Geomapping of Traumatic Spinal Cord Injury in Canada and Factors Related to Triage Pattern

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Abstract

Current research indicates that more than half of patients with traumatic spinal cord injury (tSCI) experience delays in transfer and receive surgery >24 h post-injury. The objectives of this study were to determine the geographic distribution of tSCI in Canada relative to specialized treatment facilities, to assess clinical and logistical factors at play for indirect admissions to those facilities, and to explore differences in current time to admission and simulated scenarios in an attempt to assess the potential impact of changes to triage protocols. This study included data from 876 patients with tSCI enrolled in the prospectively collected acute Rick Hansen Spinal Cord Injury Registry (RHSCIR) between January 1, 2010 and December 31, 2013 for whom there were data on the location of their injury. Patients transported directly to a RHSCIR acute facility were more likely to reach the facility within 1 h of injury, whereas those transported indirectly were more likely to arrive 7 h later. Considering the injuries occurring within 40 km of a RHSCIR acute facility ($n=323$), 249 patients (77%) were directly and 74 (23%) were indirectly admitted. In the multivariate regression analysis, only older age and longer road distance remained significantly associated with being indirectly admitted to a RHSCIR facility. Compared with the current status, the median time to admission decreased by 20% (3.5 h) in the 100% direct admission scenario, and increased by 102% (8.9 h) in the 100% indirect admission scenario.

Keywords: acute SCI; geographic information science; SCI center; trauma center; triage

Introduction

IMMEDIATELY FOLLOWING the onset of traumatic spinal cord injury (tSCI), patients are at significant risk of neurological deterioration resulting from secondary injury to the spinal cord.¹ Prompt recognition of tSCI, appropriate triage, and timely access to specialized care are critical. Evidence-based guidelines developed by expert consensus recommend early transport of patients sustaining an acute tSCI to a SCI-specialized center,^{2–6} and early surgical treatment within 24 h of injury^{7–9} to achieve optimal outcome. However, despite these guidelines and the growing evidence

supporting the benefits of expeditious transfer to a SCI center, current research indicates that more than half of patients with tSCI experience delayed admission to SCI centers,^{10,11} and receive surgery >24 h post-injury.¹²

To understand the barriers to achieving optimal care delivery, recent efforts have aimed at delineating the processes of the clinical journey from point of injury to commencement of specialized care and at identifying potential correctable delays.^{10,12–14} Processes measured in these studies included pre-hospital time, time spent in an intermediate nonspecialized center, time from injury to specialized center, time to assessment by a spine surgeon, time to

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decision regarding surgical management, and time to surgery. Results from these studies revealed that patients who were sent indirectly to the specialized center spent an average of 9–33 h in the intermediate center,^{11,12,15} and received surgery 14 h later than those who were admitted directly to the specialized center.¹¹ These findings suggest that direct admission to the specialized center would accelerate access to appropriate care; however, this might not be possible in cases requiring immediate medical stabilization caused by injury severity or geographic limitations.

Given that injuries can occur in both urban and very remote areas, there is a need to ensure that triage procedures account for differences in care depending on the geographic location of injury. In urban settings where SCI-specialized centers are accessible within a short time frame and, therefore, direct admission is feasible, the degree to which direct admission is occurring has not been examined for tSCI. There are indications from the general trauma literature that despite the published guidelines, patients are still being triaged to a non-trauma center even when they are injured within vicinity of the trauma center. A study in California reported that 42% of all indirect admissions were injured within 10 miles (16.1 km) of the trauma center,¹⁶ whereas another study in Toronto reported 63% of indirect admissions were injured within 5 miles (8 km) of the trauma center;¹⁷ in both cases patients could have bypassed nonspecialized emergency rooms in favor of being delivered directly to a trauma center as specified by evidence-based field trauma triage protocols.¹⁸

To identify opportunities to improve timely access to SCI-specialized care in Canada, we must first understand the current status of tSCI geography and triage patterns across the country. The purpose of this study was to describe the geographic distribution of tSCI and calculate the road distances between injury and the SCI center. Further, we determined the status of indirect admission to a SCI center and its associated factors for the cohort of injuries occurring in close proximity to a SCI center that could potentially be directly transported. Finally, to provide some context for the impact of a potential change in triage protocol, the Access to Care and Timing (ACT)

simulation model for tSCI care^{19,20} was applied to explore differences in time to admission between current status and simulated scenarios. This study aimed to assess the basis of triage patterns in Canadian urban settings and compare care to the recommended guidelines.

Methods

Study design

This retrospective study used data from the Rick Hansen Spinal Cord Injury Registry (RHSCIR), which is a prospective registry of patients with a new tSCI from 18 SCI acute and 13 rehabilitation facilities located in 16 cities across Canada. All RHSCIR participating acute facilities were Level I/II trauma centers at the time of study,^{21,22} and all RHSCIR facilities would be considered to be acute SCI specialty centers as defined by the recommended attributes in Parent and coworkers and Noonan and coworkers.^{4,22} Each participating facility obtained institutional research ethics board approval to enroll patients. A core data set was collected for all registrants, whereas an expanded data set was collected for those who provided informed consent. Further details about RHSCIR have been previously published.^{23,24}

This study included patients who were admitted to an acute RHSCIR facility between January 1, 2010 and December 31, 2013, provided informed consent for the collection of the expanded data set, and had level of injury at L2 and above (Fig. 1). The fairly narrow time range was chosen to minimize the effect of evolving care practice,^{2,25} specifically as a result of the guidelines regarding early transport to SCI center that have been published in recent years.^{2–5}

Study variables

Patient variables included age at time of injury and gender. Injury variables included injury mechanism (fall, transport, sports, assault, other), kinetic energy related to injury mechanism (low, high energy [i.e., any injury involving a high velocity situation, e.g., gunshot wound, pedestrian struck, auto crash >65 km/h or falls >6 m]), Glasgow Coma Scale (GCS) at admission (severe to

FIG. 1. Flow of patients in the RHSCIR and selection of patients for analysis. RHSCIR; Rick Hansen Spinal Cord Injury Registry; FSA, Forward Sortation Area.

moderate decreased level of consciousness, 3–12; mildly altered level of consciousness, 13–15), Injury Severity Score (ISS) at admission (≤ 25 ; > 25 indicating major trauma to another body region in addition to the spine),²⁶ neurological classification by American Spinal Injury Association (ASIA) Impairment Scale (AIS) (A, B, C, D) and neurological level at admission (high cervical, C1–C4; low cervical, C5–T1; thoracic, T2–T10; thoracolumbar, T11–L2), both of which were derived from the International Standards for Neurological Classification of SCI (ISNCSCI) examination.²⁷ Missing ISS data were imputed based on the joint distribution of AIS and neurological level at admission.

Geographical factors. The RHSCIR acute facility where patient was admitted and the forward sortation area (FSA) of injury location were obtained from RHSCIR. FSA is a well-defined zone within a larger geographic region based on the first three characters of the postal code.²⁸

System factors. The following durations (in hours) were calculated: time between injury and admission to non-RHSCIR acute facility, and time between injury and admission to RHSCIR acute facility.

Outcome variable. The primary outcome variable in this study was triage pattern (direct vs. indirect admission). Direct admission was defined as occurring when patients were transported directly from site of injury to a RHSCIR acute facility; indirect admission was defined as arrival at a RHSCIR acute facility from site of injury via one or more hospitals.

Geomapping analysis

MapQuest application program interface (API) (MapQuest Inc.) integrated with SAS software was applied to determine the centroid of each FSA, yielding a unique combination of latitude and longitude coordinates of each FSA's geometric center. These coordinates and that of RHSCIR acute facilities, as calculated by Geographic Information Systems (GIS) technology, were used to determine the road distance between injury and RHSCIR facility. Road distance was categorized as either <40 km, 40–350 km, or >350 km. The lower category (40 km) was based on trauma destination decision guidelines that advise trauma patients be transported to the most appropriate trauma center if transport time would be <40 min;²⁹ equivalent to ~ 40 km if driving at 60 km/h. The upper category (350 km) was based on the average distance traveled by helicopter with one tank of fuel if one was deployed for transportation of patients.

The geographical distribution of tSCI was estimated and illustrated using Maptitude 2013 (Caliper Corporation) overlaid with population density obtained from Demography Division, Statistics Canada (2011).³⁰ Positions were marked for each patient randomly within the reported FSA of injury.

Statistical analysis

Descriptive analysis was performed to describe the entire study population. Further analysis was performed with the cohort of individuals whose injury location was within 40 km of the RHSCIR acute facility, within which the direct admissions were compared with the indirect admissions using bivariate analysis. Differences among medians of continuous variables were compared using Wilcoxon rank sum test, and differences among percentages of categorical variables were examined using the χ^2 test. A multivariate logistical regression model was developed to examine the variables associated with indirect admission. Variables that were statistically and clinically significant, and provinces with indirect admissions within 40 km of a RHSCIR acute facility, were considered for inclusion in the multivariate regression model.

A sensitivity analysis was performed to examine cohort selection bias between patients included and those who were excluded because of missing FSA data. Cohorts were compared based on age, gender, injury mechanism, AIS, and neurological level at admission.

A p value of <0.05 was considered to be statistically significant. All analyses were performed using SAS software, Version 9.4 of the SAS System for Windows, copyright © 2013, SAS Institute Inc., Cary, NC.

Simulation modeling

Age and gender distribution, probability of triage pattern (direct/indirect admission), and distribution of road distance between injury location and RHSCIR acute facility, all of which were derived from the analysis cohort in this study, were used in the ACT model to explore the impact of triage pattern on process of care.

Three scenarios were analyzed: 1) current direct admission rate (baseline), 2) 100% direct admission, and 3) 100% indirect admission. The outcome of interest was time to admission, which was defined as the duration between time of injury and admission to a RHSCIR acute facility. The model was run 15 times and the final outcome was the average of the 15 replications. Outcome was calculated with the following equation: $\text{outcome} = (\text{time to admission}_{\text{scenario}} - \text{time to admission}_{\text{baseline}}) / \text{time to admission}_{\text{baseline}}$.

Results

Of the 876 patients who had FSA data on injury location (Fig. 1), 77% were male and the median age was 49 years. The top two injury mechanisms were fall (49%) and transport (28%). Other injury characteristics are described in Table 1. Median road distance between site of injury and RHSCIR acute facility was 91 km (interquartile range [IQR] 19.6 and 223.5). Admission to RHSCIR facility for all patients (directly and indirectly) took a median of 5 h. For the indirect admissions, median time to the first non-RHSCIR acute facility was 1.3 h.

A sensitivity analysis revealed that patients who were excluded from the analysis because of missing FSA data ($n=509$) were significantly younger (median age 44 vs. 49, $p<0.0001$), more likely to be male (83% vs. 77%, $p=0.01$), more likely to have a sports-related injury (17% vs. 12%, $p=0.007$) or a transport-related injury (42% vs. 28%, $p<0.0001$), than those included in the analysis. Injury severity as measured by AIS and neurological level at admission was not significantly different between the two groups.

Geographic distribution of tSCI in Canada

Figure 2 describes the geographic distribution of tSCI in each province for patients admitted to a RHSCIR acute facility. A dispersed pattern is observed in provinces with geographically dispersed populations, such as the western/central provinces (British Columbia, Alberta, Saskatchewan), and a confined pattern is observed for provinces where the population density concentrates in urban cities, such as Ontario and Quebec. Figure 3 describes the geographical distribution of injuries by distance range (<40 km, 40–350 km, >350 km) for each Canadian province. Newfoundland had the largest proportion of injuries occurring >350 km from the RHSCIR acute facility (58%). In the 40–350 km range, New Brunswick had the largest proportion of injuries (80%) followed by Saskatchewan, Quebec, and Nova Scotia (63%, 55%, and 59%, respectively). Manitoba and Ontario had the most injuries in the <40 km range (50% and 49%, respectively). British Columbia had similar proportions distributed across the three distance ranges.

TABLE 1. PATIENT CHARACTERISTICS OF INJURIES OCCURRING WITHIN 40 KM OF A RHSCIR ACUTE FACILITY, AND DIRECT ADMISSION VERSUS INDIRECT ADMISSION TO THE RHSCIR ACUTE FACILITY

Variable	Total (n=876)	Injured <40 km (n=323)	Injured <40 km		p value
			Direct admission (n=249)	Indirect admission (n=74)	
Age at injury; median (IQR)	49 (31, 64)	53 (37, 65)	49 (34, 64)	61.5 (48, 69)	<0.0001
Male gender; n (%)	675 (77.1)	252 (78)	195 (78.3)	57 (77.0)	0.8145
Injury mechanism; n (%)					0.3828
Fall	431 (49.2)	198 (61.3)	147 (59.0)	51 (68.9)	
Transport	245 (28.0)	58 (18.0)	50 (20.1)	8 (10.8)	
Sports	104 (11.9)	27 (8.4)	22 (8.8)	5 (6.8)	
Assault	38 (4.3)	22 (6.8)	17 (6.8)	5 (6.8)	
Other	58 (6.6)	18 (5.6)	13 (5.2)	5 (6.8)	
Energy of injury; n (%)					0.0034
High	379 (45.3)	113 (36.3)	97 (40.8)	16 (21.9)	
Low	457 (54.7)	198 (63.7)	141 (59.2)	57 (78.1)	
Glasgow Coma Scale; n (%)					0.34
3–12	78 (10.4)	26 (9.7)	22 (10.8)	-	
13–15	669 (89.6)	243 (90.3)	181 (89.2)	62 (93.9)	
Injury Severity Score; n (%)					0.3189
≤25	440 (57.9)	173 (62.5)	129 (60.9)	44 (67.7)	
>25	320 (42.1)	104 (37.5)	83 (39.2)	21 (32.3)	
AIS at admission; n (%)					0.3003
AIS A	260 (35.0)	86 (30.9)	70 (33.7)	16 (22.9)	
AIS B	68 (9.1)	24 (8.6)	19 (9.1)	5 (7.1)	
AIS C	151 (20.3)	53 (19.1)	38 (18.3)	15 (21.4)	
AIS D	265 (35.6)	115 (41.4)	81 (38.9)	34 (48.6)	
Neurological level at admission; n (%)					0.1038
High cervical (C1–C4)	189 (27.6)	74 (28.2)	50 (25.9)	24 (38.1)	
Low cervical (C5–T1)	230 (33.6)	94 (35.9)	77 (39.9)	17 (27.0)	
Thoracic (T2–T10)	119 (17.4)	38 (14.5)	31 (16.1)	7 (11.1)	
Thoracolumbar (T11–L2)	147 (21.5)	50 (19.1)	35 (18.1)	15 (23.8)	
Time to non-RHSCIR acute facility (h); median (IQR)	1.3 (0.8, 3.3)	1.1 (0.6, 5.2)	N/A	1.1 (0.6, 5.2)	N/A
Time to RHSCIR acute facility (h); median (IQR)	5.1 (1.7, 11.8)	1.5 (0.8, 6.9)	1.1 (0.7, 2.9)	7.9 (4.3, 40)	<0.0001
Road distance (km); median (IQR)	91.1 (19.6, 223.5)	13.1 (6.1, 24)	10.7 (5.6, 19.6)	21.3 (10.3, 32.4)	<0.0001

Data within cell <5 not shown.

Bold p values indicate statistical significance.

IQR, interquartile range; AIS, American Spinal Injury Association (ASIA) Impairment Scale; RHSCIR, Rick Hansen Spinal Cord Injury Registry.

Triage pattern from tSCI to SCI center within 40 km

Considering the injuries occurring within 40 km of a RHSCIR acute facility ($n=323$), 249 patients (77%) were directly admitted and 74 (23%) were indirectly admitted (Table 1). The percentage of direct admission for injuries within 40 km for each province varied across Canada ranging from 53% to 100% (Fig. 4). The triage pattern (direct vs. indirect admission) in five major cities is illustrated in Figure 5. Four cities demonstrated a lack of geographic distinction between direct and indirect admissions, whereas Quebec City had 100% direct admissions regardless of distance (Fig. 5e). A histogram of admission frequency (direct vs. indirect) by road distance between injury location and RHSCIR facility reveals a rightly-skewed distribution for the direct admission, suggesting that more direct admissions were observed for shorter road distances, whereas no clear pattern was observed for the indirect admissions (Fig. 6).

To explore the factors associated with patients being triaged indirectly to the RHSCIR facility when they were within the vicinity (<40 km), this group was compared with those directly ad-

mitted. The bivariate analyses showed that the indirect admission group was significantly older (62 vs. 49, $p<0.0001$), more likely to have had a low-energy injury (78% vs. 59%, $p=0.003$), more likely to have been injured relatively farther away from the RHSCIR facility (21.3 km vs. 10.7 km, $p<0.0001$), and more likely to have taken longer to reach the RHSCIR facility (8 h vs. 1 h, $p<0.0001$) than the directly admitted group (Table 1). However, the median time to the first hospital (non-RHSCIR) was 1 h for the indirectly admitted group.

In the multivariate regression analysis, only older age and longer road distance remained significantly associated with being indirectly admitted to a RHSCIR facility, adjusted for energy of injury, ISS, and neurological classification (Table 2). Specifically, the risk of not being directly admitted increased by 2.7% for every increased year of age and increased by 5.3% for every increased kilometer of road distance between the injury location and the RHSCIR facility. None of the injury factors, including energy of injury, injury severity, and extent of neurological deficit were associated with triage pattern for injuries occurring within 40 km of a RHSCIR acute facility.

FIG. 2. Geomapping of traumatic spinal cord injury admitted to Rick Hansen Spinal Cord Injury Registry (RHSCIR) acute facilities in 2010–2013.

FIG. 3. Proportion of traumatic spinal cord injuries that occurred within 40 km, 40–350 km, and beyond 350 km of a Rick Hansen Spinal Cord Injury Registry (RHSCIR) acute facility by province. BC, British Columbia; AB, Alberta; SK, Saskatchewan; MB, Manitoba; ON, Ontario; QC, Quebec; NB, New Brunswick; NS, Nova Scotia; NL, Newfoundland.

FIG. 4. Direct admission of patients injured within 40 km of a Rick Hansen Spinal Cord Injury Registry (RHSCIR) acute facility by province. Each province was randomly assigned a number. Provinces with a sample size <5 were not included.

Simulation modeling

The impact of triage pattern on process of care was explored with simulation modeling. Compared with the current status, the median time to admission decreased by 20% (3.5 h) in the 100% direct admission scenario; and increased by 102% (8.9 h) in the 100% indirect admission scenario.

Discussion

This study of the geomapping of tSCI in Canada revealed a wide spatial distribution and a varying pattern of injuries across provinces. Nearly 50% of tSCI occurred at a distance range of 40–350 km of a RHSCIR acute facility, which is a SCI center that is part of a Level I/II trauma center. More than one third of tSCI occurred within 40 km and, despite the close proximity, 23% of patients were not taken directly to the RHSCIR acute facility. Patients transported directly to a RHSCIR acute facility were more likely to reach the facility within 1 h of injury, whereas those transported indirectly were more likely to arrive a median of 7 h later. We observed that indirect admission for injuries within 40 km was associated with two independent factors: older age and greater distance between injury location and the RHSCIR acute facility.

Relationship to previous literature

The 40 km cutoff was selected because it is the maximum distance patients should be transported directly to definitive care, bypassing closer non-trauma centers, if these patients meet trauma criteria.^{29,31} Within this range, distance to the RHSCIR facility should have minimal influence on triage decision. However, our study found that this does not necessarily occur, and is supportive of another Canadian study of general traumatic injuries reporting 47% of indirect admission for injuries located within 30 min of an Ontario trauma center, and that the added distance, as short as 1 mile (1.6 km), between the closest non-trauma hospital and the trauma center decreases the likelihood that the patient would be triaged to a trauma center.¹⁷

In cases in which the closest hospital is a nonspecialized trauma center, admission to the specialized center might be further delayed, as patients would be expected to be triaged to the closer

nonspecialized trauma center according to the Golden Hour concept.³² This could be an issue in many cities where multiple trauma centers have been established to serve the dense population,²¹ but not all centers have SCI specialty. Given the lack of designated SCI centers in most provinces, currently many provincial triage destination decision guidelines consider any trauma center with orthopedic and neurosurgical capability as being appropriate for treating patients with suspected tSCI. For example, in British Columbia, two such additional trauma centers are located within 40 km of the acute SCI center (the RHSCIR acute facility). Based on this guideline, 12 trauma centers in Ontario are considered capable of providing “definitive care” for SCI,¹² 7 of which are RHSCIR acute facilities. Although we did not differentiate indirect admission coming from a non-trauma center or trauma center, unpublished data from the RHSCIR show that most of the indirect admissions were from trauma centers, indicating an awareness within the trauma community of RHSCIR facilities having a SCI specialty. In contrast to the rest of Canada, the Quebec provincial government has designated two trauma centers (the RHSCIR acute facilities in Quebec City and in Montreal) as centers of expertise in SCI; this designation might play a key role in achieving the 100% direct admission for Quebec City (Fig. 5e). Designating centers as having expertise in SCI would also position the center to forge formal collaboration with other hospitals treating seriously injured patients to ensure standards of care.

The accessibility of multiple trauma centers with orthopedic/neurosurgical capability might contribute to the lack of association between neurological deficit and direct admission to a RHSCIR facility. This is consistent with previous literature that revealed that recognition of tSCI at the scene does not increase the likelihood of direct transport to a SCI center.¹⁰ However, challenges with recognizing tSCI at the scene might be the underlying reason for not triaging to the center. Given the heterogeneity of tSCI, the clinical symptoms may be unrecognizable. Concurrent injuries such as traumatic brain injury (TBI) or decreased cognitive level may make it difficult to diagnose the tSCI, whereas low-energy injuries may not raise suspicion of a tSCI,¹⁰ and detection of fractures in older people could also be problematic. It would be of great value to document the tSCI missed at the scene to clarify how changes should be made to facilitate direct transfer of the missed population. Conversely,

FIG. 5. Triage pattern of traumatic spinal cord injury to Rick Hansen Spinal Cord Injury Registry (RHSCIR) acute facility (direct vs. indirect) by city. **(a)** Vancouver, British Columbia; **(b)** Toronto, Ontario; **(c)** Hamilton, Ontario; **(d)** London, Ontario; **(e)** Quebec City, Quebec. Direct admission is represented by an open square; indirect admission by an open circle. Location of the RHSCIR acute facility is represented by a star. Radius of 40 km from RHSCIR acute facility is approximated.

challenges in recognizing TBI during assessment of a suspected SCI have been reported,³³ which might contribute to poor documentation and result in limited reporting of TBI such as we experienced with our data. Diagnosis of combined TBI and SCI is critical in defining an appropriate clinical pathway and rehabilitation treatment; therefore, future investigation into this issue is required.

Generally, patients with fall-related injuries experience delays in accessing a trauma center, whether the fall resulted in tSCI, TBI, or general trauma.^{12,17,34} Similar studies have found that the elderly

are more likely to be transported to non-trauma center and have the greatest risk of not reaching a trauma center at all.^{10,12,17,34–37} Our finding of older age being associated with indirect admission to a RHSCIR acute facility is consistent with these studies, and suggests that an etiology other than SCI was considered for this population in which cognitive deficits and mild neurological symptoms resulting from low-energy falls are common. This growing evidence highlights the need to explore the impact of delayed access to specialized care in the elderly population in future studies.³⁸

FIG. 6. Histogram of road distance between point of injury and Rick Hansen Spinal Cord Injury Registry (RHSCIR) acute facility. Directly admitted patients, dark gray bars; indirectly admitted patients, light gray bars.

Severely injured patients are associated with delayed admission to specialized or definitive trauma care^{10,16,39} because of the immediate medical attention required and provided at a closer hospital location. Considering the injury location in relation to the nearby trauma center, in addition to the acute SCI specialty center, would help to elucidate the impact of the injury severity on triage patterns. However, ISS as an index to measure severity of injury might not be sensitive enough to pick up the seriousness of the trauma, especially when considering specific injuries²⁶ such as tSCI or burns.⁴⁰ Further, ISS has not been validated for the tSCI population, and work is ongoing to develop an index for tSCI.^{41,42}

Implications

This study shows that the majority of patients with tSCI in Canada are receiving the recommended care of early transport to a SCI center. For those injured with 40 km, 77% are being directly admitted to the RHSCIR acute facility with a median time of 1 h,

whereas the rest arrive indirectly with a median time of 8 h post-injury. However, we noted a highly variable interfacility transport time (IQR of 4.3–40 h). Similar delays associated with an indirect admission have been reported in other tSCI studies in which the median wait time is 8–12 h,^{10,12,14} and can be as long as 33 h.¹⁵ Indirect admission could risk putting patients outside of the recommended 24 h post-injury time window to surgery,^{9,24} especially older patients who have a significantly longer wait time from admission to surgery than younger patients (37 vs. 19 h).³⁸

One should address the question of whether enforcing direct admission to a SCI center would be the answer, and in what way this would impact the healthcare system. To explore this question, we used simulation modeling to analyze two opposing scenarios: 100% direct admission, which is a small increase (23%) from the current status, and 100% indirect admission, which is a conceivable scenario given that older patients have been shown to experience more indirect admission, and that this population is growing. The scenario of 100% direct admission might appear to

TABLE 2. MULTIVARIATE LOGISTICAL REGRESSION ANALYSIS PREDICTING VARIABLES ASSOCIATED WITH INDIRECT ADMISSION TO A RHSCIR ACUTE FACILITY FOR TRAUMATIC SPINAL CORD INJURY WITHIN 40 KM OF THE FACILITY

Variable	Estimates	Std. error	Odds ratio	95% CI	p value
Intercept	-2.42	0.92	-	-	0.0083
Age at injury	0.03	0.01	1.03	1.00–1.05	0.0255
Energy of injury					
Low (reference)	-	-	-	-	-
High	-0.42	0.47	0.66	0.26–1.66	0.373
Injury Severity Score					
≤25 (reference)	-	-	-	-	-
>25	-0.07	0.55	0.93	0.32–2.74	0.8965
Neurological category					
C1-C4 AIS A	-0.11	0.77	0.90	0.20–4.07	0.8865
C5-T1 AIS A	-0.72	0.93	0.49	0.08–3.04	0.441
T2-L2 AIS A	-1.69	1.00	0.18	0.03–1.31	0.0911
C1-T1 AIS B, C, D	-0.40	0.54	0.67	0.23–1.92	0.4542
T2-L2 AIS B, C, D (reference)	-	-	-	-	-
Road distance (km)	0.05	0.02	1.05	1.02–1.09	0.0007

Bold p values indicate statistical significance.

CI, confidence interval; AIS, American Spinal Injury Association (ASIA) Impairment Scale; RHSCIR, Rick Hansen Spinal Cord Injury Registry.

have little impact on the system, with savings of only 2 h; however, the clinical significance of this cannot be underestimated, as early complications of SCI such as hypotension requiring vasopressors and respiratory distress requiring intubation need to be managed in the first few hours of injury to avoid further morbidity and mortality.⁴³ Further, a recent study examining functional recovery at 1 year showed that very early treatment (<8 h) is beneficial for cervical trauma.⁸ The opposing scenario of 100% indirect admission resulted in doubling the time to reach a RHSCIR acute facility, implying that if the current triage practice is not rectified, more unnecessary indirect admissions and significant delays to specialized care could occur.

Currently, evidence supporting benefits of direct admission is limited,⁴⁴ as most SCI studies examined the benefits of early admission instead (i.e., within 24 h post-injury), and none stratified the injury by distance to SCI center.^{2,4,5,10} However, direct admission for injuries within 40 km of a SCI center, and hence early access to care, offers many opportunities that would position patients and the healthcare system to gain substantially in the long term. Direct admission to a SCI center minimizes risk of exacerbating the injury that could arise during transfer and prolonged spinal immobilization. It also reduces variability in care, as practice and expertise differ in non-SCI centers. Patients who are directly admitted can participate in clinical trials testing promising neuroprotective and neuroregenerative treatments that usually have an effective time window of <12 h.⁴⁵ From the health system perspective, reducing the unnecessary admission to the intermediate hospital and subsequent transportation to the RHSCIR acute facility can free up resources and save costs.

Next steps/gaps

To elucidate the benefits of direct admissions to specialized centers, comparing the outcomes between direct and indirect admission, as well as between those treated in RHSCIR facilities and those treated in non-RHSCIR facilities requires further investigation. It is also valuable to delineate which patient population (the specific type of SCI or age) would potentially benefit most from direct admission. Emerging evidence suggest that individuals with cervical injuries¹¹ or with incomplete injuries²⁴ have greater motor recovery if they have surgery within 24 h of injury. This could be especially relevant for the elderly, who are likely to be delayed in reaching a RHSCIR facility and being operated on;³⁸ however, given the increased rates of pre-existing comorbidities⁴⁶ and the higher likelihood of developing complications,⁴⁷ timing to specialized care might be important to this group.

The relationship between indirect admission and road distance is likely confounded by nearby trauma centers. Future research will determine the differential distance traveled for indirect admission to understand the role of the spatial relationship among trauma centers, RHSCIR acute facilities, and place of injury in the triage pattern. The spatial relationship should also be examined in terms of driving time, as it is a decision point in pre-hospital triage protocol.

To gain further insight into triage decisions, mode of transportation (ambulance or private vehicle), and timing of injury will be considered. Time of the day could impact driving times, which is especially relevant given the urban nature of the centers being studied, whereas day of the week (weekday vs. weekend) or the year (holiday) could impact surgeon or staff availability. Extending the analysis to beyond 40 km would be important, as nearly half of the tSCI occurred in the 40–350 km range. In addition, process

mapping of the pre-hospital care phase would capture the practical decision points involved in triage process. Further, all of this information would be critical for identifying appropriate solutions to enhance the triage guideline to support early transport to a SCI center.

Limitations

Our analysis required location information (FSA), which was collected from patients for whom expanded data were available, and a selection bias was introduced by excluding those without FSA data. However, given that the excluded group shared similar attributes (age and injury mechanism) with those who were injured farther than 40 km from a RHSCIR acute facility, this exclusion would not be expected to impact our findings, which concerned injuries within 40 km of a RHSCIR acute facility.

FSA did not provide precise information on injury location, and might affect the accuracy of the road distance measured. ISS was collected through the trauma registry, which primarily included patients with an ISS >12. This study was also limited by the small sample size of injuries occurring within 40 km, which prevented stratification by province for adjusting in the multivariable analysis. Finally, provincial triage protocols were not easily accessible, making it difficult to compare practice with the recommendations for each provincial trauma system.

Conclusion

The geographical pattern of tSCI discovered in this study can inform province-specific resource allocation and triage protocol to optimize the pre-hospital care within a Canadian context. Our findings that 77% of injuries located in proximity to a RHSCIR acute facility are directly admitted to indicate potential to improve early transport to SCI care. Further, our findings that older age and longer road distance decrease the likelihood of direct admission suggest that lack of recognizing tSCI at the injury scene by paramedics and lack of SCI center designation might contribute to the delayed access to SCI care. This study will inform further research into factors that influence triage and optimal pre-hospital care for individuals with tSCI, and ultimately inform the development of indicators for quality improvement.

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