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Complete List of Authors:	Teschke, Kay; University of British Columbia, School of Population and Public Health Koehoorn, Mieke; University of British Columbia, School of Population and Public Health Dennis, Jessica; University of Toronto, Dalla Lana School of Public Health

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Bicycling injury hospitalization rates in Canadian jurisdictions: Analyses examining associations with helmet legislation and mode share

Kay Teschke[1,]*, Mieke Koehoorn[1], Jessica Dennis[2]

* Corresponding author

School of Population and Public Health, University of British Columbia, 2206 East Mall, Vancouver, BC, Canada, V6T 1Z3

kay.teschke@ubc.ca

604 822-2041

[1]School of Population and Public Health, University of British Columbia, Vancouver, Canada

[2]Dalla Lana School of Public Health, University of Toronto, Toronto, Canada

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ABSTRACT

Objectives

The purpose of this study was to calculate exposure-based bicycling hospitalization rates in Canadian jurisdictions with different helmet legislation and bicycling mode shares, and to examine whether the rates were related to these differences.

Methods

For the years 2006 to 2011 inclusive, administrative data on hospital stays for bicycling injuries and national survey data on bicycling trips were used to calculate hospitalization rates for ten body region groups. Rates were calculated for 44 sex, age and jurisdiction strata for all injury causes and 22 age and jurisdiction strata for traffic-related injury causes. Inferential analyses examined associations between injury rates and sex, age group, helmet legislation, and cycling mode share.

Results

In this period in Canada, there were 3,690 hospitalizations per year and 593 million annual trips by bicycle among people 12 years of age and older, for a cycling hospitalization rate of 622 per 100 million trips (95% CI: 611-633). Hospitalization rates varied substantially across the jurisdiction, age and sex strata, but only two characteristics explained any of this variability. For all injury causes, only sex was significantly associated with hospitalization rates. Females had rates about one-half those of males, for all ten body region groups. For traffic-related injury causes, the only significant association was with cycling mode share. Higher cycling mode share was associated with lower hospitalization rates for injuries to any body region. Helmet legislation and age group were not related to hospitalization rates in any analyses.

Conclusions

These results suggest that transportation and health policy makers who aim to reduce bicycling injury rates in the population should focus on factors related to increased cycling mode share and female cycling choices. Bicycling routes designed to be physically separated from traffic or along quiet streets fit both these criteria and are associated with lower relative risks of injury.

STRENGTHS AND LIMITATIONS OF THE STUDY

- This study was the first to compare exposure-based injury rates between jurisdictions with different helmet laws and cycling mode shares, within a single country. It allowed analyses in a setting with smaller cultural and transportation policy differences than entailed in international comparisons.

- The study used the same data sources in all jurisdictions, for the numerator (hospitalizations) and denominator (bicycling trips). The focus was the most serious cycling injuries, those requiring an inpatient hospital stay. Bicycling trip data were from a national survey that asked for recall of leisure, work and school trips over a three-month period.

- Separate analyses were done for all injury causes (including transport and sport cycling) and for traffic-related injury causes (focusing on transport cycling). The denominator for traffic-related causes was likely incomplete, so we could not compare absolute traffic-related injury rates to all-cause injury rates. Within each cause, rates were comparable and these comparisons were the study focus.

- We found that females had lower bicycling hospitalization rates than males for every body region group, consistent with results found elsewhere and for other travel modes, an effect often attributed to conservative risk choices.

- We found that hospitalization rates for traffic-related injuries to any body region were lower with higher cycling mode shares, a safety-in-numbers association consistent with results elsewhere and for other modes of travel.

- Our analyses did not find associations between hospitalization rates and helmet legislation, for brain, head, face or neck injuries, indicating that factors other than helmet laws have more influence on injury rates.

- These results provide useful context about population-level policies that may or may not affect bicycling hospitalization rates.

INTRODUCTION

Bicycling offers personal health benefits because physical activity reduces the risk of many chronic diseases.[1,2] Bicycling as a mode of transport is inexpensive and reduces traffic congestion, noise, air pollution and greenhouse gas emissions.[1,3] These benefits have led governments to consider ways to increase transport cycling, but population surveys consistently show that injury-related safety concerns are the major deterrent. [4-6]

To address these concerns, it is important to understand exposure-based injury risk (i.e., the injury rate calculated as injuries per number of bike trips or per distance travelled by bike). This measure allows between-jurisdiction comparisons of cycling safety, useful for assessing the value of different cycling conditions or laws that could guide future policy choices. Some characteristics that differ between jurisdictions include helmet laws, cycling infrastructure, and the proportion of all trips made by bike (cycling "mode share"). All of these may be related to cycling injuries. Bicycling injury research is dominated by helmet research; it shows that helmet use is associated with reduced relative risk of head injuries among those injured in a crash.[7,8] Studies examining the effect of helmet legislation have shown more mixed results.[9-13] Research on cycling infrastructure is less common, but has been growing in the last decade. Results are not always consistent, but most often show that routes with bike-specific infrastructure are safer than routes without.[14-17] Research on cycling mode share has repeatedly shown that places with more cycling have lower injury and fatality rates, though the causal pathway is debated.[18-21]

In a 2008 paper, Pucher and Buehler [22] compared jurisdictions with large differences in helmet legislation, cycling infrastructure, and mode share. In the United States, the focus of safety policy was promotion or legislation of helmet use, but bike-specific facilities were rare, and the proportion of trips by bicycle was about 1%. In Netherlands, Denmark and Germany, cycling facilities separated from traffic were common, helmet use was rare, and 10 to 27% of trips were by bicycle. They also compared injury rates from 2004 to 2009.[23] The US had fatality rates 3 to 5 times higher and injury rates 7 to 21 times higher than the northern European countries, lending support to the European policy choices. Others have argued that cultural and multi-faceted transportation policy differences between European and American jurisdictions make it difficult to draw conclusions.[24]

Here we report a comparison of injury rates within a country that has smaller cultural and transportation policy differences than those between the US and northern Europe. Canada is a federation of 10 provinces and 3 northern territories whose transportation policies are set at both national and provincial levels, resulting in broad similarities in traffic laws and infrastructure but also some differences. Default traffic speeds are 50 km/h in cities and 80 km/h in rural areas; intersections of arterials typically feature traffic lights rather than roundabouts; right turns on red lights are usually permitted; and drunk driving laws usually specify a blood alcohol limit of 0.08%. Despite these similarities, there are differences in bicycling infrastructure, cycling mode shares and helmet laws between provinces and territories, providing an opportunity to examine differences in injury rates. Two data sources with comparable data across all provinces and territories were used to provide descriptive information and calculate injury rates: hospital discharge data for bicycling injuries; and national health survey data for bicycling trips. Because hospital discharge data includes all bicycling injuries, whether incurred during bicycling as a mode of transport or in bicycling sports (e.g., road racing, mountain biking, cyclo-cross, BMX, trick riding), the subset of injuries designated as traffic-related were examined separately. Inferential analyses examined whether cycling mode share or helmet legislation were related to injury rates.

METHODS

This analysis used administrative data on bicycling hospitalizations and trips over a 6-year period from 2006 to 2011 inclusive. This period was chosen because it is bracketed by census years (census data was used for some study variables), included the most recent complete hospitalization data, and represented a period of stability in helmet laws nationwide. The study was restricted to individuals aged 12 or older because data on bicycling trips were available only for these ages.

Hospitalizations

In Canada, a hospitalization record is generated when a patient is "admitted" to hospital for at least one overnight stay in a department other than the emergency department. Data on all hospitalizations for bicycling injuries in Canada in the 6-fiscal-year period from 1 April 2006 to 31 March 2012 were obtained from the Discharge Abstract Database (all inpatient admissions to acute care hospitals in Canada) managed by the Canadian Institute for Health Information (CIHI).[25] Bicycling injuries were specified as those with international classification of diseases (ICD10-CA) external cause codes V10 to V19 inclusive.[26] Hospital transfers were not included, so each hospitalization was counted once only – at the initial admission.

Tabulated data were received from CIHI stratified by jurisdiction, sex, age group, injury cause, and injured body region. Jurisdiction was specified as the location of the hospital of first treatment, to maximize the likelihood that the jurisdiction of hospitalization was where the injury occurred. Jurisdiction included 11 categories (10 provinces, and the 3 territories – Yukon, Northwest, Nunavut – in one group). Age groups were adult (18+) and youth (12 to 17). Injury causes and injured body regions were determined using ICD10-CA codes. Injury causes included all causes and the subset, traffic-related causes. Ten injured body region groups were defined: brain; head, scalp or skull; face; neck; torso; upper extremities; lower extremities; brain, head, scalp, skull or face; torso or extremities; and any body region (supplementary table). Up to 25 injuries are coded per patient, but within each body region group, a hospitalization was counted once only.

Bicycling trips

Data on bicycling trips for the years 2006 to 2011 inclusive were obtained from the Canadian Community Health Survey (CCHS) cycles 2005/6, 2007/8, 2009/10, and 2011/12. The CCHS is conducted by Statistics Canada and each year samples 65,000 people 12 years of age and older who live in private dwellings (98% of the population) in all jurisdictions and 110 health regions.[27] Samples are drawn from a geographic sampling frame using a 2-stage stratified design and from telephone number or random digit dialing sampling frames using simple random sampling within health regions. Interviews are conducted using computer-assisted in-person and telephone interviewing, at randomly selected times from January to December to avoid seasonal bias. Bicycling trip data were extracted from the CCHS public release datasets, stratified by jurisdiction, sex, and age group, as for hospitalizations.

The following questions were used to tally leisure cycling trips:

- "To begin with, I'll be dealing with physical activities not related to work, that is, leisure time activities. Have you done any of the following in the past 3 months, that is, from [date three months ago] to yesterday? Bicycling?"
- If yes, "In the past 3 months, how many times did you participate in bicycling?"

Leisure cycling trips per year in each jurisdiction, sex, and age group stratum were calculated as the sum of all self-reported times bicycling in the past 3 months multiplied by 4 for an annual count.

The following questions were used to tally work and school cycling trips:

- "Other than the (X) times you already reported bicycling was there any other time in the past 3 months when you bicycled to and from work or school?"
- If yes, "How many times?"

Work and school cycling trips per year in each jurisdiction, sex, and age group stratum were calculated using the same methods as for leisure cycling trips. The question about work or school bicycling was not asked in the 2005/6 survey, so the annual trips calculated from 2007/8 survey data was used for trips in 2006.

Total bicycling trips were calculated as the sum of leisure, work and school trips. Unlike the hospitalization data, which was complete population data, bicycling trip data was estimated from survey samples. Annual counts for the years 2006 to 2011 inclusive were therefore weighted to demographic strata using the Statistics Canada survey sampling weights to account for the sampling design and generate population-based estimates. Bootstrapping (500 replicates) was used to calculate confidence limits for the estimate of total bicycling trips.

Hospitalization rates

Two sets of hospitalization rates were calculated for injuries to each body region. The first set used data for injuries from all injury causes. Hospitalization rates were calculated by dividing the total number of hospitalizations by the total number of bicycling trips (leisure, work and school) over the 6-year period. For each body region, rates were calculated for 44 strata: 11 jurisdictions * 2 age groups * 2 sexes.

The second set of hospitalization rates were calculated for the subset of injuries that were traffic-related, since in all jurisdictions with helmet legislation, the law applies to public roads, the same location used in injury coding for "traffic-related". Trips to work or school are more likely than leisure trips to require use of public roads, so work and school trip data were used as the denominator for this rate calculation. Hospitalization rates were calculated by dividing the number of traffic-related hospitalizations by the number of bicycling trips to work or school over the 6-year period. Because traffic-related injuries were only about half of all injuries, these data were not stratified by sex, to minimize the number of strata with zero hospitalizations. For each body region, rates were calculated for 22 strata: 11 jurisdictions * 2 age groups.

Other data sources

Data on population were obtained from the 2006 and 2011 census.[28] Data on cycling mode share were averaged from the 2006 Census long form and the 2011 National Household Survey [29,30] and represent the proportion of the total employed labour force that did not work at home and reported their usual mode of transportation to and from work as bicycle.

Information about helmet laws was retrieved from a previous publication [31] and from the legislation itself. Data on helmet use in all jurisdictions were available from the 2009/2010 CCHS via the following questions: "In the past 12 months, have you done any bicycling?" and if yes, "When riding a bicycle, how often do you wear a helmet?" The proportions who reported wearing a helmet always or most of the time were calculated for the same strata as hospitalization rates.

To describe cycling conditions by jurisdiction, a summary metric, Bike Score®, based on hilliness, density of amenities, road connectivity, and density of bike lanes, bike paths and local street bikeways is reported for the most populous city with available data in each jurisdiction (personal communication, Matt Lerner, CTO, Walk Score®, Seattle, WA, May 4, 2012).

Associations between hospitalization rates and cycling mode share, helmet laws, age group, sex

For injuries to any body region and to the brain, head, scalp, skull or face, the associations between cycling mode share and hospitalization rates for all injury causes (44 strata) and for traffic-related injury causes (22 strata) were examined using scatter plots and simple linear regression.

For injuries to each body region group potentially associated with helmet legislation (brain, head, scalp, skull or face; brain; head, scalp or skull; face; neck), the associations between categories of helmet legislation and hospitalization rates for all injury causes (44 strata) and for traffic-related injury causes (22 strata) were examined using ANOVA. The categories were:

- no helmet law (all ages in Manitoba, Newfoundland & Labrador, Quebec, Saskatchewan, and the three Territories);
- helmet law in jurisdiction, but does not apply (adults in Alberta and Ontario); and
- helmet law applies (all ages in British Columbia, New Brunswick, Nova Scotia, and PEI; youths in Alberta and Ontario).

This and other methods of categorizing helmet legislation jurisdictions (i.e., law vs. no law; and all ages law vs. child only law vs. no law) were examined to determine which was most strongly related to helmet use. The one described in detail above explained the most variation, and was used in subsequent analyses. Simple linear regressions were also conducted to directly examine the relationship between hospitalization rates and the proportions using helmets in study strata to check the potential effect of jurisdictions without provincial legislation but with helmet bylaws in some municipalities.

Mixed effects linear regression was used to examine the association between hospitalization rates for all injury causes (44 strata) and helmet legislation, cycling mode share, sex and age group (all as fixed effects), for injuries to the ten body region groups. Jurisdiction was included as a random effect to adjust for within-jurisdiction correlation not explained by the fixed effects in the model. The same modelling was repeated to examine associations between traffic-related hospitalization rates (22 strata) and helmet legislation, cycling mode share, and age group. Note that hospitalization rate has an asymptote of zero, so modeling the logarithm of the rates would be expected to better fit the data. This was not the case in the range of rates in this study, so the simpler linear relationships are reported here.

For some body region groups, one or more strata had zero hospitalizations. Omitting strata with zero hospitalizations from analyses would be biased, so two methods were used to provide rates:

- hospitalization rate calculated for the stratum using a numerator of 0.1 injuries; and
- hospitalization rate = mean rate for all strata with non-zero hospitalizations for that body region.

Analyses were repeated using both substitution methods, but none of the results materially differed. Results are reported using the first, since it reflects the low number of injuries in the stratum.

CCHS data were generated using SAS version 9.4 (SAS Institute Inc., Cary, NC), rates were calculated using Excel version 14.4.7 (Microsoft, Redmond, WA), and all other analyses were done using JMP 10 (SAS Institute Inc., Cary, NC).

RESULTS

In Canada over the period 2006 to 2011, there was an annual average of 3,690 hospitalizations for injuries incurred during bicycling among people 12 years of age and older. Table 1 lists the causes of the injury events. A slight majority (53%) of adult injuries were traffic-related, but only 41% of youth injuries were. Almost all collisions with motor vehicles (ICD-10 Codes V12, V13, V14) were traffic-related. For both youths and adults, a majority of injuries were non-collision transport accidents (V18), and most of these were not traffic-related.

Table 1. Annual average number of hospitalizations for bicycling injuries and percent that were traffic-related*, by cause of injury and age group, in Canada in the period from 2006 to 2011.

		Youths, ages 12 to 17		Adults, ages 18+	
ICD-10 Code	Cause of injury description: Pedal cyclist injured in …[a]	Annual average number of hospitalizations[b]	% traffic-related[c]	Annual average number of hospitalizations[b]	% traffic-related[c]
V10	collision with pedestrian or animal	4	31.8	23	43.7
V11	collision with other pedal cyclist	9	47.2	66	64.1
V12	collision with 2- or 3-wheeled motor vehicle	1	75.0	8	82.2
V13	collision with car, pick-up truck or van	94	95.9	513	97.1
V14	collision with heavy transport vehicle or bus	6	97.1	29	98.3
V15	collision with railway train or railway vehicle	0	-	2	76.9
V16	collision with other non-motor vehicle	1	14.3	5	63.0
V17	collision with fixed or stationary object	23	30.0	134	52.4
V18	non-collision transport accident	512	29.5	1,877	39.3
V19	other and unspecified transport accidents	74	47.2	311	59.5
V10-19	All injury causes	724	40.8	2,966	53.4

a Note that although these codes refer to "pedal cyclist injured in transport accident", all bicycling injuries are coded here, whether or not they involve transportation cycling or sport cycling
b Includes all fourth character subdivision cause of injury codes = 0, 1, 2, 3, 4, 5, 6, 8, 9
c Traffic-related restricted to fourth character subdivision cause of injury codes = 4, 5, 6, 9, i.e., those that occur "on a public highway/road"

Figure 1 shows hospitalizations in Canada by body region injured. The affected body regions followed very similar patterns in youths and adults; upper extremities were the most frequently injured, followed by lower extremities, torso, brain, head or scalp or skull, face, and neck. Torso or extremities injuries were incurred by 82% of those hospitalized; brain, head, scalp, skull or face injuries by 25%; and neck injuries by 5%. Many people experienced multiple injuries, both within broad body regions (e.g., brain and head) and across any body region (e.g., head and extremities). The majority of those injured were male (88.6% of youths, 73.4% of adults).

Table 2 provides data on the 11 jurisdictions included in this study, illustrating the differences in bicycling conditions in their most populous cities, as well as in cycling mode share on a jurisdiction-wide basis. Cycling mode share was positively correlated with Bike Score. Table 2 also provides data on the annual average number of bike trips by youths and adults, a total of 593 million trips (95% CI: 583-604 million). The proportions of bicycling trips for work or school commutes were low, though they differed by age group and jurisdiction. More trips were made by males than females (71.0% by male youths, 63.5% by male adults).

Table 2. Characteristics of Canadian provinces and territories during study period of 2006 to 2011: population, Bike Score, cycling mode share, bicycling trips for all purposes and % that were trips to work or school.

				Youths, ages 12 to 17		Adults, ages 18+	
	Population[a]	Bike Score[b]	Cycling mode share (%)[c]	Annual bicycling trips	% to work or school	Annual bicycling trips	% to work or school
Alberta	3,467,804	62	1.10	12,262,406	11.1	41,985,585	15.6
British Columbia	4,256,772	73	2.05	14,064,898	13.7	67,454,711	21.9
Manitoba	1,178,335	-	1.67	5,284,444	15.0	17,859,145	18.9
New Brunswick	740,584	35	0.57	3,243,263	8.3	7,827,567	13.8
Newfoundland & Labrador	510,003	21	0.23	1,838,508	3.9	2,755,552	13.7
Nova Scotia	917,595	62	0.66	2,638,119	4.2	7,116,612	12.4
Ontario	12,506,052	60	1.20	55,940,049	14.3	169,979,958	15.7
Prince Edward Island	138,028	41	0.53	518,984	3.1	1,248,071	6.4
Quebec	7,724,566	69	1.37	32,309,917	11.7	130,818,129	15.7
Saskatchewan	1,000,769	66	1.36	4,219,897	15.3	12,061,879	14.6
Territories: Nunavut, Northwest, Yukon	104,288	-	1.86	503,842	14.9	1,292,224	23.3
Canada	32,544,796		1.30	132,824,327	12.8	460,399,432	16.6

a Mean population, 2006 and 2011 Censuses, Statistics Canada

b Bike Score for most populous city on the jurisdiction, except New Brunswick where second most populous used (Moncton); not available for cities in Manitoba or the Territories

c Mean proportion of commuting population who reported usually commuting by bicycle in the 2006 Census long form and the 2011 National Household Survey

Table 3 outlines differences in helmet legislation by jurisdiction. Four provinces had legislation that applied to all ages and two had legislation that applied to children only (i.e., age 17 and under). These helmet laws came into force between 1996 and 2003, at least 3 years prior to the start of the study period in all jurisdictions. All provincial helmet laws are pursuant to traffic or motor vehicle acts and applied to bicycling on public roads. This application is not publicized and may not be well known. Helmet use was higher in jurisdictions with helmet legislation.

In the study period, the cycling hospitalization rate for youths and adults combined, was 622 hospitalizations per 100 million trips (95% CI: 611-633), with a slightly lower rate for youths than adults (545 vs. 644, respectively). This reflects a lower hospitalization rate for injuries to the torso and extremities for youths than adults (428 vs. 534, respectively), whereas rates for brain, head, scalp, skull or face injuries were very similar for the two age groups (159 vs. 152, respectively).

Figures 2a and 2b show the hospitalization rates in 44 age group, sex, and jurisdiction strata. Hospitalization rates for the torso or extremities were highly correlated with those for any body region (Pearson r = 0.98), so only the latter are shown in the figures. Rates for brain, head, scalp, skull or face injuries were less correlated with those for any body region (Pearson r = 0.81), and are shown separately. Figures 2c and 2d show the hospitalization rates for traffic-related injury causes (i.e., those on public roads) using work or school trips as the denominator (22 age group and jurisdiction strata).

Table 3. Helmet legislation and helmet use, stratified by age group, in Canadian provinces and territories.

Jurisdiction	Helmet legislation: Ages included	Helmet legislation: Year in force	Youths, ages 12 to 17 helmet use (%)ø	Adults, ages 18+ helmet use (%)ø
Alberta	< 18	2002	68.6	53.9
British Columbia	All	1996	66.1	71.3
Manitoba	None [a]		27.7	30.0
New Brunswick	All	1995	63.8	61.8
Newfoundland & Labrador	None [b]		50.9	51.7
Nova Scotia	All	1997	77.8	74.8
Ontario	< 18	1995	53.4	41.2
Prince Edward Island	All	2003	72.8	59.0
Quebec	None [c]		33.5	35.3
Saskatchewan	None [d]		36.8	30.3
Territories: Nunavut, Northwest, Yukon	None [e]		32.9	47.7

ø Percent of people who reported wearing a bike helmet always or most of the time when they bicycled, 2009 Canadian Community Health Survey.
a Helmet legislation for ages < 18 was enacted in Manitoba in 2013 (after the study period) under the Highway Traffic Act.
b 5 cities in Newfoundland & Labrador (representing ~30% of the provincial population) had helmet bylaws for all ages during the study period. A province-wide all ages helmet law will take effect April 1, 2015 under the Highway Traffic Act.
c 1 city in Quebec (representing < 0.5% of the provincial population) had a helmet bylaw for all ages during the study period.
d 1 city in Saskatchewan (representing ~ 1.5% of the provincial population) had a helmet bylaw for all ages during the study period.
e 2 cities in the Territories (representing ~30% of the territorial population) had helmet bylaws for all ages during the study period.

In Figures 2a to 2d, cycling mode share in the jurisdiction is the x-axis. In simple linear regressions, only rates for traffic-related injuries to any body region were significantly associated with mode share (Figure 2c; $p < 0.05$). Higher mode shares were associated with lower hospitalization rates. The figures also denote whether the stratum was subject to helmet legislation. In ANOVA, no associations were found between hospitalization rates and the 3 categories of helmet legislation (all $p > 0.50$). Figure 3 summarizes the ANOVA results for each body region expected to be affected by helmet use. The figure shows results for all injury causes; results for traffic-related injury causes did not differ substantively. To check whether these results might be an artifact of municipal helmet bylaws in jurisdictions without helmet legislation, simple linear regressions were conducted to examine the relationship between hospitalization rates and the proportions using helmets in study strata. No associations were observed for any of the relevant body regions, for all causes or for traffic-related causes (all $p > 0.40$, all coefficients positive – opposite to expectation).

Table 4 shows the results of multiple regression models examining associations between hospitalization rates and sex, age group, helmet legislation, and cycling mode share. For all injury hospitalizations, sex was associated with hospitalization rate. Females had significantly lower hospitalization rates, typically about one-half those for males. Age, helmet legislation, and cycling mode share were not related to hospitalization rate. This pattern was also observed for analyses of each body region separately (results not shown).

For traffic-related injury hospitalizations, sex was not available as a variable. The only significant association observed was for injuries to any body region and cycling mode share (Table 4). Higher cycling mode share was associated with lower hospitalization rates; with a 1% increase in mode share, the rate was lower by about one-quarter. The same direction of association between hospitalization rates and mode share was observed for head, scalp, skull or face injuries and for each body region separately (results not shown), but none of the coefficients were significant.

Table 4. Coefficients (95% confidence limits) for associations between various characteristics and cycling hospitalization rates for injuries to any body region and injuries to the brain, head, scalp, skull or face, for all injury causes and traffic-related injury causes. Results from mixed effect multiple regression with jurisdiction as a random effect. Bold indicates statistical significance at $p < 0.05$.

	Injuries to any body region		Brain, head, scalp, skull or face injuries	
Dependent variable = all injury hospitalizations/100 million bicycling trips [a]				
Intercept [b]	**404**	**(173, 635)**	**117**	**(47, 186)**
Sex (female)	**-203**	**(-251, -155)**	**-59.4**	**(-79, -40)**
Age group (adult)	-4.5	(-57, 48)	-8.5	(-30, 13)
Helmet legislation	-7.0	(-118, 103)	-1.2	(-41, 38)
Helmet legislation, but does not apply (adults in Alberta & Ontario)	125	(-30, 278)	10.5	(-47, 67)
Cycling mode share	158	(-22, 339)	26.3	(-27, 80)
Dependent variable = traffic-related injury hospitalizations/100 million bicycling trips to work or school [c]				
Intercept [d]	**3118**	**(2063, 4172)**	**1236**	**(482, 1989)**
Age group (adult)	-192	(-640, 257)	-199	(-478, 79)
Helmet legislation	239	(-478, 955)	29.2	(-447, 505)
Helmet legislation, but does not apply (adults in Alberta & Ontario)	99	(-963, 1159)	39.6	(-661, 740)
Cycling mode share	**-801**	**(-1584, -19)**	-397	(-967, 172)

[a] 44 rates available for modeling: 11 jurisdictions x 2 age groups x 2 sexes
[b] Intercept = base hospitalization rate for male youths in a jurisdiction without helmet legislation and a cycling mode share of 0%
[c] 22 rates available for modeling: 11 jurisdictions x 2 age groups
[d] Intercept = base hospitalization rate for youths in a jurisdiction without helmet legislation and a cycling mode share of 0%

DISCUSSION

In Canada during the study period, the 3,690 annual hospitalizations for bicycling injuries among youths and adults were mainly among males (76%). Most (51%) were traffic-related (on public roads) but only 18% involved collisions with motor vehicles. Chen *et al.* [32] described 70,000 emergency department visits for bicycling injuries in the United States from 2001 to 2008. The most injured body parts were similar to those observed in our study: 70% the torso or extremities; 16% the face; and 13% the head. Similar to our results, most injuries were to males (73%) and slightly more than half of cases were injured on roads (56%), but a much higher proportion resulted from collisions with motor vehicles (58%).[32]

We calculated a hospitalization rate for all injury causes of 622 per 100 million trips. We found only one other study that reported bicycling hospitalization rates with a trip denominator. Blaizot *et al.* [33] reported a rate of 443 per 100 million trips in France, using data from a road trauma registry and a trip diary survey. Beck *et al.* [34] and Teschke *et al.* [35] calculated police-reported injury rates of 1461 and 1398 per 100 million trips in the US and Canada, respectively. These included injuries not requiring hospitalization, but likely included only injuries incurred in motor vehicle collisions.

The main purpose of this study was to calculate exposure-based injury rates in Canadian provinces and territories and to examine whether they were related to differences in helmet legislation and cycling mode shares. Hospitalization rates per 100 million trips varied substantially across the jurisdiction, age and sex strata examined, but only two characteristics explained any of this variability.

For all injury causes, sex was the only significant explanatory variable. Females had lower hospitalization rates for any body region and for each body region separately, about half that for males. Lower bicycling injury and fatality rates for females has been shown elsewhere, including the US [34], England [36], and New Zealand [37], though not France [33]. This pattern of lower injury and fatality rates for females has been observed in other transport modes including driving [34,36] and walking [33,34,36] and is often attributed to a lower propensity for risk-taking. For example, research shows that women are less likely than men to ride on major city streets or rural roads without bike facilities, infrastructure that has been shown to have higher injury risk.[16,38,39,40] Other lower risk behaviours of females include slower riding [16,38,39], and less participation in sport cycling (e.g., mountain biking).[41] In our study, in most strata, females had a somewhat higher helmet use proportion, but this variable was not associated with hospitalization rates. The only other demographic variable we examined, age group, was not significantly associated with hospitalization rates in our study. Other studies do not show consistent patterns with age.[33,34,36,37]

For traffic-related injury causes, cycling mode share was the only significant explanatory variable (sex not available for modeling). It was negatively associated with hospitalization rate, significantly so only for injuries to any body region. This association is consistent with observations in other jurisdictions: with higher mode shares, injury and fatality rates are lower.[18-20] The safety-in-numbers association has also been observed for walking and driving.[18,19] The causal pathway of this association is not established and is likely to be multi-factorial and complex. Arguments have been made that more cyclists make drivers more alert to them, more cycling means less motor vehicle traffic, more cyclists mean a larger constituency calling for safety improvements, and safer infrastructure results in more bicycling.[18-21] There is consistent evidence that safer bicycling infrastructure attracts more people to use it.[42,43]

In our study, the safety-in-numbers association was not observed for all injury causes. This may be because all causes included not only injuries incurred during transport cycling, but also during sport cycling. In some Canadian provinces, mountain biking is a popular sport that involves riding on steep slopes, through densely wooded trails, and jumping obstacles and cliffs. It involves considerably higher injury risk than transport cycling.[44] Two Canadian studies tallied transport and mountain biking injuries separately and found that 19% and 38% of all serious injuries were incurred during mountain biking (study hospitals were in Alberta and British Columbia, respectively).[41,45] These injuries would not be expected to be related to transport cycling mode share. This may in part explain the very different ordering of hospitalization rates by mode share for all injury causes versus traffic injury causes (Figure 2). Particularly notable is the change for British Columbia – this jurisdiction has the highest commuter cycling mode share and is also renowned for its mountain biking terrain.

Helmet legislation was not associated with hospitalization rates for all injury causes or traffic injury causes. We separately examined this potential relationship for each body region expected to be protected by helmet use (brain, head, scalp, skull or face; brain; head, scalp or skull; face) as well as for the neck which, in some studies, has had elevated relative risks with helmet use.[7,8] Since there was variation in helmet use within helmet legislation categories, we also examined hospitalization rates and helmet use proportions in the strata, and did not find a relationship. Studies of the relative risk of head, brain or face injuries among those injured in a cycling crash consistently show lower risk among those who wore a helmet,[7,8] though the potential for uncontrolled confounding in observational studies of a health behaviour suggests confidence in the effect estimates should not be unquestioning.[46] Before-after studies of the impact of helmet *legislation* have shown weaker and less consistent effects. Some have found reductions in brain or head injuries of 8% to 29% related to legislation [10-13], whereas others have found no effect for some or all outcomes.[9,11,13] Differences may be attributable to study design features including location, the selection of a control group unexposed to helmet legislation, whether or not baseline trends in injury rates were modeled, and whether and which surrogates were used for cycling rates. Our study compared bicycling hospitalization rates across jurisdictions rather than within a jurisdiction before and after legislation, used exposure-based denominators to control for differences in cycling rates, and compared rates in jurisdictions with similar transportation cultures.

Our study is the first to examine exposure-based injury rates between jurisdictions with different helmet laws within a single country. The fact that we did not find an effect of helmet *legislation* for injuries to any body region is not surprising, since most injuries are not head injuries. Even studies of helmet *use* have not found an effect for serious injuries to any body region.[47] The lack of an effect of legislation on brain and head injury rates is more unexpected. Helmet legislation in Canadian jurisdictions results in consistently higher helmet use, so this cannot explain the results. Insufficient power is also not an explanation, since the effect estimates for helmet legislation were either opposite to expectation or very close to the null. Our results indicate that factors other than helmet laws have more influence on injury rates. These include individual decision-making related to risk, as illustrated by the lower injury rate for females, and factors that encourage cycling, as illustrated by the lower traffic-related injury rate for higher cycling mode shares.

Strengths and limitations

The main strength of this study is comparison of injury rates calculated using the same data sources in all jurisdictions, for both the numerator (hospitalizations) and denominator (bicycling trips). International comparisons of injury rates are much more difficult because of uncertainty in the comparability of each of these components.

The injury data was a full enumeration of inpatient discharge data from all acute care hospitals in the country. These injuries required a hospital stay so the study focus was more serious cycling injuries. The coding of injury causes did not allow separation of transport and sport cycling, but it did allow identification of the subset of traffic-related injuries. This subset is defined as injuries on public roads, the same locations to which provincial helmet legislation applies.

Bicycling trip data was derived from a large survey conducted annually by Statistics Canada, with a sampling design that covers the full year. Its main limitations are that it asks each respondent to recall a 3-month period and asks about "times" bicycling rather than trips. Unlike Canada, many countries conduct national trip diary surveys that query transport behaviour over a period of one week or less, and provide careful definitions of a trip.[34-37] Although the denominator data available in Canada is less ideal, this study is notable in that it is one of few [34-37] to provide exposure-based bicycling injury rates. The bicycling data from the CCHS covered leisure trips and trips to work or school. This should include cycling for sport and for transport, therefore providing an appropriate exposure denominator for hospitalizations for all injury causes. For traffic-related injuries, there was no clearly parallel bicycling exposure definition. We chose to restrict the denominator for these hospitalizations to work and school commute cycling trips since they are very likely to require use of public roads. It is reasonable to expect that some unknown proportion of leisure trips will also use public roads, so our absolute estimates of traffic-related hospitalization rates are overestimates. The rates we calculated for traffic-related injuries were much higher than for all injuries, opposite to what Palmer *et al.* [44] found in a study that had complete denominator data for both sport and transport cycling. We were interested in comparing rates within traffic-related injury strata, rather than comparing rates for all injuries to traffic-related injuries, and for this purpose we feel our choice of denominator was reasonable.

CONCLUSIONS

In our study comparing exposure-based injury rates in 11 Canadian jurisdictions, we found that females had lower hospitalization rates than males for all injury causes and every injured body region. This difference in injury rates is consistent with other bicycling studies and studies of other modes of transportation. We found that lower rates of traffic-related injuries to any body region were associated with increased cycling mode share, a finding also reported elsewhere. We did not find a relationship between injury rates and helmet legislation.

These results suggest that policy makers interested in reducing bicycling injuries would be wise to focus on factors related to increased cycling mode share and female risk choices. Bicycling infrastructure physically separated from traffic or routed along quiet streets is a promising fit for both and is associated with lower relative risk of injury.

CONTRIBUTORSHIP STATEMENT

KT and JD conceived the study and all authors contributed to its design and interpretation. KT drafted the manuscript and all authors participated in the revision process and have approved this submission for publication. KT and MK conducted the analyses. KT takes responsibility for the hospitalization rate analyses and MK for the bicycling trip and helmet use analyses.

COMPETING INTERESTS STATEMENT

No, there are no competing interests.

DATA SHARING STATEMENT

Hospitalization data used in this study can be requested from the Canadian Institute for Health Information. Bicycling trip data can be retrieved from the Canadian Community Health Survey public release datasets.

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Figure 1. Annual average number of hospitalizations for bicycling injuries, by body region and age group, in Canada from 2006 to 2011.

Figure 2. Hospitalization rates and cycling mode share during the 6-year study period, by injury cause and body region (rates for 44 strata for all injury causes and for 22 strata for traffic-related injury causes). Note that jurisdictions can be identified via their mode share, reported in Table 2.

Figure 3. Mean hospitalization rates (and 95% confidence intervals; all injury causes, 44 strata) during the 6-year study period, by helmet legislation, for potentially associated body regions.

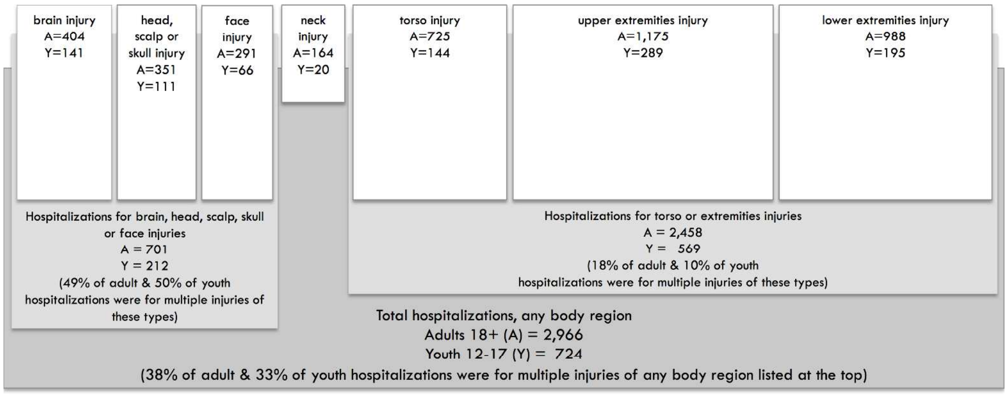
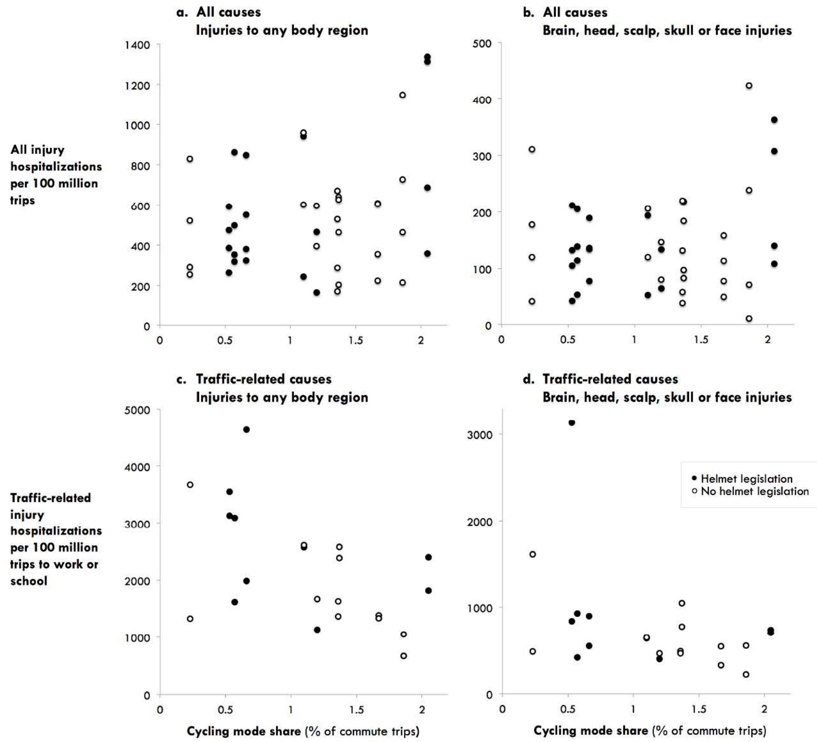


Figure 1. Annual average number of hospitalizations for bicycling injuries, by body region and age group, in Canada from 2006 to 2011.
254x190mm (300 x 300 DPI)



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254x190mm (300 x 300 DPI)

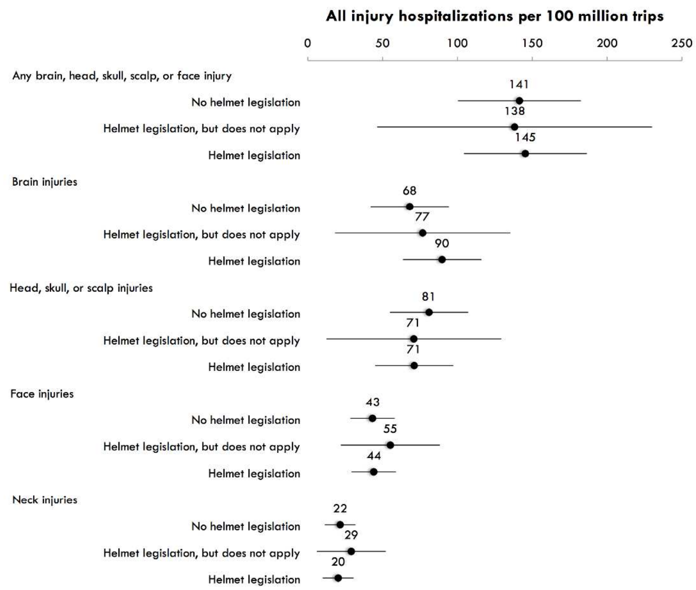

Figure 3. Mean hospitalization rates (and 95% confidence intervals; all injury causes, 44 strata) during the 6-year study period, by helmet legislation, for potentially associated body regions.
279x215mm (300 x 300 DPI)

Body Region Codes					
Parent Category - Any Injury	**Parent Category - Any Brain, Head, Face**	**Parent Category - Any Torso, Extremities**	**Parent Categories - Specific Body Regions**	**Included Codes**	**Included Codes Description**
Any injury	Any brain, head, scalp, skull or face injury		Brain	S04	Injury of cranial nerves
Any injury	Any brain, head, scalp, skull or face injury		Brain	S06	Intracranial injury
Any injury	Any brain, head, scalp, skull or face injury		Brain	T06.0	Injuries of brain and cranial nerve with injuries of nerves and spinal cord at neck level
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.0	Superficial injury of scalp
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.7	Multiple superficial injuries of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.8	Superficial injury of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.9	Superficial injury of head, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.0	Open wound of scalp
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.7	Multiple open wounds of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.8	Open wounds of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.9	Open wound of head, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.0	Fracture of vault of skull
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.1	Fracture of base of skull
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.7	Multiple fractures involving skull and facial bone
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.8	Fractures of other skull and facial bones
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.9	Fracture of skull and facial bones, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S03.3	Dislocation of other and unspecified parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S03.5	Sprain and strain of joints and ligaments of other and unspecified parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S07.1	Crushing injury of skull
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S07.8	Crushing injury of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S07.9	Crushing injury of head, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S08.0	Avulsion of scalp
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S08.8	Traumatic amputation of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S08.9	Traumatic amputation of unspecified part of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S09	Other and unspecified injuries of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T00.0	Superficial injuries involving head with neck
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T01.0	Open wound involving head with neck
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T02.0	Fractures involving head with neck
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T04.0	Crushing injuries involving head with neck

Any injury	Any brain, head, scalp, skull or face injury		Face	S00.1	Contusion of eyelid and periocular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.2	Other superficial injuries of eyelid and periocular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.3	Superficial injury of nose
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.4	Superficial injury of ear
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.5	Superficial injury of lip and oral cavity
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.1	Open wound of eyelid and periocular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.2	Open wound of nose
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.3	Open wound of ear
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.4	Open wound of cheek and temporomandibular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.5	Open wound of lip and oral cavity
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.2	Fracture of nasal bones
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.3	Fracture of orbital floor
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.4	Fracture of malar and maxillary bones
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.5	Fracture of tooth
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.6	Fracture of mandible
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.0	Dislocation of jaw
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.1	Dislocation of septal cartilage of nose
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.2	Dislocation of tooth
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.4	Sprain and strain of jaw
Any injury	Any brain, head, scalp, skull or face injury		Face	S05	Injury of eye and orbit
Any injury	Any brain, head, scalp, skull or face injury		Face	S07.0	Crushing injury of face
Any injury	Any brain, head, scalp, skull or face injury		Face	S08.1	Traumatic amputation of ear
Any injury	Any brain, head, scalp, skull or face injury		Face	T15	Foreign body on external eye
Any injury	Any brain, head, scalp, skull or face injury		Face	T16	Foreign body in ear
Any injury			Neck	S10-S19	Injuries to the neck
Any injury			Neck	T00.0	Superficial injuries involving head with neck
Any injury			Neck	T01.0	Open wound involving head with neck
Any injury			Neck	T02.0	Fractures involving head with neck
Any injury			Neck	T03.0	Dislocations, sprains and strains involving head with neck
Any injury			Neck	T04.0	Crushing injuries involving head with neck
Any injury			Neck	T06.0	Injuries of brain and cranial nerve with injuries of nerves and spinal cord at neck level

Any injury		Any torso, extremities	Torso	S20-S29	Injuries to the thorax
Any injury		Any torso, extremities	Torso	S30-S39	Injuries to the abdomen, lower back, lumbar spine, and pelvis
Any injury		Any torso, extremities	Torso	T00.1	Superficial injuries involving thorax with abdomen, lower back, and pelvis
Any injury		Any torso, extremities	Torso	T01.1	Open wounds involving thorax with abdomen, lower back and pelvis
Any injury		Any torso, extremities	Torso	T02.1	Fractures involving thorax with lower back and pelvis
Any injury		Any torso, extremities	Torso	T02.7	Fractures involving thorax with lower back and pelvis with limbs
Any injury		Any torso, extremities	Torso	T03.1	Dislocations, sprains and strains involving thorax with lower back and pelvis
Any injury		Any torso, extremities	Torso	T04.1	Crushing injuries involving thorax with abdomen, lower back and pelvis
Any injury		Any torso, extremities	Torso	T04.7	Crushing injuries of thorax with abdomen, lower back and pelvis with limbs
Any injury		Any torso, extremities	Torso	T06.5	Injuries of intrathoracic organs with intra-abdominal and pelvic organs
Any injury		Any torso, extremities	Torso	T08	Fracture of spine, level unspecified
Any injury		Any torso, extremities	Torso	T09	Other injuries of spine and trunk, level unspecified
Any injury		Any torso, extremities	Torso	T17	Foreign body in respiratory tract
Any injury		Any torso, extremities	Torso	T18	Foreign body in alimentary tract
Any injury		Any torso, extremities	Torso	T19	Foreign body in genitourinary tract
Any injury		Any torso, extremities	Upper extremities	S40-S49	Injuries to the shoulder and upper arm
Any injury		Any torso, extremities	Upper extremities	S50-S59	Injuries to the elbow and forearm
Any injury		Any torso, extremities	Upper extremities	S60-S69	Injuries to the wrist and hand
Any injury		Any torso, extremities	Upper extremities	T00.2	Superficial injuries involving multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T00.6	Superficial injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T01.2	Open wounds involing multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T01.6	Open wounds involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T02.2	Fractures involving multiple regions of one upper limb
Any injury		Any torso, extremities	Upper extremities	T02.4	Fractures involving multiple regions of both upper limbs
Any injury		Any torso, extremities	Upper extremities	T02.6	Fractures involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T02.7	Fractures involving thorax with lower back and pelvis with limbs
Any injury		Any torso, extremities	Upper extremities	T03.2	Dislocations, sprains and strains involving multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T03.4	Dislocations, sprains and strains invovling multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T04.2	Crushing injuries involving multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T04.4	Crushing injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T04.7	Crushing injuries of thorax with abdomen, lower back and pelvis with limbs

Any injury		Any torso, extremities	Upper extremities	T05.0	Traumatic amputation of both hands
Any injury		Any torso, extremities	Upper extremities	T05.1	Traumatic amputation of one hand and other arm [any level, except hand]
Any injury		Any torso, extremities	Upper extremities	T05.2	Traumatic amputation of both arms [any level]
Any injury		Any torso, extremities	Upper extremities	T05.6	Traumatic amputation of upper and lower limbs, any combination [any level]
Any injury		Any torso, extremities	Upper extremities	T10	Fracture of upper limb, level unspecified
Any injury		Any torso, extremities	Upper extremities	T11	Other injuries of upper limb, level unspecified
Any injury		Any torso, extremities	Lower Extremities	S70-S79	Injuries to the hip and thigh
Any injury		Any torso, extremities	Lower Extremities	S80-S89	Injuries to the knee and lower leg
Any injury		Any torso, extremities	Lower Extremities	S90-S99	Injuries to the ankle and foot
Any injury		Any torso, extremities	Lower Extremities	T00.3	Superficial injuries involving multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T00.6	Superficial injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T01.3	Open wounds of multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T01.6	Open wounds involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T02.3	Fractures involving multiple regions of one lower limb
Any injury		Any torso, extremities	Lower Extremities	T02.5	Fractures involving multiple regions of both lower limbs
Any injury		Any torso, extremities	Lower Extremities	T02.6	Fractures involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T02.7	Fractures involving thorax with lower back and pelvis with limbs
Any injury		Any torso, extremities	Lower Extremities	T03.3	Dislocations, sprains and strains invovling multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T03.4	Dislocations, sprains and strains invovling multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T04.3	Crushing injuries involving multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T04.4	Crushing injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T04.7	Crushing injuries of thorax with abdomen, lower back and pelvis with limbs
Any injury		Any torso, extremities	Lower Extremities	T05.3	Traumatic amputation of both feet
Any injury		Any torso, extremities	Lower Extremities	T05.4	Traumatic amputation of one foot and other leg [any level, except foot]
Any injury		Any torso, extremities	Lower Extremities	T05.5	Traumatic amputation of both legs [any level]
Any injury		Any torso, extremities	Lower Extremities	T05.6	Traumatic amputation of upper and lower limbs, any combination [any level]
Any injury		Any torso, extremities	Lower Extremities	T12	Fracture of lower limb, level unspecified
Any injury		Any torso, extremities	Lower Extremities	T13	Other injuries of lower limb, level unspecified
Any injury				T00.8	Superficial injuries involving other combinations of body regions
Any injury				T00.9	Multiple superficial injuries, unspecified
Any injury				T01.8	Open wounds involving other combinations of body regions

Any injury				T01.9	Multiple open wounds of unspecified site
Any injury				T02.8	Fractures involving other combinations of body regions
Any injury				T02.9	Multiple fractures, unspecified
Any injury				T03.8	Dislocations, sprains and strains involving other combinations of body regions
Any injury				T03.9	Multiple dislocations, sprains and strains, unspecified
Any injury				T04.8	Crushing injuries involving other combinations of body regions
Any injury				T04.9	Multiple crushing injuries, unspecified
Any injury				T05.8	Traumatic amputations involving other combinations of body regions
Any injury				T05.9	Multiple traumatic amputations, unspecified
Any injury				T06.1	Injuries of nerves and spinal cord involving multiple body regions
Any injury				T06.2	Injuries of nerves involving multiple body regions
Any injury				T06.3	Injuries of blood vessels involving multiple body regions
Any injury				T06.4	Injuries of muscles and tendons involving multiple body regions
Any injury				T06.8	Other specified injuries involving multiple body regions
Any injury				T07	Unspecified multiple injuries
Any injury				T14	Injury of unspecified body region

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Bicycling injury hospitalization rates in Canadian jurisdictions: Analyses examining associations with helmet legislation and mode share

Kay Teschke[1,]*, Mieke Koehoorn[1], Hui Shen[1], Jessica Dennis[2]

* Corresponding author

School of Population and Public Health, University of British Columbia, 2206 East Mall, Vancouver, BC, Canada, V6T 1Z3

kay.teschke@ubc.ca

604 822-2041

[1]School of Population and Public Health, University of British Columbia, Vancouver, Canada

[2]Dalla Lana School of Public Health, University of Toronto, Toronto, Canada

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ABSTRACT

Objectives

The purpose of this study was to calculate exposure-based bicycling hospitalization rates in Canadian jurisdictions with different helmet legislation and bicycling mode shares, and to examine whether the rates were related to these differences.

Methods

Administrative data on hospital stays for bicycling injuries to ten body region groups and national survey data on bicycling trips were used to calculate hospitalization rates. Rates were calculated for 44 sex, age and jurisdiction strata for all injury causes and 22 age and jurisdiction strata for traffic-related injury causes. Inferential analyses examined associations between hospitalization rates and sex, age group, helmet legislation, and bicycling mode share.

Results

In Canada, over the study period 2006 to 2011, there was an average of 3,690 hospitalizations per year and an estimated 593 million annual trips by bicycle among people 12 years of age and older, for a cycling hospitalization rate of 622 per 100 million trips (95% CI: 611-633). Hospitalization rates varied substantially across the jurisdiction, age and sex strata, but only two characteristics explained this variability. For all injury causes, sex was associated with hospitalization rates; females had rates consistently lower than males. For traffic-related injury causes, higher cycling mode share was consistently associated with lower hospitalization rates. Helmet legislation was not associated with hospitalization rates for brain, head, scalp, skull, face or neck injuries.

Conclusions

These results suggest that transportation and health policy makers who aim to reduce bicycling injury rates in the population should focus on factors related to increased cycling mode share and female cycling choices. Bicycling routes designed to be physically separated from traffic or along quiet streets fit both these criteria and are associated with lower relative risks of injury.

STRENGTHS AND LIMITATIONS OF THE STUDY

- This study was the first to compare exposure-based injury rates between jurisdictions with different helmet laws and cycling mode shares in one country. It allowed analyses in a setting with smaller cultural and transportation policy differences than in international comparisons.

- The study used the same data sources in all jurisdictions, for the numerator (hospitalizations) and denominator (bicycling trips). The focus was the most serious cycling injuries, those requiring an inpatient hospital stay. Bicycling trip data were from a series of national surveys that asked for recall of leisure, work and school trips over a three-month period.

- Separate analyses were done for all injury causes (including transport and sport cycling) and for traffic-related injury causes (focusing on transport cycling). The denominator for traffic-related causes was likely incomplete, so we could not compare absolute traffic-related injury rates to all-cause injury rates. Within each cause, rates were comparable and these comparisons were the study focus.

- We found that females had lower bicycling hospitalization rates than males in analyses of all injury causes, consistent with results found elsewhere and for other travel modes, an effect often attributed to conservative risk choices.

- We found that hospitalization rates for traffic-related injuries were lower with higher cycling mode shares, a "safety-in-numbers" association consistent with results elsewhere and for other modes of travel.

- Helmet legislation was not associated with reduced hospitalization rates for brain, head, scalp, skull, or face injuries, indicating that factors other than helmet laws have more influence on injury rates.

- These results provide useful context about population-level policies that may or may not affect bicycling hospitalization rates.

INTRODUCTION

Bicycling offers personal health benefits because physical activity reduces the risk of many chronic diseases.[1,2] Bicycling as a mode of transport is inexpensive and reduces traffic congestion, noise, air pollution and greenhouse gas emissions.[1,3] These benefits have led governments to consider ways to increase transport cycling, but population surveys consistently show that injury-related safety concerns are the major deterrent.[4-6]

To address these concerns, it is important to understand exposure-based injury risk (i.e., the injury rate calculated as injuries per number of bike trips or per distance travelled by bike). This measure allows between-jurisdiction comparisons of cycling safety, useful for assessing the value of different cycling conditions or laws that could guide future policy choices. Some characteristics that differ between jurisdictions include helmet laws, cycling infrastructure, and the proportion of all trips made by bike (cycling "mode share"). All of these may be related to cycling injuries. Bicycling injury research is dominated by helmet research; it shows that helmet use is associated with reduced relative risk of head injuries among those injured in a crash.[7,8] Studies examining the effect of helmet legislation have shown more mixed results.[9-13] Research on cycling infrastructure is less common, but has been growing in the last decade. Results are not always consistent, but most often show that routes with bike-specific infrastructure are safer than routes without.[14-17] Research on cycling mode share has repeatedly shown that places with more cycling have lower injury and fatality rates, though the causal pathway is debated.[18-21]

In a 2008 paper, Pucher and Buehler [22] compared jurisdictions with large differences in helmet legislation, cycling infrastructure, and mode share. In the United States, the focus of safety policy was promotion or legislation of helmet use, but bike-specific facilities were rare, and the proportion of trips by bicycle was about 1%. In Netherlands, Denmark and Germany, cycling facilities separated from traffic were common, helmet use was rare, and 10 to 27% of trips were by bicycle. They also compared injury rates from 2004 to 2009.[23] The US had fatality rates 3 to 5 times higher and injury rates 7 to 21 times higher than the northern European countries, lending support to the European policy choices. Others have argued that cultural and multi-faceted transportation policy differences between European and American jurisdictions make it difficult to draw conclusions.[24]

Here we report a comparison of injury rates within a country that has smaller cultural and transportation policy differences than those between the US and northern Europe. Canada is a federation of 10 provinces and 3 northern territories whose transportation policies are set at both national and provincial levels, resulting in broad similarities in traffic laws and infrastructure but also some differences. Default traffic speeds are 50 km/h in cities and 80 km/h in rural areas; intersections of arterials typically feature traffic lights rather than roundabouts; right turns on red lights are usually permitted; and drunk driving laws usually specify a blood alcohol limit of 0.08%. Despite these similarities, there are differences in bicycling infrastructure, cycling mode shares and helmet laws between provinces and territories, providing an opportunity to examine differences in injury rates. Two data sources with comparable data across all provinces and territories were used to provide descriptive information and calculate injury rates: hospital discharge data for bicycling injuries; and national health survey data for bicycling trips. Because hospital discharge data include all bicycling injuries, whether incurred during bicycling as a mode of transport or in bicycling sports (e.g., road racing, mountain biking, cyclo-cross, BMX, trick riding), the subset of injuries designated as traffic-related were examined separately. Inferential analyses examined whether cycling mode share or helmet legislation were related to injury rates.

METHODS

This analysis used administrative data on bicycling hospitalizations and trips matched as closely as possible to the 6-year period from 2006 to 2011 inclusive. This period was chosen because it is bracketed by census years (census data were used for some study variables), included the most recent complete hospitalization data, and represented a period of stability in helmet laws nationwide. The study was restricted to individuals aged 12 or older because data on bicycling trips were available only for these ages.

Hospitalizations

In Canada, a hospitalization record is generated when a patient is "admitted" to hospital for at least one overnight stay in a department other than the emergency department. These data include deaths after admission to hospital, though they represent a small proportion of all hospitalizations [9] and are not separately reported here. Data on all hospitalizations for bicycling injuries in Canada in the 6-fiscal-year period from 1 April 2006 to 31 March 2012 were obtained from the Discharge Abstract Database (all inpatient admissions to acute care hospitals in Canada) managed by the Canadian Institute for Health Information (CIHI).[25] Bicycling injuries were specified as those with international classification of diseases (ICD10-CA) external cause codes V10 to V19 inclusive.[26] The fiscal year starting April 1, 2006 was the first in which ICD-10 coding was consistently used by all hospitals in Canada. Hospital transfers were not included, so each hospitalization was counted once only – at the initial admission.

Tabulated data were received from CIHI stratified by jurisdiction, sex, age group, injury cause, and injured body region. Jurisdiction was specified as the location of the hospital of first treatment, to maximize the likelihood that the jurisdiction of hospitalization was where the injury occurred. Jurisdiction included 11 categories (10 provinces, and the 3 territories – Yukon, Northwest, Nunavut – in one group). Age groups were adult (18+) and youth (12 to 17). Injury causes and injured body regions were determined using ICD10-CA codes. Injury causes included all causes and the subset, traffic-related causes. Ten injured body region groups were defined: brain; head, scalp or skull; face; neck; torso; upper extremities; lower extremities; brain, head, scalp, skull or face; torso or extremities; and any body region (supplementary table). Up to 25 injuries are coded per patient, but within each body region group, a hospitalization was counted once only.

Bicycling trips

Data on bicycling trips for the years 2006 to 2011 inclusive were estimated from the Canadian Community Health Survey (CCHS) 2005, 2007/8, 2009/10, and 2011/12 cycles. The CCHS is conducted by Statistics Canada and each cycle samples 130,000 people 12 years of age and older who live in private dwellings (98% of the population) in all jurisdictions and health regions.[27] Prior to 2007, the CCHS was conducted over a one-year period every two years. From 2007 forward, it was conducted throughout the 2-year cycle, with 65,000 people surveyed each year. Samples are drawn from a geographic sampling frame using a 2-stage stratified design, and from telephone number or random digit dialing sampling frames using simple random sampling within health regions. Interviews are conducted using computer-assisted in-person and telephone interviewing, at randomly selected times from January to December to avoid seasonal bias. Bicycling trip data were extracted from the CCHS public release datasets, stratified by jurisdiction, sex, and age group, as for hospitalizations.

The following questions were used to tally leisure cycling trips:

- "To begin with, I'll be dealing with physical activities not related to work, that is, leisure time activities. Have you done any of the following in the past 3 months, that is, from [date three months ago] to yesterday? Bicycling?"
- If yes, "In the past 3 months, how many times did you participate in bicycling?"

Leisure cycling trips per year in each jurisdiction, sex, and age group stratum were calculated as the sum of all self-reported times bicycling in the past 3 months multiplied by 4 for an annual count.

The following questions were used to tally work and school cycling trips:

- "Other than the (X) times you already reported bicycling was there any other time in the past 3 months when you bicycled to and from work or school?"
- If yes, "How many times?"

Work and school cycling trips per year in each jurisdiction, sex, and age group stratum were calculated using the same methods as for leisure cycling trips.

The CCHS was not conducted in 2006 so annual leisure cycling trips for that year were estimated from the 2005 survey data, and annual work and school cycling trips were estimated from the 2007 survey data (as this was not asked on the 2005 survey).

Total bicycling trips were calculated as the sum of leisure, work and school trips. Unlike the hospitalization data, which was complete population data, bicycling trip data were estimated from survey samples. Counts were therefore weighted to demographic strata using the Statistics Canada survey sampling weights to account for the sampling design and generate population-based estimates. We followed the Statistics Canada bootstrapping protocol (500 replicates) to calculate confidence limits for the estimate of total bicycling trips.

Hospitalization rates

Two sets of hospitalization rates were calculated for injuries to each body region. The first set used data for injuries from all injury causes. Hospitalization rates were calculated by dividing the total number of hospitalizations over the 6-year period by the total estimated number of bicycling trips (leisure, work and school) for the period. For each body region, rates were calculated for 44 strata: 11 jurisdictions * 2 age groups * 2 sexes.

The second set of hospitalization rates were calculated for the subset of injuries that were traffic-related, since in all jurisdictions with helmet legislation, the law applies to public roads, the same location used in injury coding for "traffic-related". Trips to work or school are more likely than leisure trips to require use of public roads, so work and school trip data were used as the denominator for this rate calculation. Hospitalization rates were calculated by dividing the number of traffic-related hospitalizations over the 6-year period by the estimated number of bicycling trips to work or school for the period. Because traffic-related injuries were only about half of all injuries, these data were not stratified by sex, to minimize the number of strata with zero hospitalizations. For each body region, rates were calculated for 22 strata: 11 jurisdictions * 2 age groups.

Other data sources

Data on population size were obtained from the 2006 and 2011 censuses (each conducted on a single date in mid-May).[28] Data on cycling mode share were averaged from the 2006 Census long form and the 2011 National Household Survey [29,30] and represent the proportion of the total employed labour force that did not work at home and reported their usual mode of transportation to and from work as bicycle.

Information about helmet laws was retrieved from a previous publication [31] and from the legislation itself. Data on helmet use in all jurisdictions were available from the 2009/2010 CCHS via the following questions: "In the past 12 months, have you done any bicycling?" and if yes, "When riding a bicycle, how often do you wear a helmet?" The proportions who reported wearing a helmet always or most of the time were calculated for the same strata as hospitalization rates.

To describe cycling conditions by jurisdiction, a summary metric, Bike Score®, based on hilliness, density of amenities, road connectivity, and density of bike lanes, bike paths and local street bikeways is reported for the most populous city with available data in each jurisdiction (personal communication, Matt Lerner, CTO, Walk Score®, Seattle, WA, May 4, 2012).

Associations between hospitalization rates and cycling mode share, helmet legislation, age group, sex

For injuries to any body region and to the brain, head, scalp, skull or face, the associations between cycling mode share and hospitalization rates for all injury causes (44 strata) and for traffic-related injury causes (22 strata) were examined using scatter plots.

For inferential analyses, the hospitalization rate variables for each injury cause and body region group were transformed using the logit ($\ln[r/(1-r)]$, where r = hospitalization rate). This transformation of the bounded (0,1) rates ensured that the dependent variable was normally distributed ($p >> 0.05$, Shapiro-Wilks goodness of fit test, all hospitalization rate variables). Exponentiated coefficients for the independent variables were reported as odd ratios.

Simple least squares regression was used to examine associations between mode share and the logit of hospitalization rates for injuries to any body region and to the brain, head, scalp, skull or face, for all injury causes (44 strata) and for traffic-related injury causes (22 strata). Similar analyses were conducted to examine associations between hospitalization rates and helmet legislation, though these were extended to separately examine each body region group potentially associated with helmet legislation (brain, head, scalp, skull or face; brain; head, scalp or skull; face; neck). Helmet legislation was categorized as:

- no helmet law (all ages in Manitoba, Newfoundland & Labrador, Quebec, Saskatchewan, and the three Territories; adults in Alberta and Ontario); and
- helmet law (all ages in British Columbia, New Brunswick, Nova Scotia, and PEI; youths in Alberta and Ontario).

Multiple regression was used to examine the association between the logit of hospitalization rate for all injury causes (44 strata) and helmet legislation, cycling mode share, sex and age group (all as fixed effects), for injuries to any body region and to the brain, head, scalp, skull or face. Jurisdiction was offered as a random effect to adjust for within-jurisdiction correlation not explained by the fixed effects in the model, but removed if it was not a substantial (>20%) or statistically significant component of variance. The same modelling was repeated to examine associations between traffic-related hospitalization rates (22 strata) and helmet legislation, cycling mode share, and age group.

The helmet legislation results of the above models were checked via separate analyses of each body region group potentially impacted by helmet legislation (brain, head, scalp, skull or face; brain; head, scalp or skull; face; neck). In addition, since some jurisdictions without provincial legislation had helmet bylaws in municipalities, these analyses were repeated, substituting the proportions using helmets in study strata for the helmet legislation variable.

For some body region groups, one or more strata had zero hospitalizations. Omitting strata with zero hospitalizations from analyses would be biased, so we calculated the hospitalization rate for the these strata using a numerator of 0.1 injuries. Of the four main analyses, only one included a stratum with a zero injury count requiring this substitution, (all cause injuries to the brain, head, scalp, skull or face).

CCHS data were generated using SAS version 9.4 (SAS Institute Inc., Cary, NC), rate calculations and all other analyses were done using JMP 11 (SAS Institute Inc., Cary, NC).

RESULTS

In Canada over the period 2006 to 2011, there was an annual average of 3,690 hospitalizations for injuries incurred during bicycling among people 12 years of age and older. Table 1 lists the causes of the injury events. A slight majority (53%) of adult injuries were traffic-related, but only 41% of youth injuries were. Almost all collisions with motor vehicles (ICD-10 Codes V12, V13, V14) were traffic-related. For both youths and adults, a majority of injuries were non-collision transport accidents (V18), and most of these were not traffic-related.

Table 1. Annual average number of hospitalizations for bicycling injuries and percent that were traffic-related, by cause of injury and age group, in Canada in the period from 2006 to 2011.

		Youths, ages 12 to 17		Adults, ages 18+	
ICD-10 Code	Cause of injury description: Pedal cyclist injured in …[a]	Annual average number of hospitalizations[b]	% traffic-related[c]	Annual average number of hospitalizations[b]	% traffic-related[c]
V10	collision with pedestrian or animal	4	31.8	23	43.7
V11	collision with other pedal cyclist	9	47.2	66	64.1
V12	collision with 2- or 3-wheeled motor vehicle	1	75.0	8	82.2
V13	collision with car, pick-up truck or van	94	95.9	513	97.1
V14	collision with heavy transport vehicle or bus	6	97.1	29	98.3
V15	collision with railway train or railway vehicle	0	-	2	76.9
V16	collision with other non-motor vehicle	1	14.3	5	63.0
V17	collision with fixed or stationary object	23	30.0	134	52.4
V18	non-collision transport accident	512	29.5	1,877	39.3
V19	other and unspecified transport accidents	74	47.2	311	59.5
V10-19	All injury causes	724	40.8	2,966	53.4

a Note that although these codes refer to "pedal cyclist injured in transport accident", all bicycling injuries are coded here, whether or not they involve transportation cycling or sport cycling

b Includes all fourth character subdivision cause of injury codes = 0, 1, 2, 3, 4, 5, 6, 8, 9

c Traffic-related restricted to fourth character subdivision cause of injury codes = 4, 5, 6, 9, i.e., those that occur "on a public highway/road"

Figure 1 shows hospitalizations in Canada by body region injured. The affected body regions followed very similar patterns in youths and adults; upper extremities were the most frequently injured, followed by lower extremities, torso, brain, head or scalp or skull, face, and neck. Torso or extremities injuries were incurred by 82% of those hospitalized; brain, head, scalp, skull or face injuries by 25%; and neck injuries by 5%. Many people experienced multiple injuries, both within broad body regions (e.g., brain and head) and across any body region (e.g., head and extremities). The majority of those injured were male (88.6% of youths, 73.4% of adults).

Table 2 provides data on the 11 jurisdictions included in this study, illustrating the differences in bicycling conditions in their most populous cities, as well as in cycling mode share on a jurisdiction-wide basis. Cycling mode share was positively correlated with Bike Score. Table 2 also provides data on the annual average number of bike trips by youths and adults, a total of 593 million trips (95% CI: 583-604 million). The proportions of bicycling trips for work or school commutes were low, though they differed by age group and jurisdiction. More trips were made by males than females (71.0% by male youths, 63.5% by male adults).

Table 2. Characteristics of Canadian provinces and territories during study period of 2006 to 2011: population, Bike Score, cycling mode share, bicycling trips for all purposes and % that were trips to work or school.

				Youths, ages 12 to 17		Adults, ages 18+	
	Population[a]	Bike Score[b]	Cycling mode share (%)[c]	Annual bicycling trips	% to work or school	Annual bicycling trips	% to work or school
Alberta	3,467,804	62	1.10	12,262,406	11.1	41,985,585	15.6
British Columbia	4,256,772	73	2.05	14,064,898	13.7	67,454,711	21.9
Manitoba	1,178,335	-	1.67	5,284,444	15.0	17,859,145	18.9
New Brunswick	740,584	35	0.57	3,243,263	8.3	7,827,567	13.8
Newfoundland & Labrador	510,003	21	0.23	1,838,508	3.9	2,755,552	13.7
Nova Scotia	917,595	62	0.66	2,638,119	4.2	7,116,612	12.4
Ontario	12,506,052	60	1.20	55,940,049	14.3	169,979,958	15.7
Prince Edward Island	138,028	41	0.53	518,984	3.1	1,248,071	6.4
Quebec	7,724,566	69	1.37	32,309,917	11.7	130,818,129	15.7
Saskatchewan	1,000,769	66	1.36	4,219,897	15.3	12,061,879	14.6
Territories: Nunavut, Northwest, Yukon	104,288	-	1.86	503,842	14.9	1,292,224	23.3
Canada	32,544,796		1.30	132,824,327	12.8	460,399,432	16.6

a Mean population, 2006 and 2011 Censuses, Statistics Canada
b Bike Score for most populous city on the jurisdiction, except New Brunswick where score is for second most populous (Moncton); not available for cities in Manitoba or the Territories
c Mean proportion of commuting population who reported usually commuting by bicycle in the 2006 Census long form and the 2011 National Household Survey

Table 3 outlines differences in helmet legislation by jurisdiction. Four provinces had legislation that applied to all ages and two had legislation that applied to children only (i.e., age 17 and under). These helmet laws came into force between 1996 and 2003, at least 3 years prior to the start of the study period in all jurisdictions. All provincial helmet laws are pursuant to traffic or motor vehicle acts and applied to bicycling on public roads. This application is not publicized and may not be well known. Figure 2 presents the helmet use data in Table 3 graphically and illustrates that helmet use was higher with helmet laws than without.

Table 3. Helmet legislation and helmet use, stratified by age group, in Canadian provinces and territories.

Jurisdiction	Helmet legislation: Ages included	Helmet legislation: Year in force	Youths, ages 12 to 17 helmet use (%)ø	Adults, ages 18+ helmet use (%)ø
Alberta	< 18	2002	68.6	53.9
British Columbia	All	1996	66.1	71.3
Manitoba	None [a]		27.7	30.0
New Brunswick	All	1995	63.8	61.8
Newfoundland & Labrador	None [b]		50.9	51.7
Nova Scotia	All	1997	77.8	74.8
Ontario	< 18	1995	53.4	41.2
Prince Edward Island	All	2003	72.8	59.0
Quebec	None [c]		33.5	35.3
Saskatchewan	None [d]		36.8	30.3
Territories: Nunavut, Northwest, Yukon	None [e]		32.9	47.7

ø Percent of people who reported wearing a bike helmet always or most of the time when they bicycled, 2009 Canadian Community Health Survey.
a Helmet legislation for ages < 18 was enacted in Manitoba in 2013 (after the study period) under the Highway Traffic Act.
b 5 cities in Newfoundland & Labrador (representing ~30% of the provincial population) had helmet bylaws for all ages during the study period. A province-wide all ages helmet law will take effect April 1, 2015 under the Highway Traffic Act.
c 1 city in Quebec (representing < 0.5% of the provincial population) had a helmet bylaw for all ages during the study period.
d 1 city in Saskatchewan (representing ~ 1.5% of the provincial population) had a helmet bylaw for all ages during the study period.
e 2 cities in the Territories (representing ~30% of the territorial population) had helmet bylaws for all ages during the study period.

In the study period, the cycling hospitalization rate for youths and adults combined, was 622 hospitalizations per 100 million trips (95% CI: 611-633), with a slightly lower rate for youths than adults (545 vs. 644, respectively). This reflects a lower hospitalization rate for injuries to the torso and extremities for youths than adults (428 vs. 534, respectively), whereas rates for brain, head, scalp, skull or face injuries were very similar for the two age groups (159 vs. 152, respectively).

Figures 3a and 3b show the hospitalization rates in 44 age group, sex, and jurisdiction strata. Hospitalization rates for the torso or extremities were highly correlated with those for any body region (Pearson r = 0.98), so only the latter are shown. Rates for brain, head, scalp, skull or face injuries were less correlated with those for any body region (Pearson r = 0.81), so are shown separately. Figures 3c and 3d show the rates for traffic-related injury causes (i.e., those on public roads) using work or school trips as the denominator (22 age group and jurisdiction strata).

In Figures 3a to 3d, cycling mode share in the jurisdiction is the x-axis. In simple least squares regression, hospitalization rates for traffic-related injuries (logit-transformed) were significantly associated with mode share (Figures 3c and 3d). Higher mode shares were associated with lower hospitalization rates. The figures also denote whether the stratum was subject to helmet legislation. Figure 4 summarizes the results of analyses examining associations between hospitalization rates and helmet laws. No associations were found for body regions potentially affected by helmets (any brain, head, scalp, skull or face; brain; head, scalp or skull; face; neck).

Table 4 shows the results of multiple regression models examining associations between hospitalization rates and sex, age group, helmet legislation, and cycling mode share. For all injury hospitalizations, sex was significantly associated with hospitalization rate; females had substantially lower hospitalization rates than males. Age, helmet legislation, and cycling mode share were not related to hospitalization rate.

For traffic-related injury hospitalizations, sex was not available as a variable (Table 4). A significant association was observed for injuries to any body region and cycling mode share. Higher cycling mode share was associated with lower hospitalization rates. A nearly identical association between hospitalization rates and mode share was observed for injuries to the brain, head, scalp, skull or face. Neither helmet legislation nor age were associated with traffic-related hospitalization rates.

In separate models for each body region group expected to be impacted by helmets (brain, head, scalp, skull or face; brain; head, scalp or skull; face; neck), helmet legislation was not associated with hospitalization rates. To check whether the absence of associations between helmet laws and hospitalization rates might be an artifact of municipal helmet bylaws in jurisdictions without helmet legislation (Table 3), models were rerun to examine the relationships between hospitalization rates and the proportions using helmets in study strata. Coefficients were all positive – opposite to expectation.

Table 4. Odds ratios (95% confidence limits) for associations between various characteristics and hospitalization rates for injuries to any body region and injuries to the brain, head, scalp, skull or face, for all injury causes and traffic-related injury causes. Bold indicates statistical significance.

	Injuries to any body region		Injuries to the brain, head, scalp, skull or face	
All injury causes, dependent variable = logit (all injury hospitalizations/all bicycling trips) [a]				
Sex (female)	**0.67**	**(0.61, 0.73)**	**0.63**	**(0.54, 0.75)**
Age group (youth)	0.92	(0.84, 1.01)	1.00	(0.84, 1.18)
Helmet law applies (yes)	1.03	(0.88, 1.20)	1.08	(0.91, 1.28)
Cycling mode share (for a 1% increase)	1.20	(0.88, 1.62)	1.07	(0.79, 1.44)
Traffic-related injury causes, dependent variable = logit (traffic-related injury hospitalizations/bicycling trips to work or school) [b]				
Age group (youth)	1.03	(0.86, 1.24)	1.16	(0.92, 1.46)
Helmet law applies (yes)	1.14	(0.94, 1.39)	1.08	(0.85, 1.36)
Cycling mode share (per 1% increase)[c]	**0.69**	**(0.49, 0.97)**	0.68	(0.45, 1.03)

[a] 44 rates available for modeling: 11 jurisdictions x 2 age groups x 2 sexes; model for injuries to any body region includes random effect for jurisdiction

[b] 22 rates available for modeling: 11 jurisdictions x 2 age groups

[c] Coefficient represents the multiplicative reduction in the traffic-related hospitalization rate for each 1% increase in mode share. Note that this relationship was observed within the range of low mode shares (0.23 to 2.05%) of the jurisdictions in this study.

DISCUSSION

In Canada during the study period, the 3,690 annual hospitalizations for bicycling injuries among youths and adults were mainly among males (76%). Most (51%) were traffic-related (on public roads) but only 18% involved collisions with motor vehicles. Chen *et al.* [32] described 70,000 emergency department visits for bicycling injuries in the United States from 2001 to 2008. The most injured body parts were similar to those observed in our study: 70% the torso or extremities; 16% the face; and 13% the head. Similar to our results, most injuries were to males (73%) and slightly more than half of cases were injured on roads (56%), but a much higher proportion resulted from collisions with motor vehicles (58%).[32]

We calculated a hospitalization rate for all injury causes of 622 per 100 million trips, or one hospitalization per 161,000 trips. We found only one other study that reported bicycling hospitalization rates with a trip denominator. Blaizot *et al.* [33] reported a rate of 443 per 100 million trips in France, using data from a road trauma registry and a trip diary survey. Beck *et al.* [34] and Teschke *et al.* [35] calculated police-reported injury rates of 1461 and 1398 per 100 million trips in the US and Canada, respectively. These included injuries not requiring hospitalization, but likely included only injuries incurred in motor vehicle collisions.

The main purpose of this study was to calculate exposure-based injury rates in Canadian provinces and territories and to examine whether they were related to differences in helmet legislation and cycling mode shares. Hospitalization rates per 100 million trips varied substantially across the jurisdiction, age and sex strata examined, but only two characteristics explained any of this variability.

For all injury causes, sex was the only significant explanatory variable. Females had lower hospitalization rates than males. Lower bicycling injury and fatality rates for females has been shown elsewhere [34, 36-38], though not always [33, 38]. A pattern of lower injury and fatality rates for females has been observed in other transport modes including driving [34,36] and walking [33,34,36] and is often attributed to a lower propensity for risk taking. For example, research shows that women are less likely than men to ride on major city streets or rural roads without bike facilities, infrastructure that has been shown to have higher injury risk.[16, 39-41] Other lower risk behaviours of females include slower riding [16,39,40], and less participation in sport cycling (e.g., mountain biking).[42] In our study, in most strata, females had a somewhat higher helmet use proportion, but this variable was not associated with lower hospitalization rates. The only other demographic variable we examined, age group, was not significantly associated with hospitalization rates in our study. Other studies do not show consistent patterns with age.[33,34,36,37]

For traffic-related injury causes, cycling mode share was the only explanatory variable (sex not available for modeling). It was negatively associated with hospitalization rate, significantly so for injuries to any body region. This association is consistent with observations in other jurisdictions: with higher mode shares, injury and fatality rates are lower.[18-20] The "safety-in-numbers" association has also been observed for walking and driving.[18,19] The causal pathway of this association is not established and is likely to be multi-factorial and complex. Arguments have been made that more cyclists make drivers more alert to them, and more cycling means less motor vehicle traffic.[18-21] It is also possible that the relationship is in the opposite direction, for example, safer infrastructure results in more bicycling. There is consistent evidence that safer bicycling infrastructure attracts more people to use it.[43,44] This may result in a virtuous circle, if more cyclists mean a larger constituency calling for further safety improvements.

In our study, the safety-in-numbers association was not observed for all injury causes. This may be because *all causes* included injuries incurred during both transport cycling and sport cycling. In some Canadian provinces, mountain biking is a popular sport that involves riding on steep slopes, through densely wooded trails, and jumping obstacles and cliffs. It involves considerably higher injury risk than transport cycling.[45] Two Canadian studies reported that 19% and 38% of all serious injuries were incurred during mountain biking (study hospitals were in Alberta and British Columbia, respectively).[42,46] These injuries would not be expected to be related to transport cycling mode share. This may in part explain the very different ordering of hospitalization rates by mode share for all injury causes versus traffic injury causes (Figure 3). Particularly notable is the change for British Columbia – this jurisdiction has the highest commuter cycling mode share and is also renowned for its mountain biking terrain.

Helmet legislation was not associated with hospitalization rates for all injury or traffic-related injury causes. We separately examined potential associations for each body region expected to be protected by helmet use (brain, head, scalp, skull or face; brain; head, scalp or skull; face) as well as for the neck which, in some studies, has had elevated relative risks with helmet use.[7,8] There was variation in helmet use with helmet legislation, and this may have been related to municipal bylaws mandating helmet use within some provinces or territories without helmet laws (Table 3). We therefore also examined the relationship between hospitalization rates and helmet use proportions in the strata, and again did not find the expected protective effect. Studies of the relative risk of head, brain or face injuries among those injured in a cycling crash consistently show lower risk among those who wore a helmet,[7,8] though the potential for uncontrolled confounding in observational studies of a health behaviour suggests confidence in the effect estimates should not be unquestioning.[47] Before-after studies of the impact of helmet *legislation* have shown weaker and less consistent effects. Some have found reductions in brain or head injuries of 8% to 29% related to legislation [10-13], whereas others have found no effect for some or all outcomes.[9,11,13] Differences may be attributable to study design features including location, the selection of a control group unexposed to helmet legislation, whether baseline trends in injury rates were modeled, and whether and which surrogates were used for cycling rates. Our study compared bicycling hospitalization rates across jurisdictions rather than within a jurisdiction before and after legislation, and used exposure-based denominators to control for differences in cycling rates.

Our study is the first to examine exposure-based injury rates between jurisdictions within a single country with similar transportation cultures but different helmet laws. The fact that we did not find an effect of helmet *legislation* for injuries to any body region is not surprising, since most injuries were not head injuries. Even studies of helmet *use* have not found an effect for serious injuries to any body region.[48] After a crash, injuries to the torso, extremities and neck cannot be mitigated by a helmet, and injuries to these body regions were incurred in 87% of the hospitalizations in this study. The lack of a protective effect of legislation on brain and head injury rates is more unexpected. Helmet legislation in Canada has resulted in higher helmet use, so this cannot explain the results. The difference in helmet use proportions was not 100% vs. 0% (i.e., yes vs. no, as in helmet *use* studies), but on average ~ 67% where helmet laws apply vs. ~ 39% where they do not. This narrower difference would suggest a lesser impact of helmet *legislation* than individual helmet *use*, but not the results we found: effect estimates for helmet legislation were most often opposite to expectation or very close to the null. These results also indicate that insufficient power is not an explanation. Perhaps helmet laws simply influence injury severity, shifting the injury burden from deaths to hospitalizations? Our data included deaths after admission to hospital (estimated to be about 0.4% of all hospitalizations or 15 per year in our dataset [9]). Although deaths prior to admission were not included in our data, bicycling deaths are rare – those involving motor vehicles averaged 57 per year in the study period [49] – and unlikely to have an impact on our results, given 3,690 hospitalizations per year. A potential explanation for the lack of an effect of helmet *legislation* is that our study examined injury risk, including both the chance of being in a crash, as well as the chance that the crash caused a head injury. Helmets are designed to reduce the latter. But what about the effect of helmet use or legislation on the chance of being in a crash? This has been the basis for a great deal of debate, for example, if helmet legislation discourages cycling and the causal pathway of "safety in numbers", at least in part, is from numbers to safety, then injury risk may rise with reduced cycling.[10,19] Others have considered the impact of helmet use on risk-related behaviours. For example, one study showed that new male helmet users increased their cycling speed and another showed that drivers approached a cyclist more closely when he was wearing a helmet.[50,51]

In our view, the most important implication of our results is that factors other than helmet legislation influenced bicycling hospitalization rates, whereas helmet legislation did not. Females had lower rates in our study and they have been shown to cycle more slowly, and to choose routes on quiet streets and with bike-specific infrastructure.[16, 39-41] We also found lower traffic-related hospitalization rates with higher cycling mode shares. Here too there is a reasonable link to safer bicycling infrastructure, since it has been shown to draw more people to bicycling.[43,44]

Strengths and limitations

The main strength of this study is comparison of injury rates calculated using the same data sources in all jurisdictions, for both the numerator (hospitalizations) and denominator (bicycling trips). International comparisons of injury rates are much more difficult because of uncertainty in the comparability of each of these components.

The injury dataset was a full enumeration of inpatient discharge data from all acute care hospitals in the country. These injuries required a hospital stay so the study focus was more serious cycling injuries. The coding of injury causes did not allow separation of transport and sport cycling, but it did allow identification of the subset of traffic-related injuries. This subset is defined as injuries on public roads, the same locations to which provincial helmet legislation applies.

Bicycling trip data were derived from large surveys conducted by Statistics Canada, with a sampling design that covers the full year and thus every season. Its main limitations are that it asks each respondent to recall a 3-month period and asks about "times" bicycling rather than trips. Unlike Canada, many countries conduct national trip diary surveys that query transport behaviour over a period of one week or less, and provide careful definitions of a trip.[34-37] Although the denominator data available in Canada are less ideal, this study is notable in that it is one of few [34-38] to provide exposure-based bicycling injury rates. The bicycling data from the CCHS covered leisure trips and trips to work or school. This should include cycling for sport and for transport, therefore providing an appropriate exposure denominator for hospitalizations for all injury causes. For traffic-related injuries, there was no clearly parallel bicycling exposure definition. We chose to restrict the denominator for these hospitalizations to work and school commute cycling trips since they are very likely to require use of public roads. It is reasonable to expect that some unknown proportion of leisure trips will also use public roads, so our absolute estimates of traffic-related hospitalization rates are overestimates. The rates we calculated for traffic-related injuries were much higher than for all injuries, opposite to what Palmer *et al.* [45] found in a study that had complete denominator data for both sport and transport cycling. We were interested in comparing rates within traffic-related injury strata, rather than comparing rates for all injuries to traffic-related injuries, and for this purpose we feel our choice of denominator was reasonable.

The six years of numerator and denominator data did not match perfectly on the temporal scale. Hospitalization data compiled by the Canadian Institutes for Health Information are provided by all Canadian hospitals on a fiscal year starting in April rather than a calendar year; this created a 3-month discrepancy at either end of the 6-year study period. In addition, the Canadian Community Health Survey was not conducted in 2006, so trip data for that year were estimated from 2005 and 2007 data. Differences in the number of trips by survey period did not suggest a temporal trend and were small, especially compared to the large differences in bicycling trips between the age, sex and jurisdiction strata. We pooled 6 years of numerator data and 6 years of denominator data to calculate the hospitalization rates and feel that these provided reasonable estimates, despite the partial temporal mismatch.

CONCLUSIONS

In our study comparing exposure-based injury rates in 11 Canadian jurisdictions, we found that females had lower hospitalization rates than males. This difference in injury rates is consistent with other bicycling studies and studies of other transportation modes. We found that lower rates of traffic-related injuries were associated with higher cycling mode shares, a finding also reported elsewhere. We did not find a relationship between injury rates and helmet legislation.

These results suggest that policy makers interested in reducing bicycling injuries would be wise to focus on factors related to higher cycling mode shares and female cycling preferences. Bicycling infrastructure physically separated from traffic or routed along quiet streets is a promising fit for both and is associated with lower relative risk of injury.

CONTRIBUTORSHIP

KT and JD conceived the study and all authors contributed to its design and/or interpretation. KT drafted the manuscript and all authors participated in the revision process and have approved this submission for publication. KT and MK conducted the analyses. KT takes responsibility for the hospitalization rate analyses and MK for the bicycling trip and helmet use analyses.

DATA SHARING

Hospitalization data used in this study can be requested from the Canadian Institute for Health Information. Bicycling trip data can be retrieved from the Canadian Community Health Survey public release datasets.

COMPETING INTERESTS

None

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Figure 1. Annual average number of hospitalizations for bicycling injuries, by body region and age group, in Canada from 2006 to 2011.

Figure 2. Percent of youth and adult bicycle users in each province reporting helmet use always or most of the time (2009 Canadian Community Health Survey), by helmet law type. Thin bars denote means.

Figure 3. Hospitalization rates and cycling mode share during the study period, by injury cause and body region (rates for 44 strata for all injury causes and for 22 strata for traffic-related injury causes). Note that jurisdictions can be identified via their mode share, reported in Table 2.

Figure 4. Odds ratios (and 95% confidence intervals) for associations between helmet legislation and hospitalization rates, for potentially associated body regions and for torso or extremities injuries as a comparison. Reference group in each case is no helmet law (OR=1).

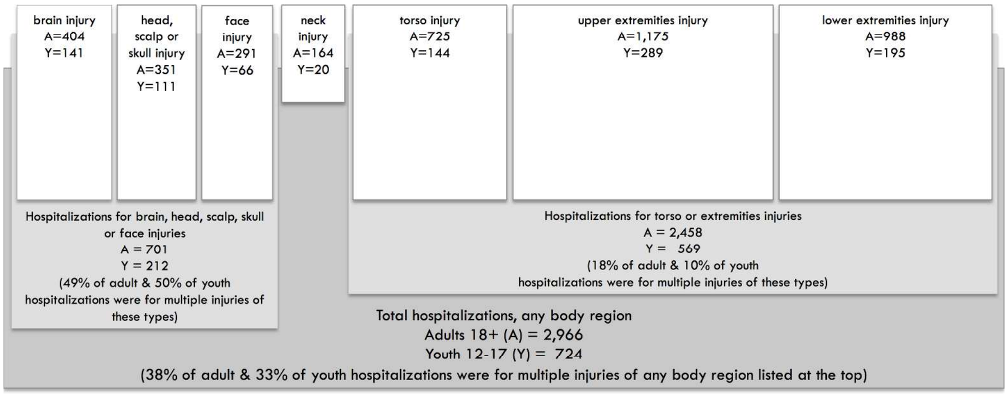

Figure 1. Annual average number of hospitalizations for bicycling injuries, by body region and age group, in Canada from 2006 to 2011.
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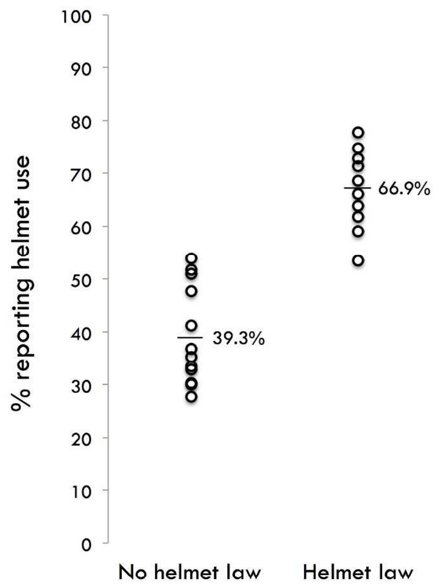

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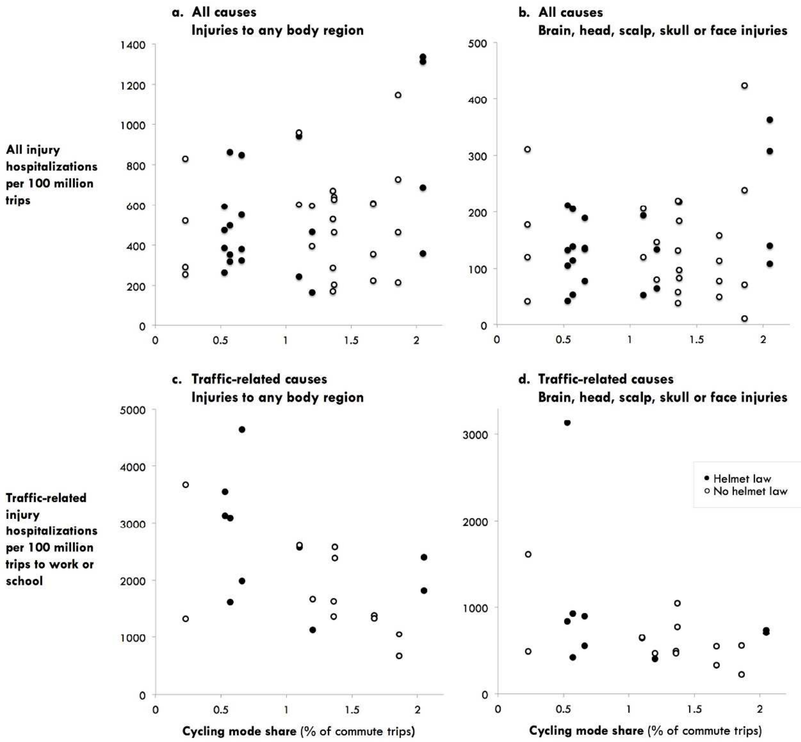

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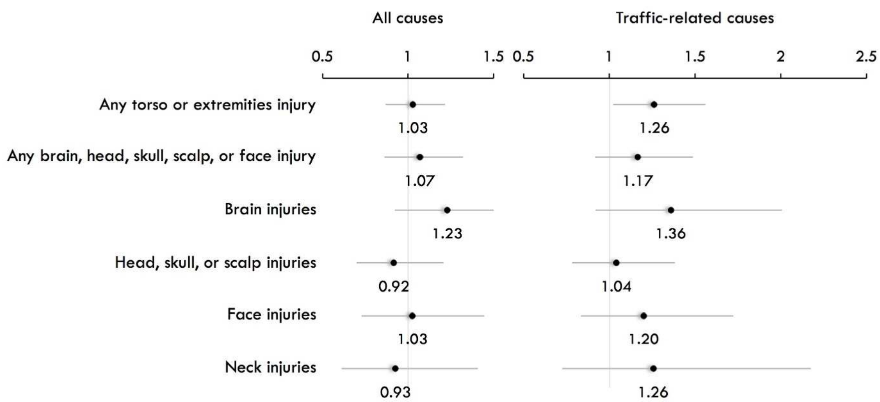

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Body Region Codes					
Parent Category - Any Injury	**Parent Category - Any Brain, Head, Face**	**Parent Category - Any Torso, Extremities**	**Parent Categories - Specific Body Regions**	**Included Codes**	**Included Codes Description**
Any injury	Any brain, head, scalp, skull or face injury		Brain	S04	Injury of cranial nerves
Any injury	Any brain, head, scalp, skull or face injury		Brain	S06	Intracranial injury
Any injury	Any brain, head, scalp, skull or face injury		Brain	T06.0	Injuries of brain and cranial nerve with injuries of nerves and spinal cord at neck level
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.0	Superficial injury of scalp
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.7	Multiple superficial injuries of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.8	Superficial injury of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.9	Superficial injury of head, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.0	Open wound of scalp
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.7	Multiple open wounds of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.8	Open wounds of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.9	Open wound of head, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.0	Fracture of vault of skull
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.1	Fracture of base of skull
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.7	Multiple fractures involving skull and facial bone
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.8	Fractures of other skull and facial bones
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.9	Fracture of skull and facial bones, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S03.3	Dislocation of other and unspecified parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S03.5	Sprain and strain of joints and ligaments of other and unspecified parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S07.1	Crushing injury of skull
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S07.8	Crushing injury of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S07.9	Crushing injury of head, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S08.0	Avulsion of scalp
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S08.8	Traumatic amputation of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S08.9	Traumatic amputation of unspecified part of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S09	Other and unspecified injuries of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T00.0	Superficial injuries involving head with neck
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T01.0	Open wound involving head with neck
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T02.0	Fractures involving head with neck
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T04.0	Crushing injuries involving head with neck

Any injury	Any brain, head, scalp, skull or face injury		Face	S00.1	Contusion of eyelid and periocular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.2	Other superficial injuries of eyelid and periocular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.3	Superficial injury of nose
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.4	Superficial injury of ear
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.5	Superficial injury of lip and oral cavity
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.1	Open wound of eyelid and periocular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.2	Open wound of nose
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.3	Open wound of ear
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.4	Open wound of cheek and temporomandibular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.5	Open wound of lip and oral cavity
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.2	Fracture of nasal bones
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.3	Fracture of orbital floor
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.4	Fracture of malar and maxillary bones
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.5	Fracture of tooth
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.6	Fracture of mandible
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.0	Dislocation of jaw
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.1	Dislocation of septal cartilage of nose
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.2	Dislocation of tooth
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.4	Sprain and strain of jaw
Any injury	Any brain, head, scalp, skull or face injury		Face	S05	Injury of eye and orbit
Any injury	Any brain, head, scalp, skull or face injury		Face	S07.0	Crushing injury of face
Any injury	Any brain, head, scalp, skull or face injury		Face	S08.1	Traumatic amputation of ear
Any injury	Any brain, head, scalp, skull or face injury		Face	T15	Foreign body on external eye
Any injury	Any brain, head, scalp, skull or face injury		Face	T16	Foreign body in ear
Any injury			Neck	S10-S19	Injuries to the neck
Any injury			Neck	T00.0	Superficial injuries involving head with neck
Any injury			Neck	T01.0	Open wound involving head with neck
Any injury			Neck	T02.0	Fractures involving head with neck
Any injury			Neck	T03.0	Dislocations, sprains and strains involving head with neck
Any injury			Neck	T04.0	Crushing injuries involving head with neck
Any injury			Neck	T06.0	Injuries of brain and cranial nerve with injuries of nerves and spinal cord at neck level

Any injury		Any torso, extremities	Torso	S20-S29	Injuries to the thorax
Any injury		Any torso, extremities	Torso	S30-S39	Injuries to the abdomen, lower back, lumbar spine, and pelvis
Any injury		Any torso, extremities	Torso	T00.1	Superficial injuries involving thorax with abdomen, lower back, and pelvis
Any injury		Any torso, extremities	Torso	T01.1	Open wounds involving thorax with abdomen, lower back and pelvis
Any injury		Any torso, extremities	Torso	T02.1	Fractures involving thorax with lower back and pelvis
Any injury		Any torso, extremities	Torso	T02.7	Fractures involving thorax with lower back and pelvis with limbs
Any injury		Any torso, extremities	Torso	T03.1	Dislocations, sprains and strains involving thorax with lower back and pelvis
Any injury		Any torso, extremities	Torso	T04.1	Crushing injuries involving thorax with abdomen, lower back and pelvis
Any injury		Any torso, extremities	Torso	T04.7	Crushing injuries of thorax with abdomen, lower back and pelvis with limbs
Any injury		Any torso, extremities	Torso	T06.5	Injuries of intrathoracic organs with intra-abdominal and pelvic organs
Any injury		Any torso, extremities	Torso	T08	Fracture of spine, level unspecified
Any injury		Any torso, extremities	Torso	T09	Other injuries of spine and trunk, level unspecified
Any injury		Any torso, extremities	Torso	T17	Foreign body in respiratory tract
Any injury		Any torso, extremities	Torso	T18	Foreign body in alimentary tract
Any injury		Any torso, extremities	Torso	T19	Foreign body in genitourinary tract
Any injury		Any torso, extremities	Upper extremities	S40-S49	Injuries to the shoulder and upper arm
Any injury		Any torso, extremities	Upper extremities	S50-S59	Injuries to the elbow and forearm
Any injury		Any torso, extremities	Upper extremities	S60-S69	Injuries to the wrist and hand
Any injury		Any torso, extremities	Upper extremities	T00.2	Superficial injuries involving multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T00.6	Superficial injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T01.2	Open wounds involing multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T01.6	Open wounds involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T02.2	Fractures involving multiple regions of one upper limb
Any injury		Any torso, extremities	Upper extremities	T02.4	Fractures involving multiple regions of both upper limbs
Any injury		Any torso, extremities	Upper extremities	T02.6	Fractures involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T02.7	Fractures involving thorax with lower back and pelvis with limbs
Any injury		Any torso, extremities	Upper extremities	T03.2	Dislocations, sprains and strains involving multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T03.4	Dislocations, sprains and strains invovling multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T04.2	Crushing injuries involving multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T04.4	Crushing injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T04.7	Crushing injuries of thorax with abdomen, lower back and pelvis with limbs

Any injury		Any torso, extremities	Upper extremities	T05.0	Traumatic amputation of both hands
Any injury		Any torso, extremities	Upper extremities	T05.1	Traumatic amputation of one hand and other arm [any level, except hand]
Any injury		Any torso, extremities	Upper extremities	T05.2	Traumatic amputation of both arms [any level]
Any injury		Any torso, extremities	Upper extremities	T05.6	Traumatic amputation of upper and lower limbs, any combination [any level]
Any injury		Any torso, extremities	Upper extremities	T10	Fracture of upper limb, level unspecified
Any injury		Any torso, extremities	Upper extremities	T11	Other injuries of upper limb, level unspecified
Any injury		Any torso, extremities	Lower Extremities	S70-S79	Injuries to the hip and thigh
Any injury		Any torso, extremities	Lower Extremities	S80-S89	Injuries to the knee and lower leg
Any injury		Any torso, extremities	Lower Extremities	S90-S99	Injuries to the ankle and foot
Any injury		Any torso, extremities	Lower Extremities	T00.3	Superficial injuries involving multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T00.6	Superficial injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T01.3	Open wounds of multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T01.6	Open wounds involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T02.3	Fractures involving multiple regions of one lower limb
Any injury		Any torso, extremities	Lower Extremities	T02.5	Fractures involving multiple regions of both lower limbs
Any injury		Any torso, extremities	Lower Extremities	T02.6	Fractures involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T02.7	Fractures involving thorax with lower back and pelvis with limbs
Any injury		Any torso, extremities	Lower Extremities	T03.3	Dislocations, sprains and strains invovling multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T03.4	Dislocations, sprains and strains invovling multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T04.3	Crushing injuries involving multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T04.4	Crushing injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T04.7	Crushing injuries of thorax with abdomen, lower back and pelvis with limbs
Any injury		Any torso, extremities	Lower Extremities	T05.3	Traumatic amputation of both feet
Any injury		Any torso, extremities	Lower Extremities	T05.4	Traumatic amputation of one foot and other leg [any level, except foot]
Any injury		Any torso, extremities	Lower Extremities	T05.5	Traumatic amputation of both legs [any level]
Any injury		Any torso, extremities	Lower Extremities	T05.6	Traumatic amputation of upper and lower limbs, any combination [any level]
Any injury		Any torso, extremities	Lower Extremities	T12	Fracture of lower limb, level unspecified
Any injury		Any torso, extremities	Lower Extremities	T13	Other injuries of lower limb, level unspecified
Any injury				T00.8	Superficial injuries involving other combinations of body regions
Any injury				T00.9	Multiple superficial injuries, unspecified
Any injury				T01.8	Open wounds involving other combinations of body regions

Any injury				T01.9	Multiple open wounds of unspecified site
Any injury				T02.8	Fractures involving other combinations of body regions
Any injury				T02.9	Multiple fractures, unspecified
Any injury				T03.8	Dislocations, sprains and strains involving other combinations of body regions
Any injury				T03.9	Multiple dislocations, sprains and strains, unspecified
Any injury				T04.8	Crushing injuries involving other combinations of body regions
Any injury				T04.9	Multiple crushing injuries, unspecified
Any injury				T05.8	Traumatic amputations involving other combinations of body regions
Any injury				T05.9	Multiple traumatic amputations, unspecified
Any injury				T06.1	Injuries of nerves and spinal cord involving multiple body regions
Any injury				T06.2	Injuries of nerves involving multiple body regions
Any injury				T06.3	Injuries of blood vessels involving multiple body regions
Any injury				T06.4	Injuries of muscles and tendons involving multiple body regions
Any injury				T06.8	Other specified injuries involving multiple body regions
Any injury				T07	Unspecified multiple injuries
Any injury				T14	Injury of unspecified body region

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Bicycling injury hospitalization rates in Canadian jurisdictions: Analyses examining associations with helmet legislation and mode share

Kay Teschke[1,*], Mieke Koehoorn[1], Hui Shen[1], Jessica Dennis[2]

* Corresponding author

School of Population and Public Health, University of British Columbia, 2206 East Mall,

Vancouver, BC, Canada, V6T 1Z3

kay.teschke@ubc.ca

604 822-2041

[1]School of Population and Public Health, University of British Columbia, Vancouver, Canada

[2]Dalla Lana School of Public Health, University of Toronto, Toronto, Canada

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ABSTRACT

Objectives
The purpose of this study was to calculate exposure-based bicycling hospitalization rates in Canadian jurisdictions with different helmet legislation and bicycling mode shares, and to examine whether the rates were related to these differences.

Methods
Administrative data on hospital stays for bicycling injuries to ten body region groups and national survey data on bicycling trips were used to calculate hospitalization rates. Rates were calculated for 44 sex, age and jurisdiction strata for all injury causes and 22 age and jurisdiction strata for traffic-related injury causes. Inferential analyses examined associations between hospitalization rates and sex, age group, helmet legislation, and bicycling mode share.

Results
In Canada, over the study period 2006 to 2011, there was an average of 3,690 hospitalizations per year and an estimated 593 million annual trips by bicycle among people 12 years of age and older, for a cycling hospitalization rate of 622 per 100 million trips (95% CI: 611-633). Hospitalization rates varied substantially across the jurisdiction, age and sex strata, but only two characteristics explained this variability. For all injury causes, sex was associated with hospitalization rates; females had rates consistently lower than males. For traffic-related injury causes, higher cycling mode share was consistently associated with lower hospitalization rates. Helmet legislation was not associated with hospitalization rates for brain, head, scalp, skull, face or neck injuries.

Conclusions
These results suggest that transportation and health policy makers who aim to reduce bicycling injury rates in the population should focus on factors related to increased cycling mode share and female cycling choices. Bicycling routes designed to be physically separated from traffic or along quiet streets fit both these criteria and are associated with lower relative risks of injury.

STRENGTHS AND LIMITATIONS OF THE STUDY

- This study was the first to compare exposure-based injury rates between jurisdictions with different helmet laws and cycling mode shares in one country. It allowed analyses in a setting with smaller cultural and transportation policy differences than in international comparisons.

- The study used the same data sources in all jurisdictions, for the numerator (hospitalizations) and denominator (bicycling trips). The focus was the most serious cycling injuries, those requiring an inpatient hospital stay. Bicycling trip data were from a series of national surveys that asked for recall of leisure, work and school trips over a three-month period.

- Separate analyses were done for all injury causes (including transport and sport cycling) and for traffic-related injury causes (focusing on transport cycling). The denominator for traffic-related causes was likely incomplete, so we could not compare absolute traffic-related injury rates to all-cause injury rates. Within each cause, rates were comparable and these comparisons were the study focus.

- We found that females had lower bicycling hospitalization rates than males in analyses of all injury causes, consistent with results found elsewhere and for other travel modes, an effect often attributed to conservative risk choices.

- We found that hospitalization rates for traffic-related injuries were lower with higher cycling mode shares, a "safety-in-numbers" association consistent with results elsewhere and for other modes of travel.

- Helmet legislation was not associated with reduced hospitalization rates for brain, head, scalp, skull, or face injuries, indicating that factors other than helmet laws have more influence on injury rates.

- These results provide useful context about population-level policies that may or may not affect bicycling hospitalization rates.

INTRODUCTION

Bicycling offers personal health benefits because physical activity reduces the risk of many chronic diseases.[1,2] Bicycling as a mode of transport is inexpensive and reduces traffic congestion, noise, air pollution and greenhouse gas emissions.[1,3] These benefits have led governments to consider ways to increase transport cycling, but population surveys consistently show that injury-related safety concerns are the major deterrent.[4-6]

To address these concerns, it is important to understand exposure-based injury risk (i.e., the injury rate calculated as injuries per number of bike trips or per distance travelled by bike). This measure allows between-jurisdiction comparisons of cycling safety, useful for assessing the value of different cycling conditions or laws that could guide future policy choices. Some characteristics that differ between jurisdictions include helmet laws, cycling infrastructure, and the proportion of all trips made by bike ("mode share"). All of these may be related to cycling injuries. Bicycling injury research is dominated by helmet research; it shows that helmet use is associated with reduced odds of head injuries among those injured in a crash.[7,8] Studies examining the effect of helmet legislation have shown more mixed results.[9-13] Research on cycling infrastructure is less common, but has been growing in the last decade. Results are not always consistent, but most often show that routes with bike-specific infrastructure are safer than routes without.[14-17] Research on cycling mode share has repeatedly shown that places with more cycling have lower injury and fatality rates, though the causal pathway is debated.[18-21]

In a 2008 paper, Pucher and Buehler [22] compared jurisdictions with large differences in helmet legislation, cycling infrastructure, and mode share. In the United States, the focus of safety policy was promotion or legislation of helmet use, but bike-specific facilities were rare, and the proportion of trips by bicycle was about 1%. In Netherlands, Denmark and Germany, cycling facilities separated from traffic were common, helmet use was rare, and 10 to 27% of trips were by bicycle. They also compared injury rates from 2004 to 2009.[23] The US had fatality rates 3 to 5 times higher and injury rates 7 to 21 times higher than the northern European countries, lending support to the European policy choices. Others have argued that cultural and multi-faceted transportation policy differences between European and American jurisdictions make it difficult to draw conclusions.[24]

Here we report a comparison of injury rates within a country that has smaller cultural and transportation policy differences than those between the US and northern Europe. Canada is a federation of 10 provinces and 3 northern territories whose transportation policies are set at both national and provincial levels, resulting in broad similarities in traffic laws and infrastructure but also some differences. Default traffic speeds are 50 km/h in cities and 80 km/h in rural areas; intersections of arterials typically feature traffic lights rather than roundabouts; right turns on red lights are usually permitted; and drunk driving laws usually specify a blood alcohol limit of 0.08%. Despite these similarities, there are differences in bicycling infrastructure, cycling mode shares and helmet laws between provinces and territories, providing an opportunity to examine differences in injury rates. Two data sources with comparable data across all provinces and territories were used to provide descriptive information and calculate injury rates: hospital discharge data for bicycling injuries; and national health survey data for bicycling trips. Because hospital discharge data include all bicycling injuries, whether incurred during bicycling as a mode of transport or in bicycling sports (e.g., road racing, mountain biking, cyclo-cross, BMX, trick riding), the subset of injuries designated as traffic-related were examined separately. Inferential analyses examined whether cycling mode share or helmet legislation were related to injury rates.

METHODS

This analysis used administrative data on bicycling hospitalizations and trips matched as closely as possible to the 6-year period from 2006 to 2011 inclusive. This period was chosen because it is bracketed by census years (census data were used for some study variables), included the most recent complete hospitalization data, and represented a period of stability in helmet laws nationwide. The study was restricted to individuals aged 12 or older because data on bicycling trips were available only for these ages.

Hospitalizations

In Canada, a hospitalization record is generated when a patient is "admitted" to hospital for at least one overnight stay in a department other than the emergency department. These data include deaths after admission to hospital, though they represent a small proportion of all hospitalizations [9] and are not separately reported here. Data on all hospitalizations for bicycling injuries in Canada in the 6-fiscal-year period from 1 April 2006 to 31 March 2012 (all years combined) were obtained from the Discharge Abstract Database (all inpatient admissions to acute care hospitals in Canada) managed by the Canadian Institute for Health Information (CIHI).[25] Bicycling injuries were specified as those with international classification of diseases (ICD10-CA) external cause codes V10 to V19 inclusive.[26] The fiscal year starting April 1, 2006 was the first in which ICD-10 coding was consistently used by all hospitals in Canada. Hospital transfers were not included, so each hospitalization was counted once only – at the initial admission.

Tabulated data were received from CIHI stratified by jurisdiction, sex, age group, injury cause, and injured body region (data format, Supplementary File 1). Jurisdiction was specified as the location of the hospital of first treatment, to maximize the likelihood that the jurisdiction of hospitalization was where the injury occurred. Jurisdiction included 11 categories (10 provinces, and the 3 territories – Yukon, Northwest, Nunavut – in one group). Age groups were adult (18+) and youth (12 to 17). Injury causes and injured body regions were determined using ICD10-CA codes. Injury causes included all causes and the subset, traffic-related causes. Ten injured body region groups were defined: brain; head, scalp or skull; face; neck; torso; upper extremities; lower extremities; brain, head, scalp, skull or face; torso or extremities; and any body region (codes, Supplementary File 2). Up to 25 injuries are coded per patient, but within each body region group, a hospitalization was counted once only.

Bicycling trips

Data on bicycling trips for the years 2006 to 2011 inclusive were estimated from the Canadian Community Health Survey (CCHS) 2005, 2007/8, 2009/10, and 2011/12 cycles. The CCHS is conducted by Statistics Canada and each cycle samples 130,000 people 12 years of age and older who live in private dwellings (98% of the population) in all jurisdictions and health regions.[27] Prior to 2007, the CCHS was conducted over a one-year period every two years. From 2007 forward, it was conducted throughout the 2-year cycle, with 65,000 people surveyed each year. Samples are drawn from a geographic sampling frame using a 2-stage stratified design, and from telephone number or random digit dialing sampling frames using simple random sampling within health regions. Interviews are conducted using computer-assisted in-person and telephone interviewing, at randomly selected times from January to December to avoid seasonal bias. Bicycling trip data were extracted from the CCHS public release datasets, stratified by jurisdiction, sex, and age group, as for hospitalizations.

The following questions were used to tally leisure cycling trips:

- "To begin with, I'll be dealing with physical activities not related to work, that is, leisure time activities. Have you done any of the following in the past 3 months, that is, from [date three months ago] to yesterday? Bicycling?"
- If yes, "In the past 3 months, how many times did you participate in bicycling?"

Leisure cycling trips per year in each jurisdiction, sex, and age group stratum were calculated as the sum of all self-reported times bicycling in the past 3 months multiplied by 4 for an annual count.

The following questions were used to tally work and school cycling trips:

- "Other than the (X) times you already reported bicycling was there any other time in the past 3 months when you bicycled to and from work or school?"
- If yes, "How many times?"

Work and school cycling trips per year in each jurisdiction, sex, and age group stratum were calculated using the same methods as for leisure cycling trips.

The CCHS data collected in 2005 used a sampling design by Statistics Canada meant to be representative of the entire population and their health behaviours for a two-year cycle (2005 and 2006). This data was used to calculate annual leisure cycling trips for 2006. Annual work and school cycling trips were estimated from the 2007 survey data, as this was not asked on the 2005 survey.

Total bicycling trips were calculated as the sum of leisure, work and school trips. Unlike the hospitalization data, which was complete population data, bicycling trip data were estimated from survey samples. Counts were therefore weighted to demographic strata using the Statistics Canada survey sampling weights to account for the sampling design and generate population-based estimates. We followed the Statistics Canada bootstrapping protocol (500 replicates) to calculate confidence limits for the estimate of total bicycling trips.

Hospitalization rates

Two sets of hospitalization rates were calculated for injuries to each body region. The first set used data for injuries from all injury causes. Hospitalization rates were calculated by dividing the total number of hospitalizations over the 6-year period by the total estimated number of bicycling trips (leisure, work and school) for the period. For each body region, rates were calculated for 44 strata: 11 jurisdictions * 2 age groups * 2 sexes.

The second set of hospitalization rates were calculated for the subset of injuries that were traffic-related, since in all jurisdictions with helmet legislation, the law applies to public roads, the same location used in injury coding for "traffic-related". Trips to work or school are more likely than leisure trips to require use of public roads, so work and school trip data were used as the denominator for this rate calculation. Hospitalization rates were calculated by dividing the total number of traffic-related hospitalizations over the 6-year period by the estimated number of bicycling trips to work or school for the period. Because traffic-related injuries were only about half of all injuries, these data were not stratified by sex, to minimize the number of strata with zero hospitalizations. For each body region, rates were calculated for 22 strata: 11 jurisdictions * 2 age groups.

Other data sources

Data on population size were obtained from the 2006 and 2011 censuses (each conducted on a single date in mid-May).[28] Data on cycling mode share were averaged from the 2006 Census long form and the 2011 National Household Survey [29,30] and represent the proportion of the total employed labour force that did not work at home and reported their usual mode of transportation to and from work as bicycle.

Information about helmet laws was retrieved from a previous publication [31] and from the legislation itself. Data on helmet use in all jurisdictions were available from the 2009/2010 CCHS via the following questions: "In the past 12 months, have you done any bicycling?" and if yes, "When riding a bicycle, how often do you wear a helmet?" The proportions who reported wearing a helmet always or most of the time were calculated for the same strata as hospitalization rates.

To provide a sense of cycling conditions by jurisdiction, a summary metric, Bike Score®, is reported for the most populous city with available data in each jurisdiction. For Canadian cities, it is based on hilliness, density of amenities, road connectivity, and density of bike lanes, bike paths and local street bikeways (personal communication, Matt Lerner, CTO, Walk Score®, Seattle, WA, May 4, 2012).

Associations between hospitalization rates and cycling mode share, helmet legislation, age group, sex

For injuries to any body region and to the brain, head, scalp, skull or face, the associations between cycling mode share and hospitalization rates for all injury causes (44 strata) and for traffic-related injury causes (22 strata) were examined using scatter plots.

For inferential analyses, the hospitalization rate variables for each injury cause and body region group were transformed using the logit (ln[r/(1-r)], where r = hospitalization rate). This transformation of the bounded (0,1) rates ensured that the dependent variable was normally distributed ($p >> 0.05$, Shapiro-Wilks goodness of fit test, all hospitalization rate variables). Exponentiated coefficients for the independent variables were reported as odd ratios.

Simple linear regression was used to examine associations between mode share and the logit of hospitalization rates for injuries to any body region and to the brain, head, scalp, skull or face, for all injury causes (44 strata) and for traffic-related injury causes (22 strata). Similar analyses were conducted to examine associations between hospitalization rates and helmet legislation, though these were extended to separately examine each body region group potentially associated with helmet legislation (brain, head, scalp, skull or face; brain; head, scalp or skull; face; neck). Helmet legislation was categorized as:

- no helmet law (all ages in Manitoba, Newfoundland & Labrador, Quebec, Saskatchewan, and the three Territories; adults in Alberta and Ontario); and
- helmet law (all ages in British Columbia, New Brunswick, Nova Scotia, and PEI; youths in Alberta and Ontario).

Multiple regression was used to examine the association between the logit of hospitalization rate for all injury causes (44 strata) and helmet legislation, cycling mode share, sex and age group (all as fixed effects), for injuries to any body region and to the brain, head, scalp, skull or face. Jurisdiction was offered as a random effect to adjust for within-jurisdiction correlation not explained by the fixed effects in the model, but removed if it was not a substantial (>20%) or statistically significant component of variance. The same modelling was repeated to examine associations between traffic-related hospitalization rates (22 strata) and helmet legislation, cycling mode share, and age group.

The helmet legislation results of the above models were checked via separate analyses of each body region group potentially impacted by helmet legislation (brain, head, scalp, skull or face; brain; head, scalp or skull; face; neck). In addition, since some jurisdictions without provincial legislation had helmet bylaws in municipalities, these analyses were repeated, substituting the proportions using helmets in study strata for the helmet legislation variable.

For some body region groups, one or more strata had zero hospitalizations. Omitting strata with zero hospitalizations from analyses would be biased, so we calculated the hospitalization rate for the these strata using a numerator of 0.1 injuries. Of the four main analyses, only one included a single stratum with a zero injury count requiring this substitution (all cause injuries to the brain, head, scalp, skull or face).

CCHS data were generated using SAS version 9.4 (SAS Institute Inc., Cary, NC), rate calculations and all other analyses were done using JMP 11 (SAS Institute Inc., Cary, NC).

RESULTS

In Canada over the period 2006 to 2011, there was an annual average of 3,690 hospitalizations for injuries incurred during bicycling among people 12 years of age and older. Table 1 lists the causes of the injury events. A slight majority (53%) of adult injuries were traffic-related, but only 41% of youth injuries were. Almost all collisions with motor vehicles (ICD-10 Codes V12, V13, V14) were traffic-related. For both youths and adults, a majority of injuries were non-collision transport accidents (V18), and most of these were not traffic-related.

Figure 1 shows hospitalizations in Canada by body region injured. The affected body regions followed very similar patterns in youths and adults; upper extremities were the most frequently injured, followed by lower extremities, torso, brain, head or scalp or skull, face, and neck. Torso or extremities injuries were incurred by 82% of those hospitalized; brain, head, scalp, skull or face injuries by 25%; and neck injuries by 5%. Many people experienced multiple injuries, both within broad body regions (e.g., brain and head) and across any body region (e.g., head and extremities). The majority of those injured were male (88.6% of youths, 73.4% of adults).

Table 2 provides data on the 11 jurisdictions included in this study, illustrating the differences in bicycling conditions in their most populous cities, as well as in cycling mode share on a jurisdiction-wide basis. Although their regional coverage differed, provincial cycling mode share was positively correlated with Bike Score® in the most populous city. Table 2 also provides data on the annual average number of bike trips by youths and adults, a total of 593 million trips (95% CI: 583-604 million). The proportions of bicycling trips for work or school commutes were low, though they differed by age group and jurisdiction. More trips were made by males than females (71.0% by male youths, 63.5% by male adults).

Table 1. Annual average number of hospitalizations for bicycling injuries and percent that were traffic-related, by cause of injury and age group, in Canada in the period from 2006 to 2011.

ICD-10 Code	Cause of injury description: Pedal cyclist injured in …[a]	Youths, ages 12 to 17: Annual average number of hospitalizations[b]	Youths, ages 12 to 17: % traffic-related[c]	Adults, ages 18+: Annual average number of hospitalizations[b]	Adults, ages 18+: % traffic-related[c]
V10	collision with pedestrian or animal	4	31.8	23	43.7
V11	collision with other pedal cyclist	9	47.2	66	64.1
V12	collision with 2- or 3-wheeled motor vehicle	1	75.0	8	82.2
V13	collision with car, pick-up truck or van	94	95.9	513	97.1
V14	collision with heavy transport vehicle or bus	6	97.1	29	98.3
V15	collision with railway train or railway vehicle	0	-	2	76.9
V16	collision with other non-motor vehicle	1	14.3	5	63.0
V17	collision with fixed or stationary object	23	30.0	134	52.4
V18	non-collision transport accident	512	29.5	1,877	39.3
V19	other and unspecified transport accidents	74	47.2	311	59.5
V10-19	All injury causes	724	40.8	2,966	53.4

a Note that although these codes refer to "pedal cyclist injured in transport accident", all bicycling injuries are coded here, whether or not they involve transportation cycling or sport cycling
b Includes all fourth character subdivision cause of injury codes = 0, 1, 2, 3, 4, 5, 6, 8, 9
c Traffic-related restricted to fourth character subdivision cause of injury codes = 4, 5, 6, 9, i.e., those that occur "on a public highway/road"

Table 3 outlines differences in helmet legislation by jurisdiction. Four provinces had legislation that applied to all ages and two had legislation that applied to children only (i.e., age 17 and under). These helmet laws came into force between 1996 and 2003, at least 3 years prior to the start of the study period in all jurisdictions. All provincial helmet laws are pursuant to traffic or motor vehicle acts and applied to bicycling on public roads. This application is not publicized and may not be well known. Figure 2 presents the helmet use data in Table 3 graphically and illustrates that helmet use was higher with helmet laws than without.

In the study period, the cycling hospitalization rate for youths and adults combined, was 622 hospitalizations per 100 million trips (95% CI: 611-633), with a slightly lower rate for youths than adults (545 vs. 644, respectively). This reflects a lower hospitalization rate for injuries to the torso and extremities for youths than adults (428 vs. 534, respectively), whereas rates for brain, head, scalp, skull or face injuries were very similar for the two age groups (159 vs. 152, respectively).

Figures 3a and 3b show the hospitalization rates in 44 age group, sex, and jurisdiction strata. Hospitalization rates for the torso or extremities were highly correlated with those for any body region (Pearson r = 0.98), so only the latter are shown. Rates for brain, head, scalp, skull or face injuries were less correlated with those for any body region (r = 0.81), so are shown separately. Figures 3c and 3d show the rates for traffic-related injury causes (i.e., those on public roads) using work or school trips as the denominator (22 age group and jurisdiction strata).

In Figures 3a to 3d, cycling mode share in the jurisdiction is the x-axis. In simple linear regression, hospitalization rates for traffic-related injuries (logit-transformed) were significantly associated with mode share (Figures 3c and 3d). Higher mode shares were associated with lower hospitalization rates. The figures also denote whether the stratum was subject to helmet legislation. Figure 4 summarizes the results of analyses examining associations between hospitalization rates and helmet laws. No associations were found for body regions potentially affected by helmets (any brain, head, scalp, skull or face; brain; head, scalp or skull; face; neck).

Table 2. Characteristics of Canadian provinces and territories during study period of 2006 to 2011: population, Bike Score, cycling mode share, bicycling trips for all purposes and % that were trips to work or school.

				Youths, ages 12 to 17		Adults, ages 18+	
	Population[a]	Bike Score[b]	Cycling mode share (%)[c]	Annual bicycling trips	% to work or school	Annual bicycling trips	% to work or school
Alberta	3,467,804	62	1.10	12,262,406	11.1	41,985,585	15.6
British Columbia	4,256,772	73	2.05	14,064,898	13.7	67,454,711	21.9
Manitoba	1,178,335	-	1.67	5,284,444	15.0	17,859,145	18.9
New Brunswick	740,584	35	0.57	3,243,263	8.3	7,827,567	13.8
Newfoundland & Labrador	510,003	21	0.23	1,838,508	3.9	2,755,552	13.7
Nova Scotia	917,595	62	0.66	2,638,119	4.2	7,116,612	12.4
Ontario	12,506,052	60	1.20	55,940,049	14.3	169,979,958	15.7
Prince Edward Island	138,028	41	0.53	518,984	3.1	1,248,071	6.4
Quebec	7,724,566	69	1.37	32,309,917	11.7	130,818,129	15.7
Saskatchewan	1,000,769	66	1.36	4,219,897	15.3	12,061,879	14.6
Territories: Nunavut, Northwest, Yukon	104,288	-	1.86	503,842	14.9	1,292,224	23.3
Canada	32,544,796		1.30	132,824,327	12.8	460,399,432	16.6

a Mean population, 2006 and 2011 Censuses, Statistics Canada
b Score for most populous city on the jurisdiction, except New Brunswick where score is for second most populous (Moncton); not available for cities in Manitoba or the Territories
c Mean proportion of commuting population who reported usually commuting by bicycle in the 2006 Census long form and the 2011 National Household Survey

Table 3. Helmet legislation and helmet use, stratified by age group, in Canadian provinces and territories.

	Helmet legislation			
Jurisdiction	Ages included	Year in force	Youths, ages 12 to 17 helmet use (%)[ø]	Adults, ages 18+ helmet use (%)[ø]
Alberta	< 18	2002	68.6	53.9
British Columbia	All	1996	66.1	71.3
Manitoba	None [a]		27.7	30.0
New Brunswick	All	1995	63.8	61.8
Newfoundland & Labrador	None [b]		50.9	51.7
Nova Scotia	All	1997	77.8	74.8
Ontario	< 18	1995	53.4	41.2
Prince Edward Island	All	2003	72.8	59.0
Quebec	None [c]		33.5	35.3
Saskatchewan	None [d]		36.8	30.3
Territories: Nunavut, Northwest, Yukon	None [e]		32.9	47.7

ø Percent of people who reported wearing a bike helmet always or most of the time when they bicycled, 2009 Canadian Community Health Survey.
a Helmet legislation for ages < 18 was enacted in Manitoba in 2013 (after the study period) under the Highway Traffic Act.
b 5 cities in Newfoundland & Labrador (representing ~30% of the provincial population) had helmet bylaws for all ages during the study period. A province-wide all ages helmet law will take effect April 1, 2015 under the Highway Traffic Act.
c 1 city in Quebec (representing < 0.5% of the provincial population) had a helmet bylaw for all ages during the study period.
d 1 city in Saskatchewan (representing ~ 1.5% of the provincial population) had a helmet bylaw for all ages during the study period.
e 2 cities in the Territories (representing ~30% of the territorial population) had helmet bylaws for all ages during the study period.

Table 4 shows the results of multiple regression models examining associations between hospitalization rates and sex, age group, helmet legislation, and cycling mode share. For all injury hospitalizations, sex was significantly associated with hospitalization rate; females had substantially lower hospitalization rates than males. Age, helmet legislation, and cycling mode share were not related to hospitalization rate.

For traffic-related injury hospitalizations, sex was not available as a variable (Table 4). A significant association was observed for injuries to any body region and cycling mode share. Higher cycling mode share was associated with lower hospitalization rates. A nearly identical association between hospitalization rates and mode share was observed for injuries to the brain, head, scalp, skull or face. Neither helmet legislation nor age were associated with traffic-related hospitalization rates.

In separate models for each body region group expected to be impacted by helmets (brain, head, scalp, skull or face; brain; head, scalp or skull; face; neck), helmet legislation was not associated with hospitalization rates. To check whether the absence of associations between helmet laws and hospitalization rates might be an artifact of municipal helmet bylaws in jurisdictions without helmet legislation (Table 3), models were rerun to examine the relationships between hospitalization rates and the proportions using helmets in study strata. Coefficients were all positive – opposite to expectation.

Table 4. Odds ratios (95% confidence limits) for associations between various characteristics and hospitalization rates for injuries to any body region and injuries to the brain, head, scalp, skull or face, for all injury causes and traffic-related injury causes. Bold indicates statistical significance.

	Injuries to any body region		Injuries to the brain, head, scalp, skull or face	
All injury causes, dependent variable = logit (all injury hospitalizations/all bicycling trips) [a]				
Sex (female)	**0.45**	**(0.37, 0.53)**	**0.40**	**(0.29, 0.56)**
Age group (youth)	0.85	(0.70, 1.02)	1.00	(0.71, 1.40)
Helmet law applies (yes)	1.06	(0.78, 1.43)	1.16	(0.82, 1.65)
Cycling mode share (for a 1% increase)	1.20	(0.88, 1.62)	1.07	(0.79, 1.44)
Traffic-related injury causes, dependent variable = logit (traffic-related injury hospitalizations/bicycling trips to work or school) [b]				
Age group (youth)	1.06	(0.73, 1.54)	1.35	(0.85, 2.13)
Helmet law applies (yes)	1.31	(0.89, 1.92)	1.16	(0.72, 1.86)
Cycling mode share (per 1% increase)[c]	**0.69**	**(0.49, 0.97)**	0.68	(0.45, 1.03)

[a] 44 rates available for modeling: 11 jurisdictions x 2 age groups x 2 sexes; model for injuries to any body region includes random effect for jurisdiction

[b] 22 rates available for modeling: 11 jurisdictions x 2 age groups

[c] Coefficient represents the multiplicative reduction in the traffic-related hospitalization rate for each 1% increase in mode share. Note that this relationship was observed within the range of low mode shares (0.23 to 2.05%) of the jurisdictions in this study.

DISCUSSION

In Canada during the study period, the 3,690 annual hospitalizations for bicycling injuries among youths and adults were mainly among males (76%). Most (51%) were traffic-related (on public roads) but only 18% resulted from collisions with motor vehicles. Chen *et al.* [32] described 70,000 emergency department visits for bicycling injuries in the United States from 2001 to 2008. The most injured body parts were similar to those observed in our study: 70% the torso or extremities; 16% the face; and 13% the head. Similar to our results, most injuries were to males (73%) and slightly more than half of cases were injured on roads (56%), but a much higher proportion resulted from collisions with motor vehicles (58%).[32]

We calculated a hospitalization rate for all injury causes of 622 per 100 million trips, or one hospitalization per 161,000 trips. We found only one other study that reported bicycling hospitalization rates with a trip denominator. Blaizot *et al.* [33] reported a rate of 443 per 100 million trips in France, using data from a road trauma registry and a trip diary survey. Beck *et al.* [34] and Teschke *et al.* [35] calculated police-reported injury rates of 1461 and 1398 per 100 million trips in the US and Canada, respectively. These included injuries not requiring hospitalization, but likely included only injuries incurred in motor vehicle collisions.

The main purpose of this study was to calculate exposure-based injury rates in Canadian provinces and territories and to examine whether they were related to differences in helmet legislation and cycling mode shares. Hospitalization rates per 100 million trips varied substantially across the jurisdiction, age and sex strata examined, but only two characteristics explained any of this variability.

For all injury causes, sex was the only significant explanatory variable. Females had lower hospitalization rates than males. Lower bicycling injury and fatality rates for females has been shown elsewhere [34, 36-38], though not always [33, 38]. A pattern of lower injury and fatality rates for females has been observed in other transport modes including driving [34,36] and walking [33,34,36] and is often attributed to a lower propensity for risk taking. For example, research shows that women are less likely than men to ride on major city streets or rural roads without bike facilities, infrastructure that has been shown to have higher injury risk.[16, 39-41] Other lower risk behaviours of females include slower riding [16,39,40], and less participation in sport cycling (e.g., mountain biking).[42] In our study, in most strata, females had a somewhat higher helmet use proportion, but this variable was not associated with lower hospitalization rates. The only other demographic variable we examined, age group, was not significantly associated with hospitalization rates in our study. Other studies do not show consistent patterns with age.[33,34,36,37]

For traffic-related injury causes, cycling mode share was the only explanatory variable (sex not available for modeling). It was negatively associated with hospitalization rate, significantly so for injuries to any body region (in simple and multiple regression) and to the brain, head, scalp, skull or face (in simple regression). This association is consistent with observations in other jurisdictions: with higher mode shares, injury and fatality rates are lower.[18-20] The "safety-in-numbers" association has also been observed for walking.[18,19] The causal pathway of this association is not established and is likely to be multi-factorial and complex. Arguments have been made that more cyclists make drivers more alert to them, and more cycling means less motor vehicle traffic.[18-21] It is also possible that the relationship is in the opposite direction, for example, safer infrastructure results in more bicycling. There is consistent evidence that safer bicycling infrastructure attracts more people to use it.[43,44] This may result in a virtuous circle, if more cyclists mean a larger constituency calling for further safety improvements.

In our study, the safety-in-numbers association was not observed for all injury causes. This may be because *all causes* included injuries incurred during both transport cycling and sport cycling. In some Canadian provinces, mountain biking is a popular sport that involves riding on steep slopes, through densely wooded trails, and jumping obstacles and cliffs. It involves considerably higher injury risk than transport cycling.[45] Two Canadian studies reported that 19% and 38% of all serious injuries were incurred during mountain biking (study hospitals were in Alberta and British Columbia, respectively).[42,46] These injuries would not be expected to be related to transport cycling mode share. This may in part explain the very different pattern of hospitalization rates by mode share for all injury causes versus traffic injury causes (Figure 3). Particularly notable is the change for British Columbia – this jurisdiction has the highest commuter cycling mode share and is also renowned for its mountain biking terrain.

Helmet legislation was not associated with hospitalization rates for all injury or traffic-related injury causes. We separately examined potential associations for each body region expected to be protected by helmet use (brain, head, scalp, skull or face; brain; head, scalp or skull; face) as well as for the neck which, in some studies, has had elevated odds of injury with helmet use.[7,8] There was variation in helmet use with helmet legislation, and this may have been related to municipal bylaws mandating helmet use within some provinces or territories without helmet laws (Table 3). We therefore also examined the relationship between hospitalization rates and helmet use proportions in the strata, and again did not find the expected protective effect. Studies among those injured in a cycling crash consistently show lower odds of head, brain or face injuries among those who wore a helmet,[7,8] though the potential for uncontrolled confounding in observational studies of a health behaviour suggests confidence in the effect estimates should not be unquestioning.[47] Before-after studies of the impact of helmet *legislation* have shown weaker and less consistent effects. Some have found reductions in brain or head injuries of 8% to 29% related to legislation [10-13], whereas others have found no effect for some or all outcomes.[9,11,13] Differences may be attributable to study design features including location, the selection of a control group unexposed to helmet legislation, whether baseline trends in injury rates were modeled, and whether and which surrogates were used for cycling rates. Our study compared bicycling hospitalization rates across jurisdictions rather than within a jurisdiction before and after legislation, and used exposure-based denominators to control for differences in cycling rates.

Our study is the first to examine exposure-based injury rates between jurisdictions within a single country with similar transportation cultures but different helmet laws. The fact that we did not find an effect of helmet *legislation* for injuries to any body region is not surprising, since most injuries were not head injuries. Even studies of helmet *use* have not found an effect for serious injuries to any body region.[48] After a crash, injuries to the torso, extremities and neck cannot be mitigated by a helmet, and injuries to these body regions were incurred in 87% of the hospitalizations in this study. The lack of a protective effect of legislation on brain and head injury rates is more unexpected. Helmet legislation in Canada has resulted in higher helmet use, so this cannot explain the results. The difference in helmet use proportions was not 100% vs. 0% (i.e., yes vs. no, as in helmet *use* studies), but on average ~ 67% where helmet laws apply vs. ~ 39% where they do not. This narrower difference would suggest a lesser impact of helmet *legislation* than individual helmet *use*, but not the results we found: effect estimates for helmet legislation were most often opposite to expectation or close to the null. These results also indicate that insufficient power is not an explanation. Perhaps helmet laws simply influence injury severity, shifting the injury burden from deaths to hospitalizations? Our data included deaths after admission to hospital (estimated to be about 0.4% of all hospitalizations [9] or 15 per year in our dataset). Although deaths prior to admission were not included in our data, bicycling deaths are rare – those involving motor vehicles averaged 57 per year in the study period [49] – and unlikely to have an impact on our results, given 3,690 hospitalizations per year. A potential explanation for the lack of an effect of helmet *legislation* is that our study examined injury risk, including both the chance of being in a crash, as well as the chance that the crash caused a head injury. Helmets are designed to reduce the latter. But what about the effect of helmet use or legislation on the chance of being in a crash? This has been the basis for a great deal of debate, for example, if helmet legislation discourages cycling and the causal pathway of "safety in numbers", at least in part, is from numbers to safety, then injury risk may rise with reduced cycling.[10,19] Others have considered the impact of helmet use on risk-related behaviours. Such studies are not always consistent, but some have findings that could help explain our results. For example, one study found that new male (but not female) helmet users tended to increase their cycling speed and one found that drivers approached a cyclist more closely when he was wearing a helmet.[50,51]

In our view, the most important implication of our results is that factors other than helmet legislation influenced bicycling hospitalization rates, whereas helmet legislation did not. Females had lower rates in our study and they have been shown to cycle more slowly, and to choose routes on quiet streets and with bike-specific infrastructure.[16, 39-41] We also found lower traffic-related hospitalization rates with higher cycling mode shares. Here too there is a reasonable link to safer bicycling infrastructure, since it has been shown to draw more people to bicycling.[43,44]

Strengths and limitations

The main strength of this study is comparison of injury rates calculated using the same data sources in all jurisdictions, for both the numerator (hospitalizations) and denominator (bicycling trips). International comparisons of injury rates are much more difficult because of uncertainty in the comparability of each of these components.

The injury dataset was a full enumeration of inpatient discharge data from all acute care hospitals in the country. These injuries required a hospital stay so the study focus was more serious cycling injuries. The coding of injury causes did not allow separation of transport and sport cycling, but it did allow identification of the subset of traffic-related injuries. This subset is defined as injuries on public roads, the same locations to which provincial helmet legislation applies.

Bicycling trip data were derived from large surveys conducted by Statistics Canada, with a sampling design that covers the full year and thus every season. Its main limitations are that it asks each respondent to recall a 3-month period and asks about "times" bicycling rather than trips. Unlike Canada, many countries conduct national trip diary surveys that query transport behaviour over a period of one week or less, and provide careful definitions of a trip.[34-37] Although the denominator data available in Canada are less ideal, this study is notable in that it is one of few [34-38] to provide exposure-based bicycling injury rates. The bicycling data from the CCHS covered leisure trips and trips to work or school. This should include cycling for sport and for transport, therefore providing an appropriate exposure denominator for hospitalizations for all injury causes. For traffic-related injuries, there was no clearly parallel bicycling exposure definition. We chose to restrict the denominator for these hospitalizations to work and school commute cycling trips since they are very likely to require use of public roads. It is reasonable to expect that some unknown proportion of leisure trips will also use public roads, so our absolute estimates of traffic-related hospitalization rates are overestimates. The rates we calculated for traffic-related injuries were much higher than for all injuries, opposite to what Palmer *et al.* [45] found in a study that had complete denominator data for both sport and transport cycling. We were interested in comparing rates within traffic-related injury strata, rather than comparing rates for all injuries to traffic-related injuries, and for this purpose we believe our choice of denominator was reasonable.

The six years of numerator and denominator data did not match perfectly on the temporal scale. Hospitalization data compiled by the Canadian Institutes for Health Information are provided by all Canadian hospitals for a fiscal year starting in April rather than a calendar year; this created a 3-month discrepancy at either end of the 6-year study period (6 of 72 months). In addition, prior to 2007, Canadian Community Health Survey data was collected during one year biennially, so leisure trips for 2006 were estimated from the 2005 data collection meant to represent that 2-year period. Work and school trip data were not collected in the CCHS prior to 2007, so 2007 data were used to estimate these 2006 trips. Differences in the number of trips by survey period did not suggest a temporal trend and were small, especially compared to the large differences in bicycling trips between the age, sex and jurisdiction strata. We pooled 6 years of numerator data and 6 years of denominator data to calculate the hospitalization rates and feel that these provided reasonable estimates, despite the partial temporal mismatch.

CONCLUSIONS

In our study comparing exposure-based injury rates in 11 Canadian jurisdictions, we found that females had lower hospitalization rates than males. This difference in injury rates is consistent with other bicycling studies and studies of other transportation modes. We found that lower rates of traffic-related injuries were associated with higher cycling mode shares, a finding also reported elsewhere. We did not find a relationship between injury rates and helmet legislation.

These results suggest that policy makers interested in reducing bicycling injuries would be wise to focus on factors related to higher cycling mode shares and female cycling preferences. Bicycling infrastructure physically separated from traffic or routed along quiet streets is a promising fit for both and is associated with lower relative risk of injury.

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Figure 1. Annual average number of hospitalizations for bicycling injuries, by body region and age group, in Canada from 2006 to 2011.

Figure 2. Percent of youth and adult bicycle users in each province reporting helmet use always or most of the time (2009 Canadian Community Health Survey), by helmet law or not. Thin bars denote means.

Figure 3. Hospitalization rates and cycling mode share during the study period, by injury cause and body region (rates for 44 strata for all injury causes and for 22 strata for traffic-related injury causes). Note that jurisdictions can be identified via their mode share, reported in Table 2.

Figure 4. Odds ratios (and 95% confidence intervals) for associations between hospitalization rates and helmet legislation, for potentially associated body regions and for torso or extremities injuries as a comparison. Reference group in each case is no helmet law (OR=1).

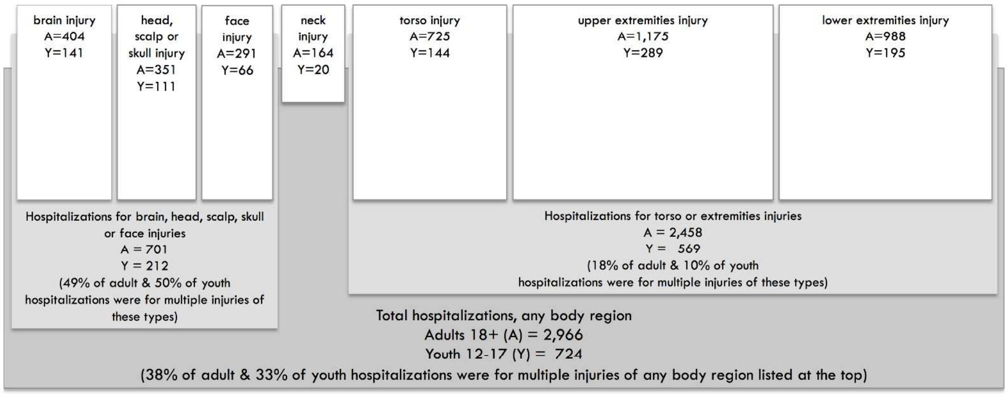

Figure 1. Annual average number of hospitalizations for bicycling injuries, by body region and age group, in Canada from 2006 to 2011.
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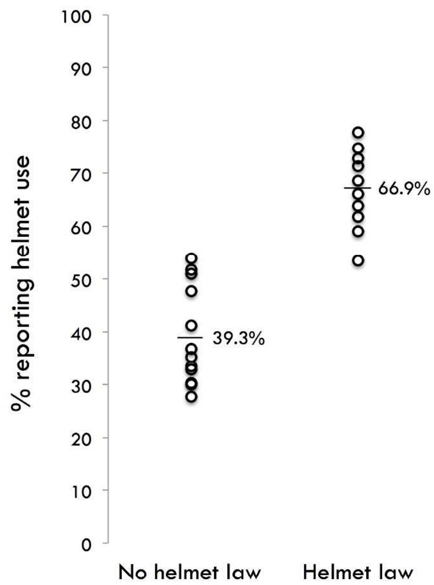

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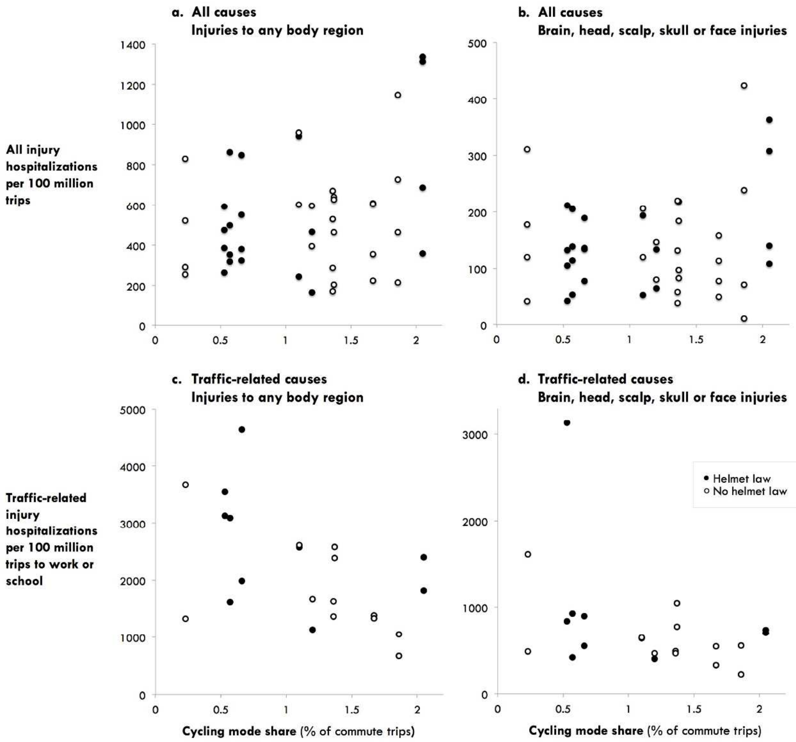

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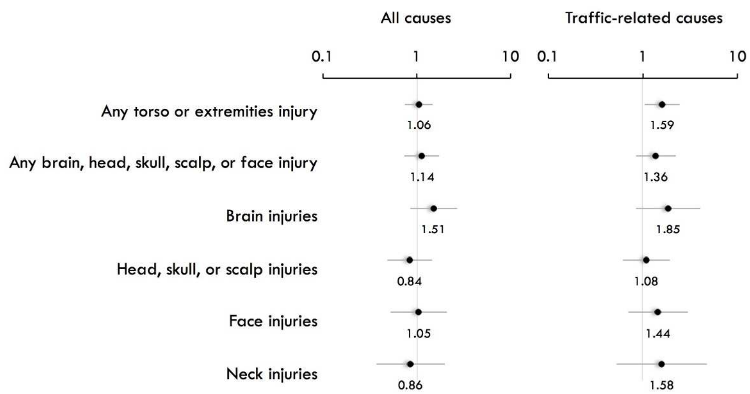

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Table A Hospitalization for injuries sustained by adult female pedal cyclists in Canada, April 1 2006-March 31 2012, by province and injury type

Years	April 1 2006 to March 31 2012
Sex	Female
Age	18 +
Cause of Injury	All

	Injury Type									
Location of Hospital	Any injury	Any brain, head, face injury	Any torso, extremities injury	Brain injury	Head, scalp or skull injury	Face injury	Neck injury	Torso injury	Upper extremities injury	Lower extremities injury
Canada										
Newfoundland										
Nova Scotia										
Prince Edward Island										
New Brunswick										
Quebec										
Ontario										
Manitoba										
Saskatchewan										
Alberta										
British Columbia										
Terrtitories										

Table B Hospitalization for injuries sustained by adult male pedal cyclists in Canada, April 1 2006-March 31 2012, by province and injury type

Years	April 1 2006 to March 31 2012
Sex	Male
Age	18 +
Cause of Injury	All

	Injury Type									
Location of Hospital	Any injury	Any brain, head, face injury	Any torso, extremities injury	Brain injury	Head, scalp or skull injury	Face injury	Neck injury	Torso injury	Upper extremities injury	Lower extremities injury
Canada										
Newfoundland										
Nova Scotia										
Prince Edward Island										
New Brunswick										
Quebec										
Ontario										
Manitoba										
Saskatchewan										
Alberta										
British Columbia										
Terrtitories										

Table C Hospitalization for injuries sustained by youth female pedal cyclists in Canada, April 1 2006-March 31 2012, by province and injury type

Years	April 1 2006 to March 31 2012
Sex	Female
Age	12 to 17 inclusive
Cause of Injury	All

	Injury Type									
Location of Hospital	Any injury	Any brain, head, face injury	Any torso, extremities injury	Brain injury	Head, scalp or skull injury	Face injury	Neck injury	Torso injury	Upper extremities injury	Lower extremities injury
Canada										
Newfoundland										
Nova Scotia										
Prince Edward Island										
New Brunswick										
Quebec										
Ontario										
Manitoba										
Saskatchewan										
Alberta										
British Columbia										
Terrtitories										

Table D Hospitalization for injuries sustained by youth male pedal cyclists in Canada, April 1 2006-March 31 2012, by province and injury type

Years	April 1 2006 to March 31 2012
Sex	Male
Age	12 to 17 inclusive
Cause of Injury	All

Location of Hospital	Injury Type: Any injury	Any brain, head, face injury	Any torso, extremities injury	Brain injury	Head, scalp or skull injury	Face injury	Neck injury	Torso injury	Upper extremities injury	Lower extremities injury
Canada										
Newfoundland										
Nova Scotia										
Prince Edward Island										
New Brunswick										
Quebec										
Ontario										
Manitoba										
Saskatchewan										
Alberta										
British Columbia										
Terrtitories										

Table E Hospitalization for injuries sustained by adult pedal cyclists in traffic accidents in Canada, April 1 2006-March 31 2012, by province and injury type

Years	April 1 2006 to March 31 2012
Sex	All
Age	18 +
Cause of Injury	Traffic; Traffic-Relatedness Code = 1

Location of Hospital	Injury Type: Any injury	Any brain, head, face injury	Any torso, extremities injury	Brain injury	Head, scalp or skull injury	Face injury	Neck injury	Torso injury	Upper extremities injury	Lower extremities injury
Canada										
Newfoundland										
Nova Scotia										
Prince Edward Island										
New Brunswick										
Quebec										
Ontario										
Manitoba										
Saskatchewan										
Alberta										
British Columbia										
Terrtitories										

Table F Hospitalization for injuries sustained by youth pedal cyclists in traffic accidents in Canada, April 1 2006-March 31 2012, by province and injury type

Years	April 1 2006 to March 31 2012
Sex	All
Age	12 to 17 inclusive
Cause of Injury	Traffic; Traffic-Relatedness Code = 1

Location of Hospital	Injury Type: Any injury	Any brain, head, face injury	Any torso, extremities injury	Brain injury	Head, scalp or skull injury	Face injury	Neck injury	Torso injury	Upper extremities injury	Lower extremities injury
Canada										
Newfoundland										
Nova Scotia										
Prince Edward Island										
New Brunswick										
Quebec										
Ontario										
Manitoba										
Saskatchewan										
Alberta										
British Columbia										
Terrtitories										

Body Region Codes					
Parent Category - Any Injury	**Parent Category - Any Brain, Head, Face**	**Parent Category - Any Torso, Extremities**	**Parent Categories - Specific Body Regions**	**Included Codes**	**Included Codes Description**
Any injury	Any brain, head, scalp, skull or face injury		Brain	S04	Injury of cranial nerves
Any injury	Any brain, head, scalp, skull or face injury		Brain	S06	Intracranial injury
Any injury	Any brain, head, scalp, skull or face injury		Brain	T06.0	Injuries of brain and cranial nerve with injuries of nerves and spinal cord at neck level
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.0	Superficial injury of scalp
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.7	Multiple superficial injuries of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.8	Superficial injury of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S00.9	Superficial injury of head, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.0	Open wound of scalp
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.7	Multiple open wounds of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.8	Open wounds of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S01.9	Open wound of head, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.0	Fracture of vault of skull
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.1	Fracture of base of skull
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.7	Multiple fractures involving skull and facial bone
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.8	Fractures of other skull and facial bones
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S02.9	Fracture of skull and facial bones, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S03.3	Dislocation of other and unspecified parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S03.5	Sprain and strain of joints and ligaments of other and unspecified parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S07.1	Crushing injury of skull
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S07.8	Crushing injury of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S07.9	Crushing injury of head, part unspecified
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S08.0	Avulsion of scalp
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S08.8	Traumatic amputation of other parts of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S08.9	Traumatic amputation of unspecified part of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	S09	Other and unspecified injuries of head
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T00.0	Superficial injuries involving head with neck
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T01.0	Open wound involving head with neck
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T02.0	Fractures involving head with neck
Any injury	Any brain, head, scalp, skull or face injury		Head, scalp or skull	T04.0	Crushing injuries involving head with neck

Any injury	Any brain, head, scalp, skull or face injury		Face	S00.1	Contusion of eyelid and periocular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.2	Other superficial injuries of eyelid and periocular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.3	Superficial injury of nose
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.4	Superficial injury of ear
Any injury	Any brain, head, scalp, skull or face injury		Face	S00.5	Superficial injury of lip and oral cavity
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.1	Open wound of eyelid and periocular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.2	Open wound of nose
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.3	Open wound of ear
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.4	Open wound of cheek and temporomandibular area
Any injury	Any brain, head, scalp, skull or face injury		Face	S01.5	Open wound of lip and oral cavity
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.2	Fracture of nasal bones
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.3	Fracture of orbital floor
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.4	Fracture of malar and maxillary bones
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.5	Fracture of tooth
Any injury	Any brain, head, scalp, skull or face injury		Face	S02.6	Fracture of mandible
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.0	Dislocation of jaw
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.1	Dislocation of septal cartilage of nose
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.2	Dislocation of tooth
Any injury	Any brain, head, scalp, skull or face injury		Face	S03.4	Sprain and strain of jaw
Any injury	Any brain, head, scalp, skull or face injury		Face	S05	Injury of eye and orbit
Any injury	Any brain, head, scalp, skull or face injury		Face	S07.0	Crushing injury of face
Any injury	Any brain, head, scalp, skull or face injury		Face	S08.1	Traumatic amputation of ear
Any injury	Any brain, head, scalp, skull or face injury		Face	T15	Foreign body on external eye
Any injury	Any brain, head, scalp, skull or face injury		Face	T16	Foreign body in ear
Any injury			Neck	S10-S19	Injuries to the neck
Any injury			Neck	T00.0	Superficial injuries involving head with neck
Any injury			Neck	T01.0	Open wound involving head with neck
Any injury			Neck	T02.0	Fractures involving head with neck
Any injury			Neck	T03.0	Dislocations, sprains and strains involving head with neck
Any injury			Neck	T04.0	Crushing injuries involving head with neck
Any injury			Neck	T06.0	Injuries of brain and cranial nerve with injuries of nerves and spinal cord at neck level

Any injury		Any torso, extremities	Torso	S20-S29	Injuries to the thorax
Any injury		Any torso, extremities	Torso	S30-S39	Injuries to the abdomen, lower back, lumbar spine, and pelvis
Any injury		Any torso, extremities	Torso	T00.1	Superficial injuries involving thorax with abdomen, lower back, and pelvis
Any injury		Any torso, extremities	Torso	T01.1	Open wounds involving thorax with abdomen, lower back and pelvis
Any injury		Any torso, extremities	Torso	T02.1	Fractures involving thorax with lower back and pelvis
Any injury		Any torso, extremities	Torso	T02.7	Fractures involving thorax with lower back and pelvis with limbs
Any injury		Any torso, extremities	Torso	T03.1	Dislocations, sprains and strains involving thorax with lower back and pelvis
Any injury		Any torso, extremities	Torso	T04.1	Crushing injuries involving thorax with abdomen, lower back and pelvis
Any injury		Any torso, extremities	Torso	T04.7	Crushing injuries of thorax with abdomen, lower back and pelvis with limbs
Any injury		Any torso, extremities	Torso	T06.5	Injuries of intrathoracic organs with intra-abdominal and pelvic organs
Any injury		Any torso, extremities	Torso	T08	Fracture of spine, level unspecified
Any injury		Any torso, extremities	Torso	T09	Other injuries of spine and trunk, level unspecified
Any injury		Any torso, extremities	Torso	T17	Foreign body in respiratory tract
Any injury		Any torso, extremities	Torso	T18	Foreign body in alimentary tract
Any injury		Any torso, extremities	Torso	T19	Foreign body in genitourinary tract
Any injury		Any torso, extremities	Upper extremities	S40-S49	Injuries to the shoulder and upper arm
Any injury		Any torso, extremities	Upper extremities	S50-S59	Injuries to the elbow and forearm
Any injury		Any torso, extremities	Upper extremities	S60-S69	Injuries to the wrist and hand
Any injury		Any torso, extremities	Upper extremities	T00.2	Superficial injuries involving multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T00.6	Superficial injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T01.2	Open wounds involing multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T01.6	Open wounds involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T02.2	Fractures involving multiple regions of one upper limb
Any injury		Any torso, extremities	Upper extremities	T02.4	Fractures involving multiple regions of both upper limbs
Any injury		Any torso, extremities	Upper extremities	T02.6	Fractures involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T02.7	Fractures involving thorax with lower back and pelvis with limbs
Any injury		Any torso, extremities	Upper extremities	T03.2	Dislocations, sprains and strains involving multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T03.4	Dislocations, sprains and strains invovling multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T04.2	Crushing injuries involving multiple regions of upper limbs
Any injury		Any torso, extremities	Upper extremities	T04.4	Crushing injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Upper extremities	T04.7	Crushing injuries of thorax with abdomen, lower back and pelvis with limbs

Any injury		Any torso, extremities	Upper extremities	T05.0	Traumatic amputation of both hands
Any injury		Any torso, extremities	Upper extremities	T05.1	Traumatic amputation of one hand and other arm [any level, except hand]
Any injury		Any torso, extremities	Upper extremities	T05.2	Traumatic amputation of both arms [any level]
Any injury		Any torso, extremities	Upper extremities	T05.6	Traumatic amputation of upper and lower limbs, any combination [any level]
Any injury		Any torso, extremities	Upper extremities	T10	Fracture of upper limb, level unspecified
Any injury		Any torso, extremities	Upper extremities	T11	Other injuries of upper limb, level unspecified
Any injury		Any torso, extremities	Lower Extremities	S70-S79	Injuries to the hip and thigh
Any injury		Any torso, extremities	Lower Extremities	S80-S89	Injuries to the knee and lower leg
Any injury		Any torso, extremities	Lower Extremities	S90-S99	Injuries to the ankle and foot
Any injury		Any torso, extremities	Lower Extremities	T00.3	Superficial injuries involving multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T00.6	Superficial injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T01.3	Open wounds of multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T01.6	Open wounds involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T02.3	Fractures involving multiple regions of one lower limb
Any injury		Any torso, extremities	Lower Extremities	T02.5	Fractures involving multiple regions of both lower limbs
Any injury		Any torso, extremities	Lower Extremities	T02.6	Fractures involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T02.7	Fractures involving thorax with lower back and pelvis with limbs
Any injury		Any torso, extremities	Lower Extremities	T03.3	Dislocations, sprains and strains invovling multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T03.4	Dislocations, sprains and strains invovling multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T04.3	Crushing injuries involving multiple regions of lower limbs
Any injury		Any torso, extremities	Lower Extremities	T04.4	Crushing injuries involving multiple regions of upper limbs with lower limbs
Any injury		Any torso, extremities	Lower Extremities	T04.7	Crushing injuries of thorax with abdomen, lower back and pelvis with limbs
Any injury		Any torso, extremities	Lower Extremities	T05.3	Traumatic amputation of both feet
Any injury		Any torso, extremities	Lower Extremities	T05.4	Traumatic amputation of one foot and other leg [any level, except foot]
Any injury		Any torso, extremities	Lower Extremities	T05.5	Traumatic amputation of both legs [any level]
Any injury		Any torso, extremities	Lower Extremities	T05.6	Traumatic amputation of upper and lower limbs, any combination [any level]
Any injury		Any torso, extremities	Lower Extremities	T12	Fracture of lower limb, level unspecified
Any injury		Any torso, extremities	Lower Extremities	T13	Other injuries of lower limb, level unspecified
Any injury				T00.8	Superficial injuries involving other combinations of body regions
Any injury				T00.9	Multiple superficial injuries, unspecified
Any injury				T01.8	Open wounds involving other combinations of body regions

Any injury				T01.9	Multiple open wounds of unspecified site
Any injury				T02.8	Fractures involving other combinations of body regions
Any injury				T02.9	Multiple fractures, unspecified
Any injury				T03.8	Dislocations, sprains and strains involving other combinations of body regions
Any injury				T03.9	Multiple dislocations, sprains and strains, unspecified
Any injury				T04.8	Crushing injuries involving other combinations of body regions
Any injury				T04.9	Multiple crushing injuries, unspecified
Any injury				T05.8	Traumatic amputations involving other combinations of body regions
Any injury				T05.9	Multiple traumatic amputations, unspecified
Any injury				T06.1	Injuries of nerves and spinal cord involving multiple body regions
Any injury				T06.2	Injuries of nerves involving multiple body regions
Any injury				T06.3	Injuries of blood vessels involving multiple body regions
Any injury				T06.4	Injuries of muscles and tendons involving multiple body regions
Any injury				T06.8	Other specified injuries involving multiple body regions
Any injury				T07	Unspecified multiple injuries
Any injury				T14	Injury of unspecified body region