the author and not those of the Canadian Institute for Health Information."

Table 2: 2011 Population of Canadian Provinces within 4.5 hour access to a Stroke Centre by EMS based on Geographic Information Systems (GIS) Technology

Province	2011 Census Population	Population with access to Comprehensive or Advanced Stroke Services within 4.5 hours using emergency medical services transport^	
British Columbia	4,400,052	3,356,102	76%
Alberta	3,645,081	3,340,445	92%
Saskatchewan	1,033,489	534,826	52%
Manitoba	1,208,268	1,057,871	88%
Ontario	12,851,791	12,396,339	96%
New Brunswick	751,161	676,261	90%
Prince Edward Island	140,204	126,608	90%
Newfoundland and Labrador	514,536	242,419	47%

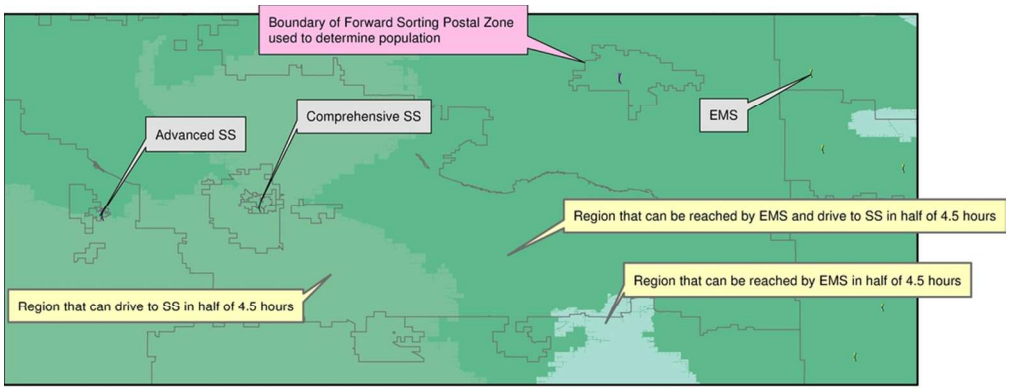
^ Assumption that drive time of 4.5 hours is divided with 50% time from EMS starting location to patient, based on place of residence, and the other 50% of time from patient location to closest comprehensive or advanced stroke center. EMS base locations not available for Nova Scotia and Quebec.

Table 3: Population Access to Acute Endovascular Therapy Services in Canada by Province

Province	2011 Census Population	Initial Escape EVT Sites (n=11): *Population within 5 hour drive time*		New EVT Sites (n=10) *Population within 5 hour drive time*		All EVT Sites *Population within 5 hour drive time*	
British Columbia	4,400,052	53,927	1%	3,677,489	84%	3,728,112	85%
Alberta	3,645,081	3,410,423	94%	-	0%	3,410,423	94%
Saskatchewan	1,033,489	932,229	90%	32,553	3%	932,229	90%
Manitoba	1,208,268	12,557	1%	1,122,016	93%	1,122,099	93%
Ontario	12,851,791	12,315,533	96%	12,545,652	98%	12,545,652	98%
Quebec	7,902,991	7,025,574	89%	7,336,516	93%	7,403,935	94%
New Brunswick	751,161	535,704	71%	740,672	99%	740,672	99%
Nova Scotia	921,727	871,989	95%	620,015	67%	871,989	95%
Prince Edward Island	140,204	139,965	100%	139,965	100%	139,995	100%
Newfoundland and Labrador	514,536	*	0%	*	0%	*	0%
Northwest Territories	41,462	*	0%	*	0%	*	0%
Yukon	33,897	*	0%	*	0%	*	0%
Nunavut	31,906	*	0%	*	0%	*	0%

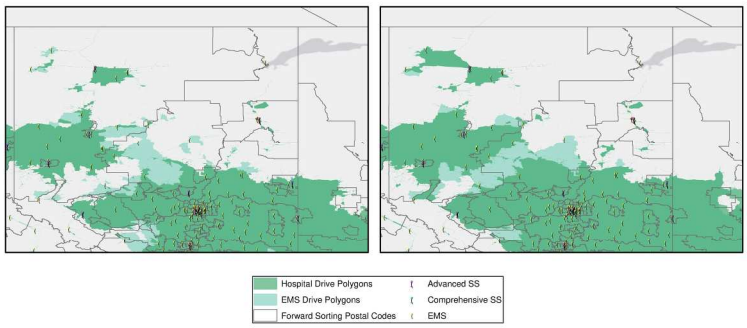
* Acute Endovascular therapy services not available in these provinces

Note: the "All EVT" column is not a sum of the previous two columns, but rather a spatial union with some, but not total, overlap. Hence, the result in this column will not necessarily be a summation of the row.



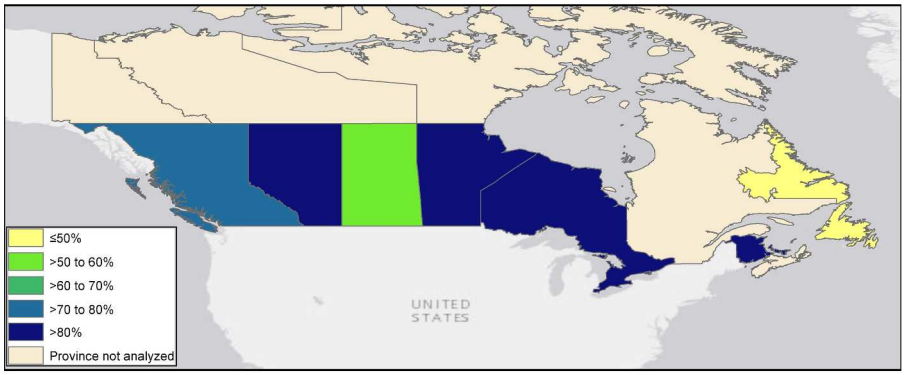
Map of Canada – Population with access to Stroke center.

92x46mm (300 x 300 DPI)



Geospatial Maps of Alberta Province. Geospatial map of Alberta province. Left: Population living within 4.5 hrs drive Right: Population living within 6 hrs drive to an advanced or comprehensive stroke center

215x166mm (300 x 300 DPI)



Map of Canada – Serviced population by province
Population by province within a 4.5-hour drive to an Advanced or Comprehensive Stroke

226x303mm (300 x 300 DPI)