Traumatic brain injury in a rural indigenous population in Canada: a community-based approach to surveillance

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OL conceived a part of the project in addition to developing the study design, methodology, abstracting primary data from patient charts, completing the data analysis and writing the manuscript. RWD conceived the project, helped with the study design and reviewed the manuscript. RF helped in organizing and designing the study, reviewed the methodology and data analysis used in the study as well as reviewing the manuscript. JT and RC helped in developing the study design, organizing and coordinating the study and reviewing the manuscript. They were also responsible for liaising with stakeholders of the communities under investigation to ensure that all content was culturally appropriate for the population of Eeyou Istchee. JM conceived the project with OL and RWD, developed the study design and methodology, reviewed the manuscript and was the main supervisor for OL's MSc degree.

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Abstract

Background: Indigenous populations are disproportionately affected by traumatic brain injury (TBI). These populations rely on large jurisdiction surveillance efforts to inform their prevention strategies, which may not always address their needs. This study aimed to describe the TBI epidemiology of a primarily indigenous region, Health Region 18 (HR-18), of Québec and compare it with two neighbouring regions and the entire province, in order to identify prevention strategy priorities for these communities that would be compared to recommendations from a province-wide surveillance initiative.

Methods: We conducted a retrospective, population-based cohort study of incident TBI hospitalizations in Québec, stratified by three neighboring rural and/or indigenous HRs between 2000-2012. Administrative hospitalization data were used for case finding. A sub-analysis of HR-18 adults was completed to assess for determinants of TBI severity/outcome. Regression models, multiple imputations, and a sensitivity analysis were used to assess for biased associations.

Results: 172 incident TBI hospitalizations, mainly caused by assaults, occurred in HR-18. The incidence rate was 92.1 per 100,000 person-years, which was 1.86 times (95% CI 1.56-2.17) higher than for the rest of the province. HR-18 rates

were higher than in a neighbouring non-indigenous population but significantly lower than in a neighbouring indigenous population. Adults using protective equipment had less severe injuries and better functional outcomes. Patients involved in motor vehicle collisions were most likely to receive rehabilitation.

Interpretation: Community-based TBI surveillance provides evidence that rural and indigenous communities can use to prioritize pertinent prevention strategies, which may not be possible with large jurisdiction surveillance initiatives.

Background

Traumatic brain injury (TBI) heterogeneously affects populations around the globe. Rural populations tend to have higher TBI occurrence and worse outcomes.[1,2]. In Canada, the poorer health status of indigenous peoples compared to the general population has been described.[3,4] Injuries are the greatest cause for potential years of life lost in this population, with rates that are four times higher than for the rest of Canadians.[5,6] More specifically, TBI represents a significant proportion of these injuries in indigenous North-American populations.[7-10] Moreover, these populations have different risk factors related to the occurrence of trauma compared to other Canadians.[11,12] For example, the predominant mechanisms of injury associated with TBI are different in urban versus rural environments where many indigenous populations reside.[13] The spectrum of disability amongst different indigenous populations varies after injuries.[14] Given that the determinants of TBI occurrence and outcomes differ significantly between indigenous populations, surveillance conducted on a community-specific basis is likely to provide evidence that informs relevant prevention strategies for these communities.[3,15]

The Institut National de Santé Publique du Québec completed a provincial TBI surveillance study in 2012 on non-intentional TBI hospitalizations and analyzed the data stratified by different health regions (HRs). This report concluded that the prevention of falls was a priority to reduce the provincial TBI disease burden. However, the two northern Québec HRs that represent indigenous communities (HR-17 - Nunavik and HR-18 - Terres-Cries-de-la-Baie-James which serves the Cree of Eeyou Istchee) and a non-indigenous region with a similar geographical milieu to the two aforementioned regions (HR-10-Nord-du-Québec) were excluded from their analysis.[16]

The primary aim of our study was to compare and contrast the rates and determinants of TBI between Eeyou Istchee and both a neighboring indigenous (HR-17) and non-indigenous community (HR-10). A secondary aim of the study was to describe severity, risk factors, functional outcomes, and use of rehabilitation resources amongst adult TBI cases in Eeyou Istchee. This analysis would then be used to formulate which prevention strategies would be relevant to this region and compare them to thoserecommended through the above province-wide surveillance study.

Methods

Study design, population, and setting

We conducted a population-based retrospective study of all hospitalized incident TBI cases from a single HR of Québec (HR-18) that represented the patients from a single indigenous population (Eeyou Istchee) from 2000-2012. The epidemiologic descriptions of two neighboring HRs (HR-17, a predominantly Inuit population, and HR-10, a predominantly non-indigenous population) and the rest of Québec were used as comparison populations (Figure 1).[17,18]

Case definitions and primary outcome

The province of Québec provides public health care coverage to its residents. For case finding, we used a provincial hospitalization database, MED-ÉCHO, which records all hospitalizations in the province and categorizes people based on their residence in a specific HR [19]. This administrative database uses the International Classification of Disease 9 (ICD-9) coding scheme from 2000-2005, whereas from 2006-2012 the Canadian version of ICD-10 was used. We used a similar case definition as the INSPQ to have comparable surveillance data to the rest of the province (Table 1).[16] However, intentional TBI cases were also included in this analysis since assaults are a prominent mechanism of injury in indigenous communities.[6]

Since TBI severity/outcome is not homogeneously assessed amongst the pediatric and adult populations and TBI predominantly affects young adults in indigenous communities, a further analysis was completed in adults (15 years or older).[20] These patients' charts were reviewed at all of the hospitals and clinics where they were treated for their incident head injury (Supplementary Figures s1 and s2).

Measured variables

The variables ascertained from MED-ÉCHO included the patient's age, gender, length of hospital stay, external cause of injury (mechanism of injury), primary and secondary diagnoses of the hospitalization, and the patient's HR/present municipality of origin. The external mechanisms of injury were coded as per the ICD-9/ICD-10-CA classifications (Table 1).[16] Using a data extraction form, a chart review was conducted by the primary author who has over 5 years experience as a neurosurgery resident and has training in epidemiology/biostatistics. The chart review was used to measure, amongst other variables (see Supplementary Methods s3), injury severity and outcome using the Glasgow Coma Scale and Glasgow Outcome Scale (GCS/GOS).[21,22]

Missing data

For the primary analysis, there were only missing data for mechanisms of injury for the entire Province of Québec

(6.6%). A listwise deletion approach was used for regression analyses using these data since they were assumed to be missing completely at random. For the secondary analysis, if charts were not accessible, missing data were multiply imputed by chained equations using 20 datasets and 10 iterations per dataset with the “R mi” package. [23]

Statistical analysis

The denominator for the TBI incidence calculation was determined through census data provided by the Statistical Institute of Québec and the Ministry of Health and Social Services.[16,24,25] The incidence rates were standardized to the 1991 Québec population structure as was done in the province-wide surveillance project.[16] Adjusted incidence rate ratios (IRRs) were computed using negative binomial models (since the variance and mean of counts were not equal) between the study population and the three referent populations, while controlling for age, gender, and year of injury. Mechanisms of injury and their association to each region were assessed using the same adjustment covariates. Based on differing environments of HR-18, the region was divided into 3 groups: “inland”, “coastal”, and “remote” communities based on their relationship to James Bay (Supplementary Figure s1 and Methods s3). For the secondary objectives, six regression models were used to assess the association of certain risk factors with the occurrence or outcome of TBI and model selection techniques used are described in Supplementary Methods s3.

For all regression coefficient estimates from regression models, a 95% confidence interval was calculated. R version 3.0.3 for Mac OS X (R Foundation for Statistical Computing, 2012) and Stata 12.0 for Mac OS X (StataCorp, 2011) statistical software were used for all data analysis. As described by Zou, to avoid biased large odds ratios, risk ratios were estimated using a Poisson regression model since the outcomes were common.[26]

Sensitivity analysis

Since the study was conducted in rural to remote populations, more hospitalizations may have occurred for milder injuries compared to an urban centre where hospital beds are proportionately more limited for a larger population. To assess for this bias, a sensitivity analysis was completed by measuring the proportion of mild, moderate, and severe TBI hospitalizations in the urban population of Montréal (HR-6) (seen as “Montréal” on Supplementary Figure s1) at a level 1 trauma centre and comparing it to HR-18 (Supplementary Methods s3).

Ethics

The Institutional Research Ethics Board of McGill University approved this study. The study conformed to the Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans and First Nations, Inuit, or Métis people. [27] Each hospital where a chart review was completed had authorization from their Director of Professional Services. The Cree Board of Health and Social Services of James Bay Public Health Department partnered with the study, which was approved by the Public Health Management Committee.

Results:

172 TBI hospitalizations occurred in HR-18 from 2000-2012, resulting in a crude incidence rate of 92.1 per 100,000 person-years (Table 2). Mechanisms of injury were mainly related to assaults followed by falls,motor vehicle collisions, and off-road vehicle collisions. For most years, the standardized rates in HR-18 were higher than in the entire province (Figure 2a). The remote community had the highest rate of TBI hospitalizations followed by coastal and inland communities. The distribution of mechanisms of injury varied by age group with the youngest and oldest having falls as the most common mechanism (Figure 2b). Adjusted for relevant confounders, HR-17 had the highest incidence rates followed by HR-18 and HR-10 (Table 2).

The multinomial regression revealed that assaults were more strongly associated with HRs-18 and 17 than with HR-10 and the rest of Québec (relative probability ratios of 10.69, 11.77, and 1.47, respectively). ATV collisions were proportionately more frequent in HR-17 than in all other HRs. HRs-18 and 10 had similar relative probability ratios of these collisions, which were higher than in Québec (Supplementary Table s4). Similar results for snowmobile collisions were observed. Off-road vehicle collisions were more common in the remote community compared to inland and coastal communities (Supplementary Table s5 and Figure 2c).

There were 117 incident TBI hospitalizations for individuals 15 years or older between 2000-2012 (Supplementary Table s6). In terms of injury severity, there were mainly mild TBI hospitalizations (83.5%) followed by severe and moderate TBI. The range of follow-up time for the GOS calculation was 5 to 14 months. Only 27% of patients who could have worn protective equipment did so. 55% of patients were reported as being intoxicated with alcohol at the time of their injury (Supplemental Figures s6 and s7).

Patients in the remote community had more severe injuries than those in the other communities. Individuals wearing protective equipment tended to have less severe injuries and had a better outcome as assessed by the GOS. Patients involved in MVCs had a higher probability of receiving rehabilitation than those with a mechanism of fall or assault (Table 3 and supplementary material s8).

Supplementary Table s10 demonstrates thatthe severity distribution of TBI hospitalizations in HR-18 and HR-6 were similar. The latter provides evidence that the indications to hospitalize patients in the rural and urban setting were similar. Therefore, the comparison of rates between the rural setting and the rest of the province appears justified.

Discussion:

This study demonstrates that the epidemiology of TBI for the entire province of Québec is different from its rural and indigenous communities. The rates of TBI are higher in these communities and the mechanisms of injury leading to TBI are significantly different. Moreover, we showed that varying geographical environments throughout these communities were important determinants of TBI occurrence and injury severity. The detailed analysis of adults living in Eeyou Istchee provided a better understanding of prevention strategies that would be useful to this community in addition to identifying inequalities in access to health care resources. Relying on province-wide surveillance initiatives failed to properly describe TBI epidemiology for this community.

The heterogeneity of TBI epidemiology between populations has been reported in various jurisdictions and has been attributed to varying case definitions, data sources, and risk factors [28–31]. For example, the provinces of Ontario and Québec completed surveillance studies on TBI hospitalizations using similar ICD coding methodology.[16,32] Their rates tended to consistently decrease over a decade and to be no higher than 83.4 cases per 100,000 person-years. In contrast, the rates in Eeyou Istchee were consistently higher and did not decrease over time (Figure 2a).[9,16,32] Since our surveillance methodology was nearly identical to the latter studies', the main variation must be due to differing risk factors in these populations. Furthermore, these two provincial surveillance studies each concluded that preventing falls is a priority for reducing TBI burden across their populations. Although this recommendation may be useful for the HR-18 population, it overlooks other important mechanisms of injury that could be the object of prevention strategies, such as assaults. Our analysis demonstrated that assaults were more common in the indigenous communities than non-indigenous communities in Québec. In Alberta and New Zealand, the main causes of TBI/trauma amongst indigenous and non-indigenous populations vary, with the indigenous populations being more affected by assaults.[6,13] In contrast, a study completed on TBI rehabilitation patients in Saskatchewan found no such association.[8] Briefly, the heterogeneity in TBI epidemiology between and within rural/indigenous communities can be explained by varying geographical environments.Varying cultural/social determinants, which were not the focus of this study, are probably important contributors as well. [33]

The detailed analysis of adult TBI cases was critical in understanding determinants of TBI severity and outcomes. For example, the main factor increasing the initial severity of TBI was living in a remote geographical zone. Previous research has demonstrated that individuals living in rural environments are more prone to transport-related accidents, which was substantiated by our findings [34]. Although mechanism of injury was controlled for, residual confounding of this association likely exists. The number of kilometers/time driven with off-road vehicles in this remote community is likely higher since they have no access to provincial roadways like the coastal/inland communities. However, the remote community of HR-18, set in the same remote environment as HR-17, had lower rates of TBI hospitalization. As above, there are probably other unmeasured cultural/social factors that play a role in TBI occurrence. Our study demonstrated that protective equipment use predicted a lower severity of injury and an improved functional outcome for HR-18 adults, which is supported by previous investigations confirming its efficacy. [35-37] Our analysis suggests that milder injuries and younger age were associated with lesser use of rehabilitation services. Patients in MVCs had a greater chance of receiving rehabilitation than those with assaults or falls. Rehabilitation services, across the spectrum of different severity TBI, have been shown to improve victims' functional outcomes.[38] These inequalities should be addressed with policies that encourage providers and the health care system to offer rehabilitation resources based on need.

This study's strengths stem from its design of comparing three neighboring indigenous/rural populations to the greater population of the province where they reside.[6,7] Two indigenous populations do not have the same environmental, cultural, or socio-economic situations, but they do have more similarities than to the general population. Our design allowed us to partially control for unmeasured covariates, which helped establish differences in TBI occurrence at the local level (i.e. varying geographical environments).[7-9,13,34] The thorough chart review permitted a detailed analysis of community-specific risk factors for TBI occurrence and outcome that is not feasible when using administrative data. The sensitivity analysis confirmed that incidence rates between urban and rural settings in Québec were comparable.

One limitation of this study is that case finding relied on hospitalization data using ICD coding. ICD codes have also been known to be less sensitive at identifying mild TBI cases.[39] Mortality cases that were never hospitalized were not included in our analysis, which leads to more underestimation of incidence rates/mortality figures. Also, our population had GOS scores from 3 to 5. Out of the 97 patients with full data, 45 (46.3%) did not have a recorded GOS. For these cases, the chart extractor interpreted clinical follow-up notes to establish the GOS. However, this method of assigning the GOS has not been validated. A score of 3 may be easy to differentiate from higher scores, but there may have been misclassification between scores of 4 and 5 because of subtleties that cannot be ascertained from a chart. If this misclassification were non-differential, the magnitudes of our association measures would be biased towards the null.

Conclusions:

Large jurisdiction surveillance efforts cannot always capture accurately the determinants of TBI for indigenous and rural communities. Community-based surveillance efforts should be encouraged in these communities so that evidence that informs relevant prevention strategies is available. Lastly, this surveillance approach would allow further research on the cultural and social determinants of TBI, which is necessary to further tailor prevention strategies to individual communities.

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Figure legends:

Figure 1:

Title: Map of Québec with HRs-10, 17 and 18.

Legend: Maps of Québec showing how the different HRs in the study are geographically related. HR-18 has 9 communities (arrows on Figure 1a) and is nested mainly within HR-10 (Figure 1b). The northernmost community of HR-18 is nested with HR-17 (Figure 1c). These images were altered from the original images that were provided by Zorion on Wikimedia Commons. The alterations are in keeping with the Creative Commons Attribution-Share Alike 3.0 Unported license on Wikimedia Commons.[17]

Figure 2:

Title: HR-18 yearly incidence rates compared to Québec and descriptive statistics on mechanisms of injury in the region.

Legend: Figure 2a shows HR-18 and Québec incidence rates were standardized to the 1991 population structure of Québec. Figures 2b and 2c demonstrate that mechanisms of injury varied by age group and geographical zone of HR-18, respectively.

Table 1:

Title: ICD codes used to define TBI incident cases and external causes of injury using ICD-9 and ICD-10 CA codes

	International Classification of Disease Iteration codes	
TBI diagnostic codes	***ICD-9***	***ICD-10 CA***
Skull fractures	800.0-801.9 803.0-804.9	S02.0-S02.1 S02.7 S02.89 S02.9
Intracranial lesions	850.0-854.1	S06.0-S06.9 T06.0
External causes of Injury	***ICD-9***	***ICD-10 CA***
Motor vehicle traffic accident	E810-E819 (.0, .1)	V30-V79 (.4-.9) V83-V85 (.0-.3)
Motorcycle accident	E810-E819 (.2, .3)	V20-V29 (.3-.9)
Snowmobile accident	E820 (.0, .2, .3, .8, .9)	V86 (0.02)
All-terrain vehicle accident (ATV)	E821 (.0, .2, .3, .8, .9)	V86 (0.03, 0.09)
Fall	E880-E882, E883 (.1-.9), E884 (.1-.9), E885, E886.9, E887-E888	W00-W01, W03-W08, W10-W15, W17-W19, X59.0
Recreational/sports accident	E828.2, E830-E831 (.4, .5), E842.6, E883-E884 (.0), E886 (.0), E902.2, E910 (.0, .1, .2), E917.0, E927.9	V80, V90-V94 (.5,.7,.8), V96, W02, W09, W16, W21, W22 (.0-.7), W51 (.0-.7), W67-W70, X50
Bicycle accident	E800-E809 (.3), E810-E819 (.6), E820-E825 (.6), E826-E829 (.1), E826.9	V10-V19
Pedestrian	E800-E809 (.2), E810-E819 (.7), E820-E825 (.7), E826-E829 (.0)	V01-V09
Assault	E960-E969	X92-X99, Y00-Y09

Legend: Similarly to the INSPQ surveillance study, ICD 9 codes were used for case definitions between 2000 and 2005 and ICD-10 CA codes were used for case definitions between 2006 and 2012.[16] This study additionally included cases that resulted from assaults, which the INSPQ did not include.

Table 2:
Title: Summary statistics and incidence rates of TBI hospitalization by health region/province-wide (Part 2A) and by geographical zone of HR-18 (Part 2B)

Summary statistics for HR-18 and referent populations (Part 2A)								
	Region 18		Region 17		Region 10		Province of Québec	
Total TBI hospitalizations	172		469		154		50,362	
Age								
Mean	24.63		23.42		35.32		45.93	
Range	0-80		0-86		0-98		0-106	
Standard deviation	18.03		16.28		24.44		29.20	
Sex (%)								
Male	113	(65.7)	255	(54.4)	100	(64.9)	32041	(57.1)
Female	59	(34.3)	214	(45.6)	54	(35.1)	18321	(42.9)
Mechanism of injury (%)								
Assault	44	(25.6)	76	(16.2)	8	(5.2)	1866	(3.7)
ATV	17	(9.9)	173	(36.9)	15	(9.7)	1243	(2.5)
Snowmobile	11	(6.4)	17	(3.6)	2	(1.3)	150	(0.3)
Fall	38	(22.1)	72	(15.3)	57	(37.0)	24086	(47.8)
MVC	36	(20.9)	41	(8.7)	31	(20.1)	9129	(18.1)
Bicycle	7	(4.1)	9	(1.9)	8	(5.2)	2851	(5.7)
Pedestrian	3	(1.7)	24	(5.1)	4	(2.6)	2365	(4.7)
Motorcycle	0	(0)	12	(2.6)	0	(0)	841	(1.7)
Recreation/sports activity	6	(3.5)	2	(0.4)	1	(0.6)	326	(0.6)
Other	10	(5.8)	43	(9.2)	28	(18.1)	4202	(8.3)
Missing	0	(0)	0	(0)	0	(0)	3303	(6.6)
Total population person-years contributed	186,581		142,059		198,786		100,545,876	
Crude incidence rate from 2000-2012 (per 100,000 person-years)	*92.10*		*330.15*		*77.47*		*50.09*	
NB regression IRR (95% CI)	*1.84 (1.56 , 2.17)*		*6.82 (6.06,7.65)*		*1.55 (1.30,1.83)*		*1.00 (Referent)*	

HR-18 analysis by geographical zone (Part 2B)			
Zone	**Inland**	**Coastal**	**Remote**
Crude incidence rate from 2000-2012 (per 100,000 person-years)	*72.04*	*95.48*	*200.00*
NB regression IRR (95% CI)	*1.00 (Referent)*	*1.32 (0.96 ,1.82)*	*2.73 (1.64, 4.27)*

Legend: Missing data were only present for province-wide data on mechanisms of injury and only represented a small proportion (6.6%). As such, for all subsequent regression models, a listwise deletion (complete case) analysis was used. The two negative binomial regression models shown were adjusted for age, sex and year of injury. NB = negative binomial, IRR = incidence rate ratio, CI = confidence interval.

Table 3:

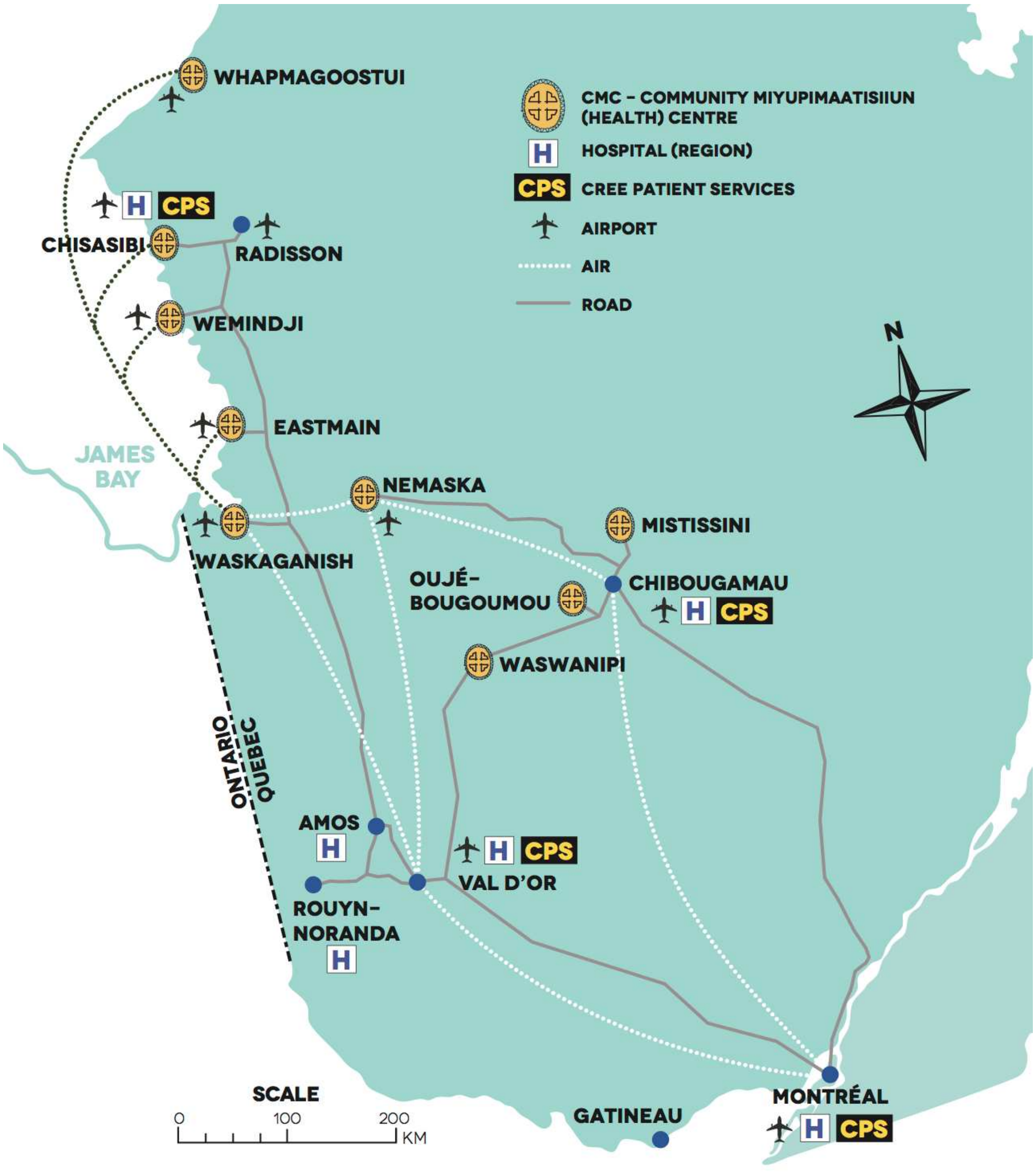
Title: Summary of regression models used in the study's secondary analysis to assess associations between TBI risk factors/determinants and injury severity, functional outcome, and use of rehabilitation.

Outcome - contrast/(regression type)	**Effect measure**	**95% CI**	**Interpretation**
GCS - remote versus inland geographical zone/(Linear)	Beta = -2.76	-4.67 , -0.84	*Living in a remote community predicted more severe TBI (lower initial GCS)*
GCS –protective equipment use/(Linear)	Beta =1.29	-0.27 , 2.85	*Use of protective equipment predicted less severe TBI*
GOS –protective equipment use/(Proportional odds)	OR = 0.17	0.03 , 0.85	*Use of protective equipment predicted better outcomes on GOS*
GOS - initial GCS/(Proportional odds)	OR = 0.57	0.44 , 0.74	*Higher initial GCS predicted better outcomes on GOS*
Rehabilitation use - initial GCS/(Poisson with robust variance)	RR = 0.86	0.78 , 0.96	*Lower initial GCS predicted use of rehabilitation services*
Rehabilitation use - MVC versus fall (Poisson with robust variance)	RR =3.79	1.53 , 9.33	*Being involved in an MVC predicted use of rehabilitation services*

Legend: Depending on the model selection results (see Supplementary Methods s3), the following covariates were included in the models: age, sex, initial GCS, six month GOS, comorbidities, geographic zone, rehabilitation use, protective equipment use, polytrauma status and alcohol intoxication status. Online Supplementary Figures s9a-s9f show the complete regression outputs for each of these regression models.Supplementary Methods s3 describes the assumptions that were made when using each of these models. RR = Risk ratio. OR = Odds ratio. CI = Confidence interval.

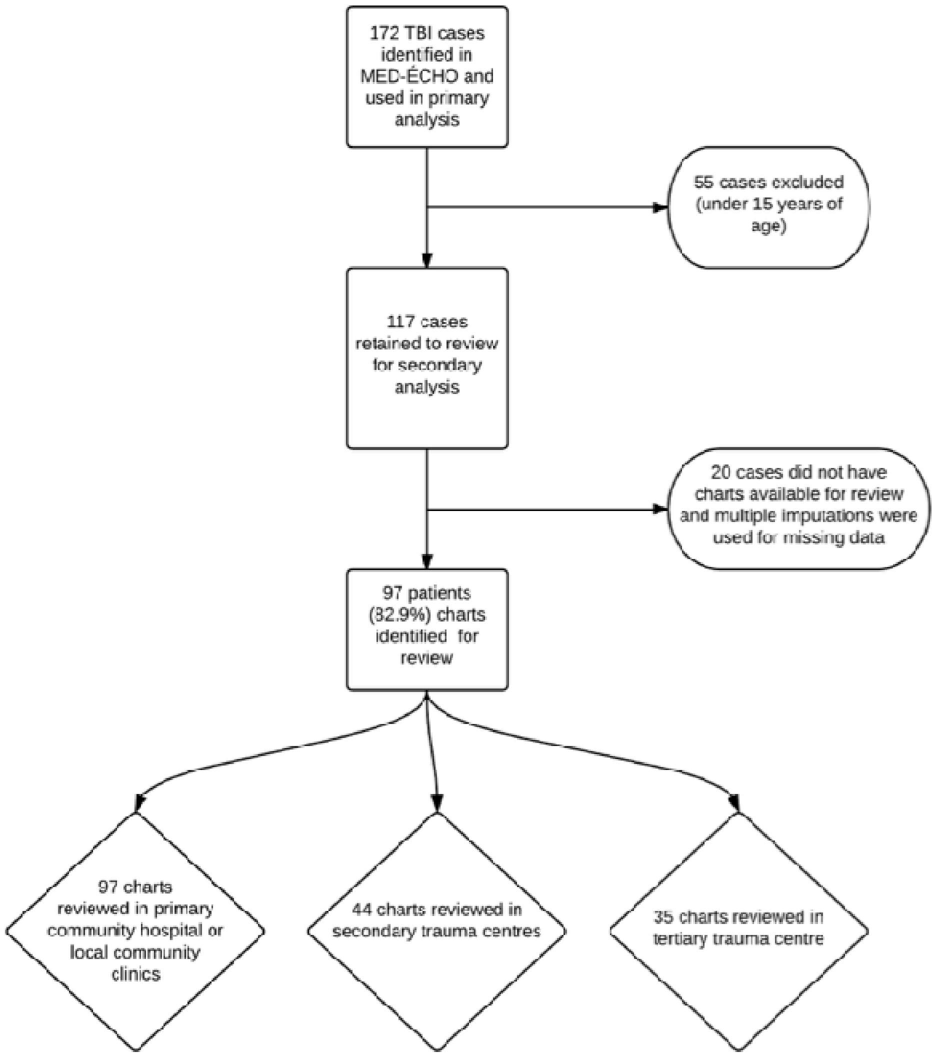
Supplementary File

Figure s1: Map of Eeyou Istchee's (HR 18) health network and road access



Each of the 9 communities in Eeyou Istchee have a local medical clinic (CMC) except for 1 community where there is a hospital. Four communities are considered inland and four other communities bordering the James Bay are considered coastal. These last communities all have access to the provincial road network. A single northernmost community bordered by the Hudson Bay is considered remote, where there is no access to the provincial road network. For the secondary analysis chart review, all local clinic charts were audited for identified cases as well as the charts at the secondary and tertiary trauma hospitals that are part of the HR 18 health network. Reproduced with permission for the CBHSSJB (Cree Board of Health and Social Services of James Bay. 2014. http://www.creehealth.org/communities. Accessed April 22, 2015).

Figure s2: Flow-chart of data ascertainment for the primary and secondary analyses.



For the primary analysis the MED-ÉCHO administrative database was used for case finding based on the definitions provided. For the secondary analysis, charts were reviewed at local community clinics. If patients were transferred numerous times between institutions (shown on Figure s1), up to three different charts of a single patient were reviewed.

Supplementary Methods s3:

Measured variables:

All-terrain vehicles (ATVs) and snowmobiles were grouped together in the analysis as "off-road vehicle" collisions. The additional variables ascertained through the chart review were used to address the secondary objectives of the study. These variables included the earliest initial post-resuscitation Glasgow Coma Score (GCS), specific use of protective material (seatbelt or helmet), polytrauma status (defined as any patient with a traumatic injury to another body region in addition to the head), comorbidity status (including any patient with 2 or more of diabetes mellitus, dyslipidemia, hypertension, coronary artery disease, history of stroke or psychiatric illness) and intoxication status with alcohol as reported by the chart note of the first physician assessment. The severity of injury was classified as "mild", "moderate" or "severe" based on the earliest recorded post-resuscitation GCS (GCS of 13-15, 9-12, 3-8, respectively).[21] Functional outcomes were assessed with the first Glasgow Outcome Scores (GOS) of patients at least 6 months after the injury, as noted in the patient's chart by their family physician at their local CMC or by a rehabilitation physician who would have sent their assessment for inclusion in the patient's chart.[22] A score of 1 was death, 2 was a vegetative state, 3 was permanent disability requiring help with daily living, 4 was moderate disability where special assistance may be need for specific tasks, and a score of 5 was a functional recovery with low disability. If a GOS score was not explicitly recorded, the chart extractor interpreted the clinical notes (by physicians or nurses following-up with the patients) 6 months after the injury to assign a GOS. Lastly, charts were reviewed to ascertain whether or not patients had used inpatient or outpatient rehabilitation services for their injury.

Region 18 communities were stratified based on their geography as either "coastal (semi-remote)", "inland" (rural and semi-remote) or "remote" as these communities have similar built environments (i.e.: coastal communities are on the James Bay coast and have distant access to the provincial network of roadways, inland communities are significantly closer to the provincial network of roadways and are not on the James Bay coast, and the remote community has local roadways that are not connected to provincial roadways or other communities) (Figure s1 above).

Missing data:

Diagnostic plots included in the package were used to verify the validity of the imputed data. All regression models used in the secondary analysis used pooled estimates of the imputed datasets. These data were assumed to be missing at random.

Statistical analysis:

Mechanisms of injury were compared between HR 18 and the reference populations using a multinomial regression model. In addition, comparisons between mechanisms of injury within HR 18 were contrasted by the geographical zones of the communities to identify whether the built/natural environment had an association with the mechanism of injury. For this last analysis, two Poisson regression models that used a robust variance to estimate the risk ratio (RR) were use to contrast the risk of incurring a TBI with a specific mechanism compared to all other mechanisms by geographical zone. The methodology behind this approach has been previously described.[26]

For the secondary objectives of the study, which were to describe the severity, risk factors, functional outcomes, and use of health care resources amongst adults affected by TBI in Eeyou Istchee, descriptive statistics on the risk factors of TBI hospitalization in adults were produced using only complete data. Moreover, different regression models subsequently described were used to compute association measures of various risk factors related to TBI on injury severity, functional outcome, use of rehabilitation and alcohol intoxication. Linear regression models were used to assess the association between the use of protective equipment/geographical zone and injury severity (GCS). Each linear model used met the assumptions used for linear regression (normality of residuals, a linear relationship between the dependent and independent variables and homoscedasticity). Cumulative odds logistic regression models were used to assess the association of protective equipment/injury severity on functional outcome at 6 months (using the GOS). If the proportional odds assumption was met, a proportional odds logistic regression was used. Poisson regression models were used (instead of logistic regression models since the outcomes were common) to assess the association between mechanism of injury and the and the use of rehabilitation services or alcohol intoxication at the time of injury.[26] These associations were set out at the start of the study to establish whether injury severity, outcome and use of rehabilitation services were affected by/associated to modifiable risk factors in HR-18. Regression models were selected based on a forward-backward iterative process using the Akaike Information Criterion statistic to select the most parsimonious model along with traditional directed acyclic graphs to ensure that only known confounders of the associations being investigated were included in the models.

Sensitivity analysis

Given that the study was conducted in rural to remote populations there was the possibility that more hospitalizations may have occurred for milder injuries compared to an urban centre where hospital beds are proportionately more limited for the larger population it serves. Thus, a sensitivity analysis was completed by measuring the proportion of mild, moderate, and severe TBI hospitalizations in the urban population of Montréal (HR-6) (indicated on Figure 2 as “Montréal”) at a level 1 trauma centre and comparing it to HR-18. The TBI database of the trauma centre that admits these patients was used to identify all the moderate and severe TBI patients admitted from their specifically defined catchment area. This database records all TBI hospitalizations along with many variables including the initial post-resuscitation GCS. Obligatorily, moderate and severe TBI patients are admitted to this specialized centre, whereas most other mild TBI cases that occur in HR-6 are managed in non-specialized trauma centres of the region. Using the MED-ÉCHO database, all TBI cases in Montréal's HR were identified that are a part of this trauma centre's catchment area. With this last denominator, the proportions of different severity TBI in this urban population were computed and compared to those of HR 18. A Chi-Square test for independence with a significance level of 5% was used to establish whether or not there was a difference in the distribution of TBI severity in the urban versus rural settings.

Supplementary Table s4: Associations between mechanism of injury leading to TBI hospitalization and HRs using multinomial regression

Region and mechanism of injury	Relative probability ratio	95% confidence interval
HR-10		
Assault	1.47	0.69 , 3.11
ATV	4.11	2.28 , 7.38
Snowmobile	4.66	1.12 , 19.37
HR-17		
Assault	11.77	8.40 , 16.48
ATV	38.06	28.40 , 51.00
Snowmobile	32.77	18.59 , 57.78
HR-18		
Assault	10.69	6.81 , 16.80
ATV	6.06	3.38 , 10.87
Snowmobile	34.20	16.97 , 68.94

The referent population is the entire province of Québec and the referent mechanism of injury is falls. The model was adjusted for age, sex and year of injury. The rest of the output is available below.

Coefficient	Odds ratio	95% confidence interval
Intercept: Assault	0.08	0.07 - 0.09
Intercept :ATV	0.07	0.06-0.08
Intercept : Bicycle	0.25	0.23-0.27
Intercept :Motorcycle	0.04	0.03-0.05
Intercept :MVC	0.84	0.79-0.89
Intercept :Other	0.35	0.32-0.37
Intercept :Pedestrian	0.21	0.19-0.23
Intercept :Recreation	0.05	0.04-0.07
Intercept :Ski	0.01	0.00-0.01
age: Assault	0.98	0.97-0.98
age:ATV	0.97	0.97-0.98
age : Bicycle	0.97	0.97-0.97
age :Motorcycle	0.98	0.98-0.99
age :MVC	0.98	0.98-0.98
age :Other	0.97	0.97-0.98
age :Pedestrian	0.99	0.99-0.99
age :Recreation	0.98	0.97-0.98
age :Ski	0.98	0.97-0.98
regionqc10: Assault	1.47	0.69-3.11
regionqc10:ATV	4.11	2.28-7.38
regionqc10: Bicycle	0.93	0.44-1.97
regionqc10:Motorcycle	0.00	0.00-Infinity
regionqc10:MVC	1.18	0.75-1.84
regionqc10:Other	1.45	0.84-2.50
regionqc10:Pedestrian	0.62	0.22-1.71
regionqc10:Recreation	1.03	0.14-7.50
regionqc10:Ski	4.66	1.12-19.37
region17: Assault	11.77	8.40-16.48
region17:ATV	38.06	28.40-51.00

region17: Bicycle	0.75	0.38-1.51
region17:Motorcycle	4.23	2.28-7.87
region17:MVC	1.06	0.72-1.56
region17:Other	1.40	0.88-2.23
region17:Pedestrian	2.40	1.51-3.83
region17:Recreation	1.13	0.27-4.63
region17:Ski	32.77	18.59-57.78
region18: Assault	10.69	6.81-16.80
region18:ATV	6.06	3.38-10.87
region18: Bicycle	1.00	0.44-2.25
region18:Motorcycle	0.00	0-Infinity
region18:MVC	1.71	1.08-2.72
region18:Other	0.71	0.32-1.60
region18:Pedestrian	0.60	0.18-1.94
region18:Recreation	5.88	2.29-15.13
region18:Ski	34.20	16.97-68.94
Sexmale: Assault	3.95	3.47-4.49
Sexmale :ATV	3.09	2.69-3.56
Sexmale : Bicycle	2.18	1.99-2.39
Sexmale :Motorcycle	2.69	2.27-3.19
Sexmale :MVC	1.28	1.21-1.35
Sexmale :Other	1.86	1.72-2.00
Sexmale :Pedestrian	0.79	0.73-0.86
Sexmale :Recreation	0.57	0.46-0.71
Sexmale :Ski	3.12	2.14-4.54

Supplementary Table s5: Association between mechanisms of injury by geographical zone in HR-18 using Poisson regression with robust variance estimation.

Population	Risk ratio	95% confidence interval
Off-road vehicles vs. other mechanisms		
Inland	1	Referent
Coastal	1.40	0.36 , 6.14
Remote	100.39	20.28 , 734.39
Assaults vs. other mechanisms		
Inland	1	Referent
Coastal	0.73	0.30 , 1.72
Remote	0.20	0.03 , 0.92

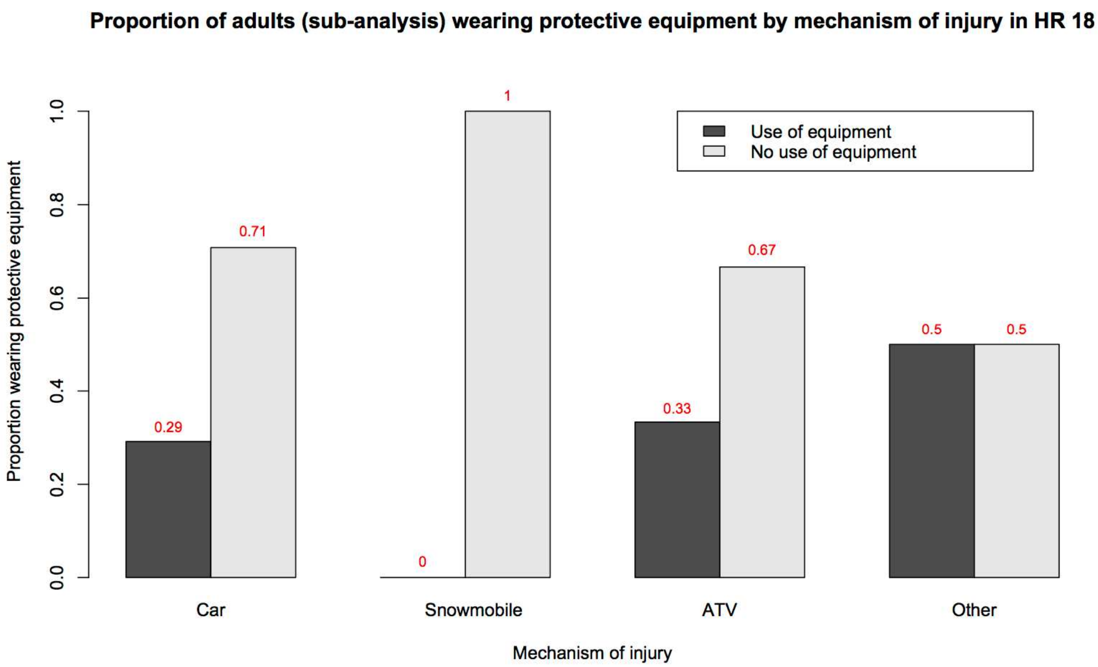
Risk ratios were estimated using two Poisson regression models that adjusted for age, sex and year of injury. The methodology behind using the Poisson regression to estimate risk ratios in cohort studies is shown elsewhere.[26]

Supplementary Table s6: Summary statistics for the sub-analysis of adults (15 years or older) in HR-18 hospitalized for TBI.

Total TBI hospitalizations	117	
Initial post-resuscitation GCS		
Mean	13.74	
Range	3-15	
Standard deviation	2.33	
TBI severity category (GCS range) (%)		
Mild (13-15)	81	(83.5)
Moderate (9-12)	7	(7.2)
Severe (3-8)	9	(9.2)
Polytrauma (%)		
Yes	43	(44.3)
No	54	(55.7)
Rehabilitation (%)		
Inpatient	12	(12.4)
Outpatient (in community)	22	(22.6)
Discharge orientation (%)		
Home	83	(85.6)
Rehabilitation (inpatient)	12	(12.4)
Deceased	0	(1.0)
Long-term care	0	(0.0)
Other hospital centre	2	(2.0)
Outcome (GOS) (%)		
1	0	(0)
2	0	(0)
3	14	(14.4)
4	52	(53.6)
5	31	(32.0)
Number of scores assigned by data extractor from interpretation of chart	45	(46.3%)
Protection (for MVC, off-road vehicle collision or bicycle injury) (%)		
Yes	11	(26.8)
No	30	(73.2)
Intoxication with alcohol (%)		
Yes	43	(44.3)
No	54	(55.7)
Missing data (%)	20	(17.1%)

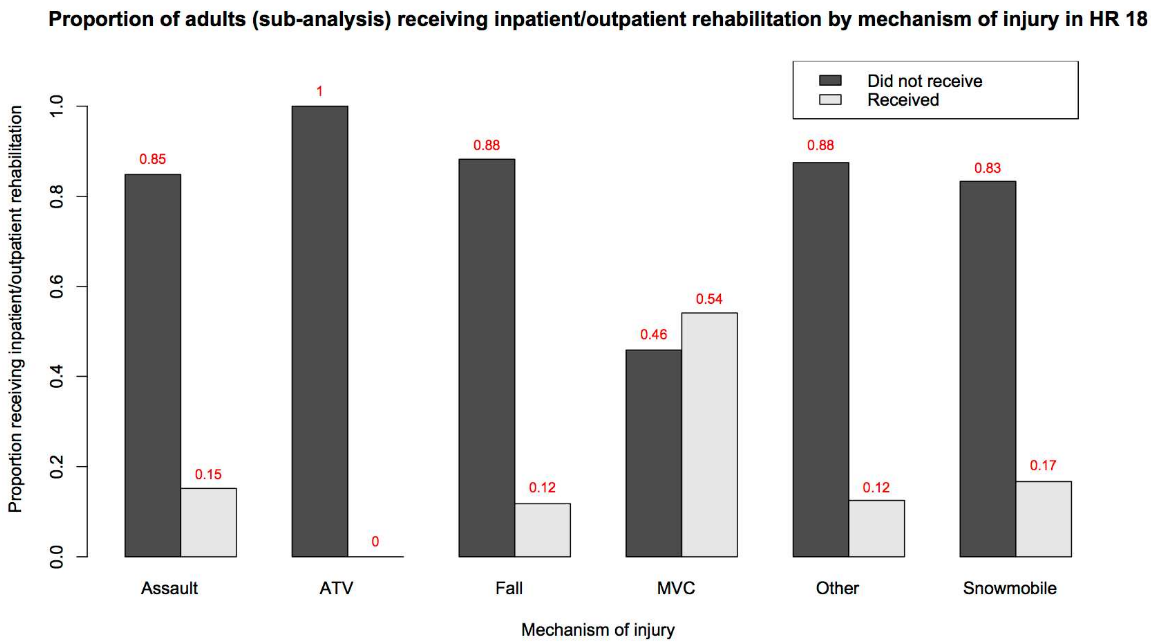
A total of 20 cases (17.1%) had missing data for 1 or more variables (and are not included in the table). Multiple imputation using chained equations was used for these missing data and all regression analyses used the pooled data from the imputation.

Supplementary Figure s7: Proportion of adults (sub-analysis) wearing protective equipment at the time of their TBI hospitalization in HR 18.



Patient involved in a recreational accident (sports/cycling) were the most likely to wear protective equipment. Most patients involved in MVCs (car) and ATV collisions did not wear protective equipment (seatbelts and helmets, respectively). No patients involved in snowmobile accidents wore a helmet.

Supplementary Figure s8: Proportion of adults (sub-analysis) receiving rehabilitation by mechanism of injury in HR 18.



Adult patients that were involved in MVCs were more likely to receive rehabilitation than all other mechanisms of injury.

Supplementary Figure s9: Full regression model outputs from sub-analysis of HR 18 adults.

Table s9a

Linear regression model output measuring the association between geographical zones and GCS in adults.

Variables	Coefficient	95% confidence interval
Intercept	14.12	12.32 , 15.93
Age(25-44)	0.51	-0.55 , 1.57
Age(45-64)	0.19	-1.25 , 1.64
Age(>65)	-0.58	-3.62 , 2.46
Sex: Male	-0.55	-1.60 , 0.50
Community:Coastal	0.01	-1.01 , 1.04
Community:Remote	-2.76	-4.67 , -0.84
Alcohol intoxication: Yes	-1.18	-2.17 , -0.19
Mechanism: Assault	0.65	-0.85 , 2.15
Mechanism: Off-road	1.65	-0.34 , 3.66
Mechanism: Other	0.46	-1.58 , 2.50
Mechanism: MVC	0.78	-0.77 , 2.33

Output for linear regression model assessing the association between geographical zones and initial injury severity (GCS) and adjusted for all the covariates listed. The referent for age was the 15-24 age group and for mechanism of injury was falls.

Table s9b

Linear regression model output measuring the association between protective equipment use and GCS in adults.

Variables	Coefficient	95% confidence interval
Intercept	13.27	11.53 , 15.01
Age(25-44)	0.42	-1.05 , 1.88
Age(45-64)	0.39	-1.90 , 2.68
Sex: Male	0.18	-1.14 , 1.51
Protection: Yes	1.29	-0.27 , 2.85
Alcohol: Yes	-0.47	-1.87 , 0.93
Mechanism: MVC	0.49	-0.91 , 1.88

Output for linear regression model assessing the association of protective equipment with initial injury severity (GCS) and adjusted for the covariates listed. This model was only used on patients that had a mechanism of injury where protective equipment could be used (e.g.: off-road vehicles and MVCs). There were no patients that were 65 years or older or that had another mechanism of injury where protection could be worn. The referent group for age is 15-24 years and is off-road vehicles (ATVs and snowmobiles) for the mechanism of injury variable.

Table s9c

Proportional odds logistic regression model output measuring the association between protective equipment use and GOS 6 months after injury in adults.

Variables	Odds ratio	95% confidence interval
Intercept 1	0.32	0.05 , 1.97
Intercept 2	11.34	1.57 , 81.96
Age(25-44)	1.67	0.35 , 7.99
Age(45-64)	12.27	0.73 , 207.68
Sex: Male	0.52	0.13 , 2.04
Comorbidity: Yes	1.05	0.14 , 7.72
Alcohol: Yes	0.61	0.15 , 2.52
Mechanism: MVC	0.30	0.07 , 1.36
Polytrauma: Yes	1.06	0.21 , 5.25
Protection: Yes	0.17	0.03 , 0.85

Output for proportional odds logistic regression measuring the association between protective equipment use and functional outcome at 6 months as measured on the GOS and adjusted for all of the listed covariates. This model was only used on patients that had a mechanism of injury where protective equipment could be used (e.g.: off-road vehicles and MVCs). There were no patients that were 65 years or older or that had another mechanism of injury where protection could be used. The proportional odds model was used since the proportionality assumption was met after running a cumulative odds logistic model. The referent group for age is 15-24 years and is off-road vehicles (ATVs and snowmobiles) for the mechanism of injury variable.

Table s9d

Proportional odds logistic regression model measuring the association between initial GCS and GOS 6 months after injury in adults.

Variables	Odds ratio	95% confidence interval
Intercept 1	109.27	2.06 , 2527.18
Intercept 2	4542.15	59.40 , 151291.23
Age(25-44)	2.84	1.05 , 7.66
Age(45-64)	12.47	2.38 , 65.26
Age(>65)	99.57	2.98 , 3324.69
Sex: Male	0.37	0.13 , 1.04
Comorbidity: Yes	1.00	0.24 , 4.09
Alcohol intoxication: Yes	1.10	0.44 , 2.76
Mechanism: Assault	0.66	0.16 , 2.76
Mechanism: Off-road	2.19	0.42 , 11.38
Mechanism: Other	0.92	0.14 , 5.90
Mechanism: MVC	0.74	0.16 , 3.48
Polytrauma: Yes	1.47	0.55 , 3.93
GCS	0.57	0.44 , 0.74

Output for proportional odds logistic regression measuring the association between initial GCS and functional outcome at 6 months as measured on the GOS and adjusted for all of the listed covariates. The proportional odds model was used since the proportionality assumption was met after running a cumulative odds logistic model. The referent group for age is 15-24 years and is falls for the mechanism of injury variable.

Table s9e

Poisson regression model measuring the association between mechanism of injury and the use of rehabilitation services in adults.

Variables	Risk ratio	95% confidence interval
Age(25-44)	1.75	0.82 , 3.74
Age(45-64)	2.55	1.07 , 6.02
Age(65+)	2.44	0.38 , 15.55
Sex: Male	0.93	0.53 , 1.62
GCS	0.86	0.78 , 0.96
Comorbidity:Yes	1.18	0.65 , 2.17
Community:Coastal	0.74	0.40 , 1.34
Community:Remote	0.56	0.15 , 2.11
Mechanism: Assault	1.06	0.33 , 3.38
Mechanism: Off-road	1.69	0.38 , 7.54
Mechanism: Other	2.49	0.89 , 7.02
Mechanism: MVC	3.79	1.53 , 9.33

Output for Poisson regression model to estimate the association between TBI patients' mechanism of injury and their probability or receiving rehabilitation services. A robust variance estimator was used to estimate a risk ratio since the outcome was common.[26] The referent group for the age group is 15-24 years of age and for mechanism of injury is falls.

Table s9f

Poisson regression model measuring the association between mechanism of injury and alcohol intoxication at the time of injury in adults.

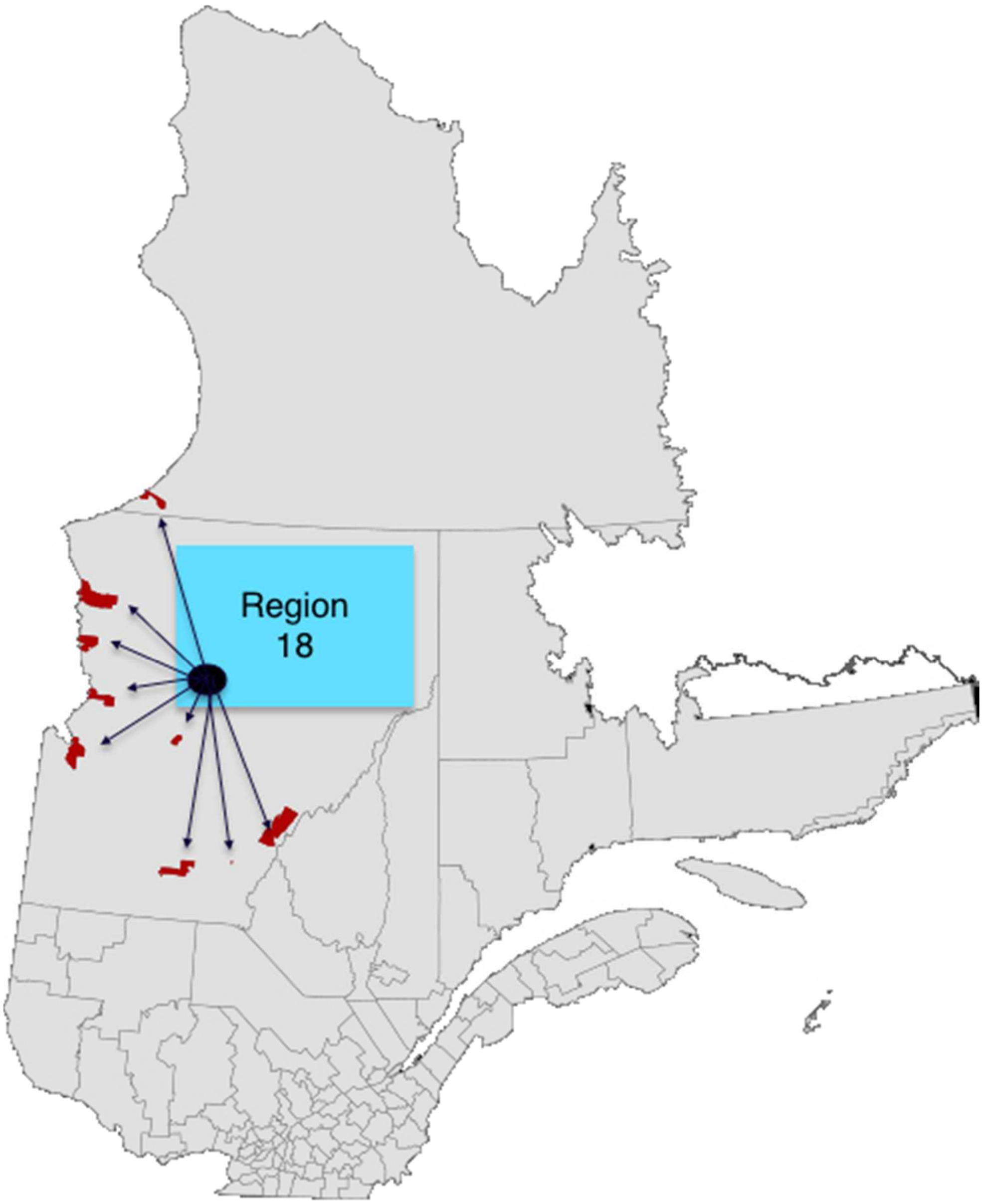
Variables	Risk ratio	95% confidence interval
Age(25-44)	0.92	0.66 , 1.30
Age(45-64)	0.52	0.23 , 1.11
Sex: Male	0.91	0.64 , 1.28
Community:Coastal	1.03	0.73 , 1.44
Community:Remote	0.63	0.27 , 1.49
Mechanism: Assault	1.70	0.80 , 3.59
Mechanism: Off-road	1.74	0.76 , 3.99
Mechanism: Other	1.21	0.46 , 3.19
Mechanism: MVC	1.46	0.67 , 3.13

Output for Poisson regression model to estimate the association between TBI patients' mechanism of injury and being intoxicated with alcohol at the time of injury. A robust variance estimator was used to estimate a risk ratio since the outcome was common.[26] The referent group for the age group is 15-24 years of age and for mechanism of injury is falls. No patients 65 years or older were intoxicated at the time of injury.

Supplementary Table s10: Comparison of the distribution of TBI severities amongst hospitalized patients in rural HR 18 and HR 6 (Montréal).

Population	**TBI hospitalization by severity (%)**		
	Mild	*Moderate*	*Severe*
HR 6 (urban)	5467 (83.6)	388 (5.9)	681 (10.4)
HR 18 (rural)	81 (83.5)	7 (7.2)	9 (9.2)
$\chi^2 = 0.3828$ df=2 $p = 0.8258$			

This sensitivity analysis was completed to investigate whether or not the incidence rates calculated for HR-18 were biased because of different hospitalization practices in the rural setting compared to the urban setting. These proportions are for the time-period from 2000-2012.



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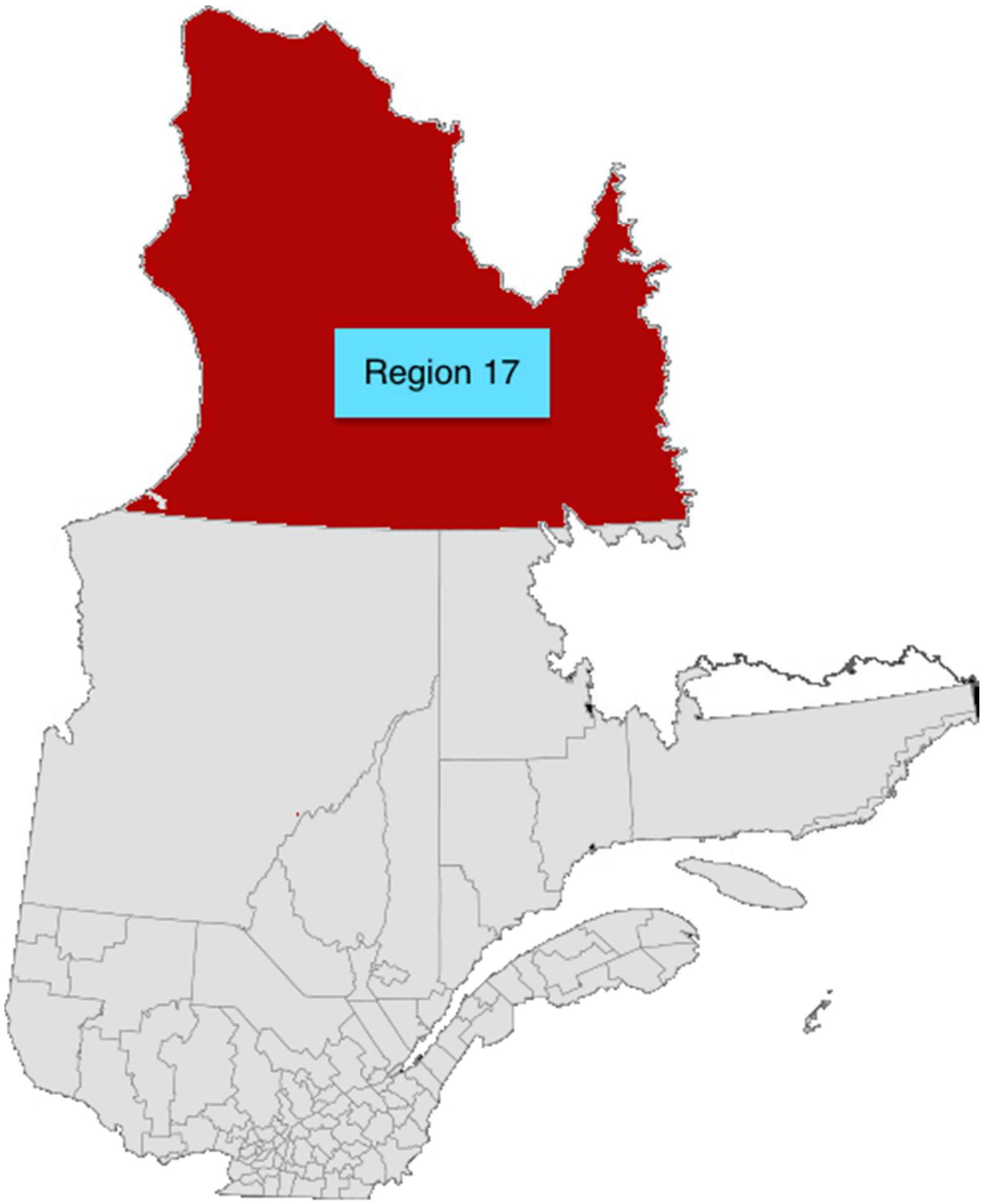

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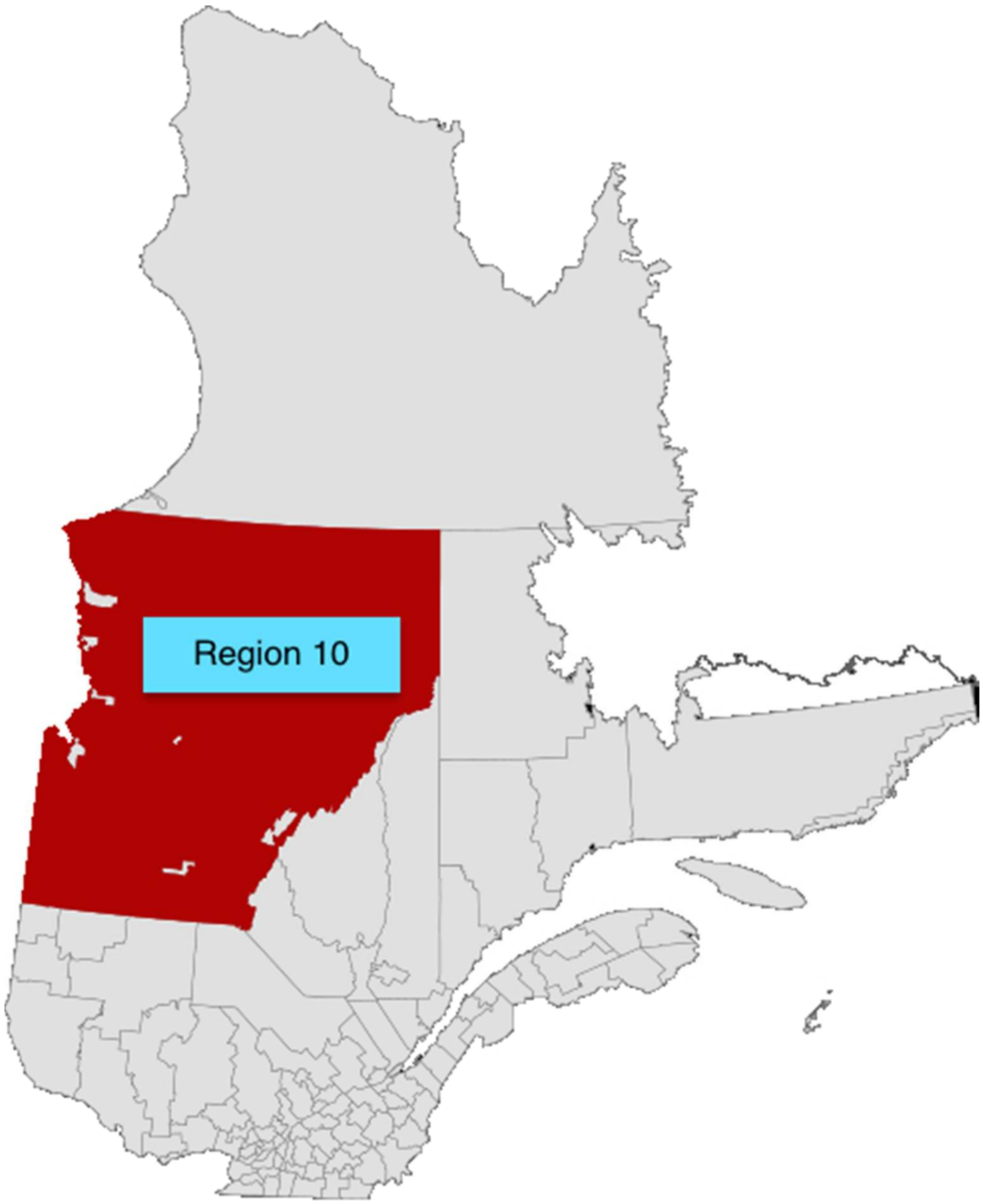

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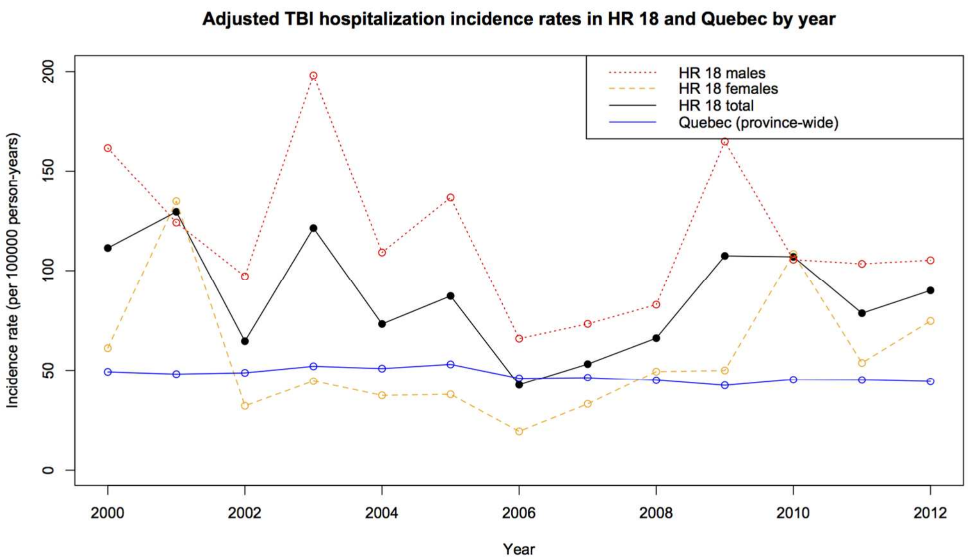

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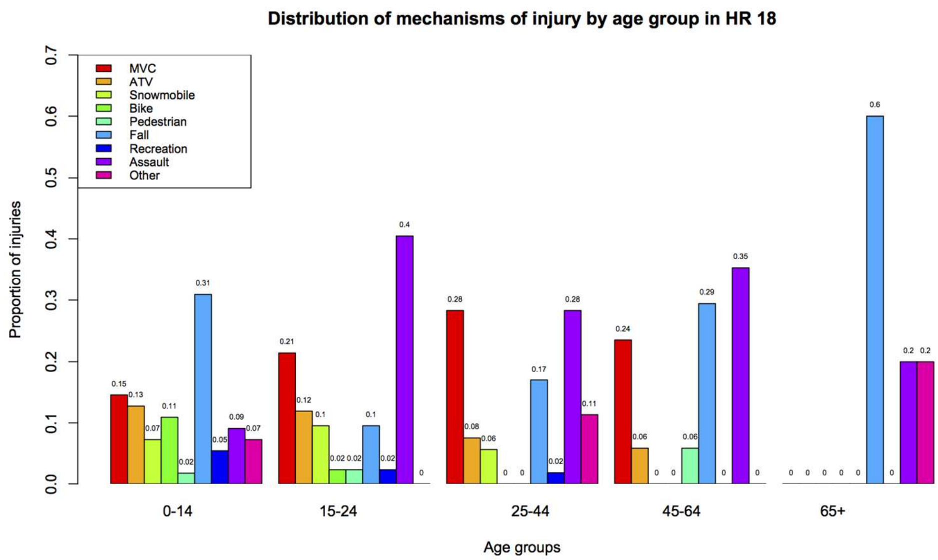

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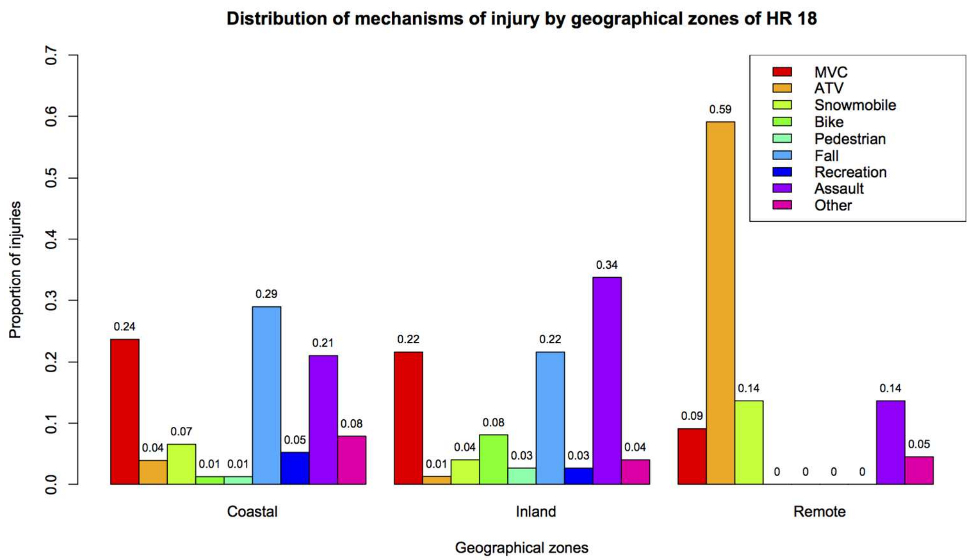

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