ORIGINAL ARTICLE

Comparative Outcomes of Traumatic Brain Injury from Biking Accidents With or Without Helmet Use

Jehane H. Dagher, Camille Costa, Julie Lamoureux, Elaine de Guise, Mitra Feyz

ABSTRACT: ***Objective***: To determine if health outcomes and demographics differ according to helmet status between persons with cycling-related traumatic brain injuries (TBI). ***Methods***: This is a retrospective study of 128 patients admitted to the Montreal General Hospital following a TBI that occurred while cycling from 2007-2011. Information was collected from the Quebec trauma registry and the coroner's office in cases of death from cycling accidents. The independent variables collected were socio-demographic, helmet status, clinical and neurological patient information. The dependent variables evaluated were length of stay (LOS), extended Glasgow outcome scale (GOS-E), injury severity scale (ISS), discharge destination and death. ***Results:*** 25% of cyclists wore a helmet. The helmet group was older, more likely to be university educated, married and retired. Unemployment, longer intensive care unit (ICU) stay, severe intracranial bleeding and neurosurgical interventions were more common in the no helmet group. There was no significant association between the severity of the TBI, ISS scores, GOS-E or death and helmet wearing. The median age of the subjects who died was higher than those who survived. ***Conclusion***: Cyclists without helmets were younger, less educated, single and unemployed. They had more severe TBIs on imaging, longer LOS in ICU and more neurosurgical interventions. Elderly cyclists admitted to the hospital appear to be at higher risk of dying in the event of a TBI.

RÉSUMÉ: Comparaison des conséquences d'un traumatisme crânien subi lors d'un accident de vélo avec ou sans port du casque. ***Objectif:*** Le but de l'étude était de déterminer si les conséquences sur la santé et si les caractéristiques démographiques des cyclistes diffèrent selon que le cycliste qui a subi un traumatisme crânien (TC) portait ou ne portait pas de casque. ***Méthode:*** Cette étude rétrospective porte sur 128 patients hospitalisés à l'Hôpital général de Montréal suite à un TC survenu à vélo entre 2007 et 2011. L'information a été recueillie du Fichier central des sinistres du Québec et du bureau du médecin légiste pour les cas de décès lors d'accidents de vélo. Les variables indépendantes recueillies étaient les données sociodémographiques, le port du casque, l'information clinique et neurologique. Les variables indépendantes étaient la durée du séjour hospitalier, le score à l'échelle de devenir de Glasgow étendue (GOS-E), le score à l'ISS (injury severity scale), la destination au moment du congé hospitalier et le décès. ***Résultats:*** Vingt-cinq pour cent des cyclistes portaient un casque. Le groupe de patients qui portaient un casque était plus âgé, plus susceptible d'avoir un niveau de scolarité universitaire, d'être marié et d'être à la retraite. Le chômage, un séjour prolongé à l'unité de soins intensifs (USI), un saignement intracrânien plus sévère et un traitement neurochirurgical étaient plus fréquemment présents dans le groupe de cyclistes qui ne portaient pas de casque. Il n'y avait pas d'association significative entre la sévérité du TC, les scores ISS, GOS-E ou le décès et le port du casque. L'âge médian des sujets qui sont décédés était plus élevé que celui des survivants. ***Conclusion:*** Les cyclistes qui ne portaient pas de casque étaient plus jeunes, moins instruits, plus fréquemment célibataires et sans emploi. Ils avaient un TC plus sévère à l'imagerie, ils ont été hospitalisés à l'USI plus longtemps et ils ont subi plus d'interventions neurochirurgicales. Le risque de décès était plus élevé chez cyclistes plus âgés qui ont été hospitalisés suite à un TC.

Keywords: Acute Care, Bicycle, Helmets, Outcome, Traumatic Brain Injury

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Traumatic brain injury (TBI) is a major public health concern; one fifth of all injury related deaths are thought to be caused by TBIs in Canada.[1] The dynamics of recovery from TBIs are multiple and largely depend on the severity of the ensuing TBI.[2] Although likely less publicized than football or hockey, cycling constitutes the number one cause of TBI in sports due to its broad appeal.[3] Traumatic brain injuries cause, at times, severe long-term disability with repercussions not only on patients' ability to be productive members of society[4] but also on their relatives' and their own quality of life.[5]

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According to a review by the Quebec public health authority, the increasing use of multiple promotional programmes related to active transportation in the province may lead to more TBIs unless preventative measures are put in place.[6] The lack of legislation on bicycle helmets makes the city of Montreal a favourable setting to evaluate the effects of helmet wearing on TBIs. With a recent bike sharing programme launch and a large increase in the number of cyclists in Quebec (500 000 more in 2010 than there were in 2005)[7], injury prevention efforts are greatly needed.

There exist many studies in the literature that compare medical outcomes of cyclists wearing helmets to those who do not, including prospective case-control studies.[8-10] These studies, discussed in a meta-analysis by Attewell and a Cochrane review by Thompson, have overwhelmingly concluded that helmets protect against serious head injuries and death.[9,10] Furthermore, convincing biomechanical evidence exists supporting helmet efficacy against severe TBIs.[11] However, there are only a few clinical studies that have evaluated the efficacy of helmet use in preventing TBIs in adults, and those that have often use unclear definitions of what they consider brain injuries or use scales that are seldom used clinically for TBIs. For instance, in Attewell's review only 50% of the studies specifically evaluated brain injuries (rather than the broader head injury), of which three studies only included children.[10,12-14] Three relied on individuals self assessment of brain injury (questionnaires).[15-17] The final two studies of the review either did not have a clear definition of brain injuries, [18] or relied on the Abbreviated Injury Scale.[19] As for the studies in Thompson's Cochrane review, many have already been addressed above.[12,18-19] The two other studies included in the review either used the AIS grading system[20] or classified all TBIs into one group, failing to differentiate between severities.[8] None of the studies utilized the GCS, which continues to be a cornerstone in the evaluation of TBI severity and prognosis.[21]

Our research hypothesis is set to answer the question whether adult cyclists with a TBI who wear helmets fare better with respect to their acute outcomes than those cyclists who do not. We specifically evaluated length of hospital stay, Extended Glasgow Outcome Scale (GOS-E), Injury Severity Scale (ISS), TBI severity, discharge destination and death from TBI.

Method

Study Design, Setting and Participants

This is a retrospective observational study of all patients admitted to McGill University Health Centre, the Montreal General Hospital (MGH), a tertiary trauma centre, following TBI that occurred while cycling between April 1st 2007 and March 31st 2011. In that time frame, a total of 6197 trauma patients were admitted to the MGH. Of those 2297 patients suffered a TBI. Of the admitted patients with TBI, 143 patients were the result of bicycle accidents. Two patients were excluded for confounding comorbidities (brain metastasis and myocardial infarct at the time of the accident). Thirteen were excluded for lack of helmet wearing information; of those, one sustained both a TBI and a spinal cord injury; no other subject sustained a concomitant spinal cord injury. Thus, 128 patients were included in our study. The subjects were evaluated by the TBI team of the MGH that included two physiatrists, two neurosurgeons, neuropsychologists, occupational therapists, physical therapists, social workers, speech language pathologists, clinical nutritionists and clinical researchers, who overviewed the information gathered for the trauma registry. The Montreal University Health Center's ethics committee and the director of professional services approved the research protocol.

In a later phase, a request was made to the Ministry of Health in Quebec, the Système d'information du registre des traumatismes du Québec (SIRTQ), the Institut national de santé publique du Québec (INSPQ) and the coroner's office to obtain the coroner's report and information on all cyclist deaths at the scenes of the accidents and on arrival in all other hospitals on the island of Montreal – (area 6) for our study period between April 1st 2007 and March 31st 2011. These cases were analyzed separately. We received 24 cases from the coroner's office of individuals who died while cycling on the island of Montreal. Of these, 17 were excluded (10 overlapped the patients already considered in our study, one was a child and six were outside the time frame of our study).

Data Collection

Data was extracted from an existing Quebec trauma registry, the TBI programme database and coroners' reports. Due to some missing data, a detailed manual review of every chart was performed to increase data completeness. The independent variables collected from the hospitalized cases were socio-demographic, helmet status, clinical, and neurological patient information. The dependent variables are length of stay (LOS) in days (total and in intensive care unit (ICU)), GOS-E collected at discharge from hospital, ISS, discharge destination and mortality. From the coroners' reports, information on sex, age, helmet use, mechanism of injury, cause of death, and time to death was collected.

Description of Data

Sociodemographic information was collected on patients' age, gender, nationality, education, marital status and employment status. Information was collected from the patient's medical chart. The data was collected retrospectively from the trauma registry and a chart review was redone to confirm all the available information.

Clinical Characteristics

Glasgow coma scale (GCS) score was collected on patient's arrival to the emergency department. Physiatrists assessed the severity of TBI separately. Traumatic brain injury severity was determined to be mild if the GCS upon hospital arrival was between 13-15, post-traumatic amnesia (PTA) was less than 24 hours, loss of consciousness (LOC) was less than 30 minutes and, if an intracranial lesion was present, it must not have required surgical intervention. For moderate TBI, the patients required one of the following: a GCS between 9-12 at arrival to hospital, LOC between 30 minutes and 24 hours, PTA between 24 hours and two weeks or a patient presenting with clinical signs of a mild TBI but requiring surgical intervention of an intracranial lesion. Severe TBI was determined if the patient had a GCS between 3-8, LOC longer than 24 hours and PTA longer than two weeks. Loss of consciousness data was collected for the two fiscal years (2007-2008 & 2008-2009). Although the length of LOC was utilized by the physiatrists for determinants of TBI severity, length of LOC was inconsistently collected in the trauma registry and rarely documented in the charts. We chose to conserve the binary

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(yes/no) annotation for LOC. Alcohol level and drug screen results for cocaine, cannabis and benzodiazepines were identified on admission. Helmet status was identified from Emergency medical system reports and also confirmed by patient interview.

Cycling accident mechanisms were categorized into the following categories: fall, bike versus (vs) bike, bike vs pedestrian, bike vs motor vehicle and bike vs stationary object. Imaging (computed tomography (CT) of the brain) was analyzed using the Marshall Classification, a severity measure and good correlate for mortality.[22] Diffuse Injury I describes all injuries without visible pathology; Diffuse Injury II includes the presence of cisterns with a midline shift of 0-5 mm, without high or mixed lesion densities of more than 25 cc; Diffuse Injury III designates injuries with swelling with compressed or absent cisterns and a midline shift of 0-5 mm, again without high or mixed lesion densities; and Diffuse Injury IV describes a midline shift of more than 5 mm, the rest of the description being identical to Diffuse Injury III.[22] The other two categories are: the evacuated mass lesion that includes all lesions that must be surgically evacuated; and the non-evacuated mass lesion that describes high or mixed density lesions of more than 25 cc that are not surgically evacuated.[22]

Medical complications were identified (renal failure, cardiac complications, urinary tract infections, pneumonia, septicaemia, haemorrhage, deep vein thrombosis, diarrhea and delirium). Neurosurgical interventions including intracranial monitoring device installation, extraventricular drain, burr hole, craniotomy and craniectomy were identified. Patients were identified as having had a polytrauma when other concomitant injuries, including one or more of the following, were present: orthopaedic, spine, abdominal, thoracic and genitourinary. Patients without polytraumas were designated as having had isolated TBIs.

The ISS was also used to determine overall injury severity and not as a TBI severity determinant. It is an established medical score that equally assesses overall trauma severity in patients who have isolated injuries and those who have polytraumas.[23-25] It correlates with mortality, morbidity and hospital stay amongst other outcomes.[24,25] The ISS is calculated based on rating each injury according to the abbreviated injury scale (AIS). The AIS uses a gradation from 1 (minor) to 6 (maximal injury, nearly not survivable) for each of the following body regions: head & neck, face, thorax, abdomen, extremities (including pelvis) and external.[24-28] The ISS score is derived from adding the squares of the three highest AIS ratings, resulting in ISS values between 0 and 75.[24-26] A notable exception to the squaring is when an injury is attributed an AIS of 6, the ISS automatically is assigned the maximal score of 75.[24,25]

Outcome Measures

The GOS-E, a validated functional outcomes measure,[29,30] was documented at patients' discharge from the acute care hospital upon consensus from the interdisciplinary team. The GOS-E is an extended version of the original Glasgow Outcome Scale, which have both been widely used and accepted as valid functional outcomes measure following TBI.[29,30] The GOS-E is best determined following a structured interview.[30] According to the guidelines established by Wilson et al., the scoring is as follows: (1) death, (2) vegetative state, (3) lower severe disability, (4) upper severe disability, (5) lower moderate disability, (6) upper moderate disability, (7) lower good recovery and (8) upper good recovery.[30]

Total hospital and ICU LOS were calculated for all patients as a marker of disease severity. Finally, discharge destination from the acute hospital directly home to in or outpatient rehabilitation and death were collected for each patient.

Statistics

Descriptive statistics are presented using means, medians, standard deviations and ranges for numeric variables and proportions for categorical variables. Bivariate associations between helmet use and demographic or accident variables were done using t-tests for numeric variables with symmetric distributions, Wilcoxon rank tests for ordinal variables and numeric variables with asymmetric distributions and chi-square tests for categorical variables. Correlations were done using Spearman rank for ordinal variables and Pearson for numeric variables. We used simple and multiple logistic regressions for predicting helmet use and simple and multiple ordinal regressions to predict severity of trauma, GOS-E and length of stay. All analyses were done using Stata 12.0.1 (StataCorp, Texas) and the level of significance was set at 0.05.

Results

Demographic variables of hospitalized cyclists

The descriptive statistics for demographic variables can be found in Table 1. Seventy-five percent of cyclists in our study did not wear helmets. The average age (± SD) of the total sample (n = 128) was 44.1 ± 17.5 years old. The distribution of age of the sample was slightly skewed to the right. The helmet group was significantly older. Seventy-two percent of the subjects were men. The proportion of men and women was not significantly different between the helmet groups. The distribution of education was not statistically significantly different between the two groups but there was a tendency for the group wearing helmets to have more years of education. The distribution of employment was significantly different between the two groups, with cyclists wearing helmets more likely to be retired and those without helmets more likely to be unemployed. Overall, 29.7% of the sample was married; this proportion was significantly higher in the helmet wearing group (50.0%) compared to the no helmet group (22.9%) The majority of the subjects were Canadian (77.3%).

There was some missing demographic information: 3.9% (n = 5) nationality, 10.9% (n = 14) education and 5.5% (n = 7) employment. The majority of the sample (n = 78, 60.9%) did not have documentation about LOC at the time of the accident. Data was unavailable to quantify PTA and LOC was dichotomized, without any notion of length of LOC. Half the subjects (n = 64) did not have their level of alcohol tested. A large majority of the subjects were not tested for drugs (n = 120, 93.8%).

A logistic regression was done to determine which of the demographic variables (age, gender, nationality, education, marital status and employment) were significantly associated with helmet wearing. The number of subjects considered in the regression was 103 because of missing values. The only two variables that had a significant predictive power (using backward deletion for p values >0.05) were education and employment status (see Table 2). Those with a university education had more than five times the odds of wearing a helmet compared to those with less education. Also, retired subjects were significantly more likely to wear a helmet compared to other employment groups.

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Table 1: Demographic Characteristics of Cyclists with TBI, stratified according to helmet wearing status

	Helmet (25%)	No Helmet (75%)	Total	Test	p-value
Sex (n = 128)					
Female	12 (37.5%)	24(25.0%)	36 (28.1%)	$\chi^2_{1df} = 1.855$	0.173
Male	20 (62.5%)	72(75.0%)	92 (71.9%)		
Age (mean ± SD)	49.9 ± 17.1	42.1 ± 17.3	44.1 ± 17.5	$t_{126df} = 2.188$	0.031
(Range)	Range (18-83)	Range (16-83)	Range (16-83)		
Nationality (n = 123)					
Canadian	24 (77.4%)	75 (81.5%)	99 (80.5%)	$\chi^2_{1df} = 0.249$	0.618
Non-Canadian	7 (22.6%)	17 (18.5%)	24 (19.5%)		
Education (n = 114)					
No education	0 (0.0%)	4 (4.7%)	4 (3.5%)	$\chi^2_{4df} = 9.382$	0.052
Elementary	5 (17.9%)	21 (24.4%)	26 (22.8%)		
High school	4 (14.3%)	21 (24.4%)	25 (21.9%)		
College	3 (10.7%)	17 (19.8%)	20 (17.5%)		
University	16 (57.1%)	23 (26.7%)	39 (34.2%)		
Employment (n = 121)					
Full time	16 (53.3%)	39 (42.9%)	55 (45.5%)	$\chi^2_{4df} = 14.728$	0.005
Part time	0 (0.0%)	6 (6.6%)	6 (5.0%)		
Unemployed	1 (3.3%)	27 (29.7%)	28 (23.1%)		
Retired	9 (30.0%)	10 (11.0%)	19 (15.7%)		
Student	4 (13.3%)	9 (9.9%)	13 (10.7%)		
Marital Status (n = 128)					
Single	16 (50.0%)	74 (77.1%)	90 (70.3%)	$\chi^2_{1df} = 8.434$	0.004
Married	16 (50.0%)	22 (22.9%)	38 (29.7%)		

SD = standard deviation, n = number, χ^2_{1df} = Chi-square, t_{126df} = Student T test

Accident variables for hospitalized cyclists

The median (and interquartile range) of GCS was 14 (13-15) with a range of 3 to 15. Overall, 74.2% of the sample had a mild TBI (n = 95), 11.7% a moderate TBI (n = 15) and 14.1% (n = 18) a severe TBI. There was no significant association between the severity of the TBI and either group (Table 3). The proportion of women in the mild severity category was higher (33.7%) compared to the other two levels of severity (less than 15%). In fact, in a simple ordinal regression with severity as the dependent variable, men had three times the odds of having a more severe trauma compared to women (OR = 3.675, 95% CI [1.192; 11.323]). There was no significant association between nationality ($\chi^2_{4df} = 2.226$, p = 0.694), education ($\chi^2_{8df} = 7.978$, p = 0.436) or marital status ($\chi^2_{2df} = 0.709$, p = 0.702). There was a significant association between employment and the severity of the trauma. Simple ordered logistic regression found those with a full time job to have significantly milder traumas ($\chi^2_{8df} = 15.804$, p = 0.045) compared to those unemployed or retired.

Table 2: Results of logistic regression analysis for helmet wearing according to demographic factors

	OR	S.E.	Prob. (χ2)	95% CI
Scholarity				
High School	0.824	0.745	0.831	0.140-4.848
College	0.781	0.769	0.802	0.114-5.371
University	5.692	5.010	0.048	1.014-31.955
Employment				
Unemployed	0.133	0.147	0.069	0.015-1.166
Retired	7.647	6.077	0.010	1.611-36.300
Student	1.059	0.785	0.938	0.247-4.529
Constant	0.993	0.392	0.985	0.458-2.153

OR = odds ratio, S.E = standard error, Prob = probability, CI = confidence interval

Fifty percent of patients did not have alcohol levels tested. Half of those tested (n = 33) had positive alcohol tests. The great majority of patients (120) did not have drug testing. Of those tested (8), two tested positive for benzodiazepines, two tested positive for cannabis and none tested positive for cocaine.

Ninety-seven subjects (72.7%) had a positive CT scan. Eighty-five percent of the sample had either Diffuse I or Diffuse II Marshall classification. A simple ordinal regression revealed that the risk of having a higher Marshall Classification was significantly higher for those without helmets (OR = 2.833, p = 0.010). This is shown in the Table 3, where the percentage of

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Table 3: Accident variables stratified according to helmet status

	Helmet	No Helmet	Total	Test	p-value
TBI severity					
Mild	27 (84.4%)	68 (70.8%)	95 (74.2%)	$\chi^2_{2df}=2.349$	0.309
Moderate	2 (6.3%)	13 (13.5%)	15 (11.7%)		
Severe	3 (9.4%)	15 (15.6%)	18 (14.1%)		
Scan					
Positive	19 (59.4%)	74 (77.1%)	93 (72.7%)	$\chi^2_{1df}=8.193$	0.004
Negative	13 (40.6%)	22 (22.9%)	35 (27.3%)		
Marshall Classification					
I	15 (46.9%)	23 (24.0%)	38 (29.7%)	$\chi^2_{4df}=8.184$	0.085
II	15 (46.9%)	56 (58.3%)	71 (55.5%)		
III	0 (0.0%)	9 (9.4%)	9 (7.0%)		
IV	2 (6.3%)	7 (7.3%)	9 (7.0%)		
Evacuated mass lesion	0 (0.0%)	1 (1.0%)	1 (0.8%)		
Mechanism of Injury					
Cyclist vs MVC	10 (32.3%)	51 (53.1%)	61 (47.7%)	$\chi^2_{3df}=9.848$	0.020
Fall	15 (48.4%)	31 (32.3%)	46 (35.9%)		
Cyclist vs fixed object	5 (16.1%)	14 (14.6%)	19 (14.8%)		
Cyclist vs cyclist	1 (3.2%)	0 (0.0%)	2 (1.6%)		
Unknown	1 (3.2%)	0 (0.0%)	1 (0.8%)		
Polytrauma					
Polytrauma	22 (68.7%)	42 (43.8%)	64 (50%)	$\chi^2_{1df}=6.000$	0.014
Isolated TBI	10 (31.3%)	54 (56.2%)	64 (50%)		

TBI = traumatic brain injury, MVC = motor vehicle collision

subjects in higher severity of Marshall categories is higher for the group without helmets. Almost 94% of all the subjects wearing helmets were in the first two categories of the Marshall Classification compared to 82.3% in the group without helmets.

Exactly 50% of the sample had an isolated TBI, the other half had a polytrauma. There was a significant association between wearing a helmet and polytrauma (see Table 3). The proportion of polytrauma was higher in the group wearing a helmet (68.8%) compared to the non-helmet group (43.8%). The odds of having a polytrauma were 2.8 times higher in the group with a helmet (OR = 2.829, p = 0.016).

The average (± SD) ISS score was 23.2 ±10.7 with a median of 21.5. The distribution of the ISS scores is given in Figure 1. There was no significant difference in the ISS scores between those with (22.6 ± 11.7) and without (23.5 ± 10.4) helmet ($t_{124df}=0.394$, p = 0.694).

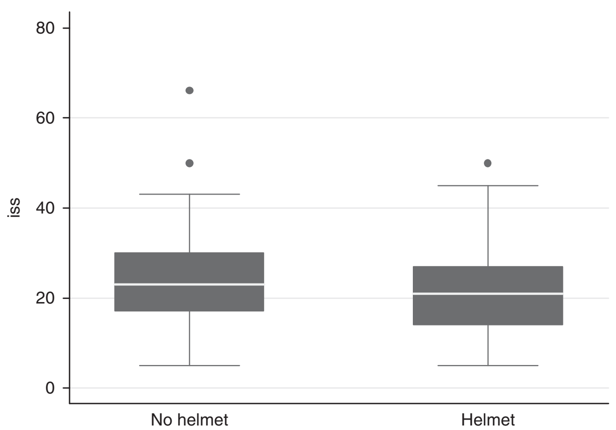

***Figure 1:** Boxplot of ISS by group (n=123)*

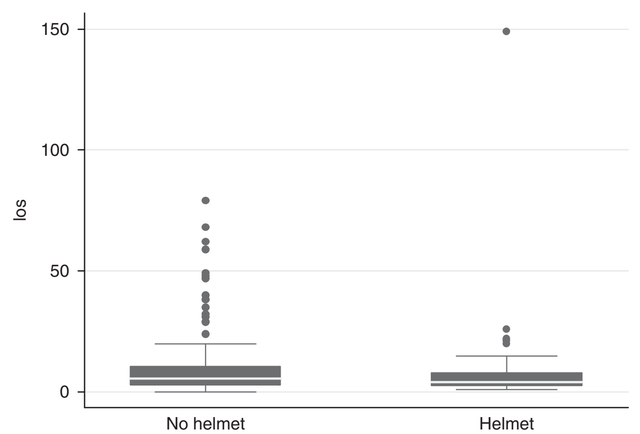

***Figure 2:** Boxplot of Hospital length of stay (n=128)*

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Table 4: Outcome variables stratified according to helmet status

	Helmet	No Helmet	Total	Test	p-value
LOS					
Total (median, IQR)	5.5 (2.5-8)	4 (3-10.5)	5 (3-10)	z = 1.306	0.191
ICU (median, IQR)	0 (0-0)	1 (0-3)	0 (0-2)	z = 3.187	0.001
#Neurosurgical interventions					
0	30 (93.8%)	75 (78.1%)	105 (82.0%)	$\chi^2_{3df} = 4.571$	0.206
1	2 (6.3%)	12 (12.5%)	14 (10.9%)		
2	0 (0.0%)	8 (8.3%)	8 (6.3%)		
3	0 (0.0%)	1 (1.0%)	1 (0.8%)		
Discharge Destination					
Home	21 (65.6%)	46 (47.9%)	67 (52.3%)	$\chi^2_{5df} = 5.088$	0.405
Outpatient Rehab	4 (12.5%)	19 (19.8%)	23 (18.0%)		
Inpatient Rehab	6 (18.8%)	17 (17.7%)	23 (18.0%)		
Long term Care	0 (0.0%)	1 (1.0%)	1 (0.8%)		
Acute care transfer	0 (0.0%)	5 (5.2%)	5 (3.9%)		
Death	1 (3.1%)	8 (8.3%)	9 (7.0%)		
GOSE (median, IQR)	6 (5-6)	6 (5-6)	6 (5-6)	z = 1.012	0.311

LOS = length of stay, IQR = interquartile range, ICU = intensive care unit, Rehab = rehabilitation, GOSE = Extended Glasgow Outcome Scale, z = standard score, χ^2_{5df} = Chi-square

The most frequent mechanism of trauma was cyclist vs motor vehicle (47.7%) followed by cyclist's fall (35.9%). The age of the cyclist was not significantly different in the various mechanisms of accident groups ($F_{(3,124)} = 0.85$, $p = 0.469$). The mechanism of accident was not significantly associated with gender ($\chi^2_{3df} = 2.117$, $p = 0.548$), with nationality ($\chi^2_{4df} = 3.160$, $p = 0.368$), with education ($\chi^2_{12df} = 12.0529$, $p = 0.441$), with marital status ($\chi^2_{3df} = 2.1932$, $p = 0.533$) nor employment ($\chi^2_{12df} = 15.343$, $p = 0.223$).

Outcome variables for hospitalized cyclists

The LOS had an asymmetric distribution as shown in Figure 2 with a mean ($\pm$SD) of 11.9 ± 19.0 and a median of 5 days. A Wilcoxon rank sum test showed no significant difference in the hospital LOS between those with and without helmet. Table 4 shows the descriptive statistics for hospital LOS for each of the two study groups. Even after controlling for confounding variables (polytrauma, severity, employment status, age, gender, ISS, etc.), wearing helmets still was not a significant predictor of hospital LOS. Hospital length of stay was significantly associated with increasing ISS scores (Spearman rank $r = 0.432$, $p < 0.001$).

The LOS in the ICU also followed an asymmetric distribution with a mean of 3.1 ± 7.3 and a median of 0 days (since more than 50% of the subjects (n = 70) were not hospitalized in the ICU). A Wilcoxon rank sum test indicated a significant difference in the ICU LOS between those with and without helmet (see Table 4). Even after controlling for confounding variables (polytrauma, severity, employment, age, gender, ISS, etc.), helmets were still a significant predictor of ICU LOS. The results of this ordinal regression with significant predictive variables are given in Table 5. The Lacy coefficient of determination (R^2O) explained 30% of the variability in ICU LOS. Without the helmet variable, this model explained 26% of the variation in ICU LOS. In this model, with everything else being equal, the risk of staying longer in the ICU was six times greater for those not wearing a helmet (OR 6.19, $p = 0.001$).

Medical complications were not frequently observed. One hundred and seven (83.6%) subjects had no medical complications. Overall, eleven subjects (8.6%) had one medical complication, five (3.9%) had two medical complications, four (3.1%) had three medical complications and one (0.8%) had six medical complications. There was no association with medical complications and the helmet groups (Wilcoxon rank sum test $z = 1.230$, $p = 0.219$). As for neurological complications, there were four occurrences of convulsions, three of them happened in subjects with no helmet. However, there was no statistical association between helmet wearing and convulsions ($\chi^2_{1df} = 0.000$, $p = 1.000$).

Neurosurgical interventions were not frequently observed. One hundred and five (82.0%) subjects had no neurosurgical interventions. Overall, patients who did not wear helmets were

Table 5: ICU LOS ordinal regression

	OR	SE	Prob. > |z|	95% CI
No Helmet	6.185	3.465	0.001	2.063-18.546
Polytrauma	2.533	1.024	0.022	1.14705.596
Severity (compared to mild)				
Moderate	7.179	3.910	0.000	2.469-20.876
Severe	28.583	15.831	0.000	9.654-84.634

OR = odds ratio, SE = standard error Prob. = probability, CI = confidence interval

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more likely to require neurosurgical interventions (Wilcoxon rank sum test $z = 2.051$, $p = 0.040$).

Just over half (52.3%) of the sample was discharged home and an equal proportion was discharged to either outpatient rehabilitation (18.0%) or inpatient rehabilitation (18.0%). Overall, there was no significant association between wearing a helmet and the discharge location, even after controlling for confounding factors ($\chi^2_{5df} = 5.088$, $p = 0.405$). There was a tendency for those wearing a helmet to be discharged home in a higher proportion (65.6%) compared to those not wearing a helmet (47.9%) but this tendency did not reach significance ($\chi^2_{1df} = 3.017$, $p = 0.082$).

In a simple ordinal regression, there was no association between wearing a helmet and GOS-E (OR = 1.511, $p = 0.315$). Even when controlling for other confounding factors (age, gender, severity, polytrauma, ISS), the GOS-E outcome was not significantly different between those with and without helmet.

There was no significant association between wearing a helmet and death in hospitalized patients ($\chi^2_{1df} = 0.996$, $p = 0.318$). Overall, 7.0% of the hospitalized patients died and this proportion was not significantly different between those wearing a helmet (3.1%) and those without a helmet (8.3%). The median age of the subjects who died after their accident was significantly higher (Wilcoxon rank $z = 3.928$, $p < 0.001$) than those who survived the accident (68 years of age for the group who died versus 44 years of age for the group who survived). Of the nine deaths, eight were not wearing a helmet at the time of the accident. Of the eight deaths without a helmet, three deaths were declared within 24 hours, three deaths within 72 hours and one in the first week. All died because of brain death from severe brain injury. The eighth death occurred two months after prolonged hospitalization in the ICU and was due to respiratory distress secondary to pneumonia. Death in the helmeted patient occurred within 48 hours of admission, secondary to severe brain injury consequences.

Demographics and outcomes variables for coroner cases

From the coroner's office records, there were seven additional adult cases of cyclists who died during the study time period. Of these seven cases, 86% were men. The mechanisms of injury associated with severe TBI death were falls (75%) and car vs bicycle (25%). Finally, time to death for the TBI cases was variable: less than 24 hours, and 3, 8 and 17 days following the accident. The average age of the cyclists was 30.7 years and, of those who died specifically from a TBI, their average age was 34 years. Four of the seven cases had documentation of not wearing a helmet and three cases had no documentation (not specified). All deaths ($n = 4$) from TBI occurred in cyclists without a helmet. Of these cases, the coroner reports specified that they all died because of brain death from severe brain injury. The other three deaths at the scene occurred because of polytrauma and not due to TBI and their helmet use was not specified in the coroners' reports. If we include the four documented cases to our hospitalized group of patients who died from TBIs, twelve of the thirteen subjects who died were not wearing helmets. When considering the coroner's cases with the hospitalized sample, we were unable to show that the lack of helmet use significantly increased the risk of death ($\chi^2_{2df} = 2.151$, $p = 0.143$). If we add the four documented cases of death at the scene of the accident, the median age of the subjects who died after their accident was still significantly higher (Wilcoxon rank $z = 2.512$, $p = 0.012$) than those who survived the accident (57 years of age for the group who died versus 44 years of age for the group who survived).

Discussion

Helmet wearers appeared to be better protected from complications associated with TBIs than their counterparts and had less changes on brain imaging, shorter length of ICU stays and less neurosurgical interventions.

Our study did not show a difference in TBI severity as measured by GCS between the group with helmets and the group without helmets. However, when compared to the general population at the time, helmeted cyclists were underrepresented in our study. Indeed, an observational study on helmet use while cycling in Montreal from 2011 found overall that 46% of cyclists wore helmets,[31] nearly double the number of cyclists in our study who sustained a TBI (25%). The paucity of helmet wearers in our study contributes to the difficulty in attaining a power of significance. Also, while speculative, given that 46% of community cyclists were found to wear helmets,[31] it may be reasonable to suspect that helmeted cyclists were better protected from sustaining TBIs in the first place and therefore did not need to be hospitalized for their bike injuries, as has been demonstrated in multiple other case-control studies.[9,10] For instance, a case-control study by Thompson found that 29.3% of cyclists with TBIs wore helmets compared to 56.8% of cyclist controls.[19]

Although no differences were found for TBI severity (GCS) according to helmet wearing, non-helmet wearers were 2.8 times more likely to have worse Marshall Classifications on admission, were more likely to require neurosurgical interventions, and had a six-fold increased risk of having prolonged ICU stays. While softer endpoints, they are still indicative of higher morbidity in the non-helmet group. We were unable to find other studies that evaluated neurosurgical interventions, Marshall Classification and ICU stay according to helmet status in cyclists. One study evaluated neurosurgical interventions; however it had an insufficient number of helmet wearing patients to be able to compare groups according to helmet status.[32]

Knowing that patients without helmets had increased need for neurosurgical intervention and longer ICU hospitalizations, healthcare professionals may be able to identify this group of patients as being at higher risk in a more timely manner and possibly minimize potential complications.

Our study may have been underpowered to distinguish differences in mortality between helmet and non-helmet wearers. Indeed, in our sample only nine hospitalized patients died following their TBI. Eight of the nine patients were not wearing a helmet at the time of their accident. However, although when considering all cyclists deaths, helmet-wearing was not a statistically significant factor, the fact that every person who died from TBI was not wearing a helmet in the cyclists added from the coroner's reports supports the idea that helmets may reduce the risk of death and may possibly minimize the severity of traumatic brain injuries.

A Thompson case-control study found that helmets were effective at reducing brain injuries regardless of age.[19] It is well established that elderly patients sustaining TBIs are at increased risk for mortality than younger patients.[33] However, bicycling accidents are not the accidents one thinks of when considering potential risks for TBI in the elderly. Our results showing that elderly patients are more likely to die from TBIs while cycling than their younger counterparts is supported by previous studies.[34] While the elderly population was well represented in the helmeted group, they represent a large segment of the cycling population and, with the ageing population stand to gain the most protection from helmet wearing, this group may nevertheless benefit from preventative efforts targeted to them.

Our study corroborates others' findings that male cyclists are three times more likely to sustain severe TBIs than women.[1] This is indicative that our sample may be generalizable to other populations. The groups at highest risk of not wearing helmets in our study were the younger, unemployed, single and less educated cyclists. Other than the elderly patients, those at highest risk for adverse outcomes were the unemployed. Another Canadian study also found that helmet use was associated with higher income and higher education.[35]

Finally, although there was an increased risk of polytrauma in the helmeted group, when comparing the severity of injury as measured by ISS, there were no differences. Since ISS is a superior, objective and validated method to assess severity of injuries between groups, we believe that the increased risk for polytrauma should be downgraded in importance, as it is a soft measure of other bodily traumas. It may be hypothesized that the risk of having more bodily injuries in patients who wear helmets suggests that they are less cautious than certain authors have suggested.[36]

We believe that helmet wearing is protective against certain complications related to TBIs in cyclists and should be promoted. In our opinion, all adult cyclists should wear helmets in the city of Montreal. Our recommendation is that promotion efforts target young, single men, the less educated, the unemployed, as well as the elderly population due to their increased risk of death following TBIs.

Strengths and Limitations

In comparing TBIs sustained by helmeted cyclists compared to non-helmeted cyclists assumes that the only difference between the two groups is the headgear. This assumption may not hold; perhaps cyclists who wear helmets are more likely to follow road regulations, speed less, be generally more precautious, as Goldacre postulated in their editorial.[36] They may be more conspicuous to drivers and therefore less likely to be hit in the first place, rather than protected by the headgear. Others have suggested that the most equipped cyclists usually are the most experienced and tend to cycle faster, therefore would be at risk for more severe injuries.[37] Yet others claim that wearing a helmet leads to risk compensation, whereby the wearer feels safer, thus engages in more risky behaviour to compensate.[38] Perhaps the truth is that helmet wearing is associated with different behaviours in different cyclists. Regardless, we were unable to assess it in our study and therefore it is possible that confounding variables exist to explain the poor outcomes in the non-helmeted cyclists.

From the data collected, it is impossible to evaluate if the cyclists wore their helmets correctly or if the helmet was in good working condition. A good example of this limitation is that one patient's helmet was found on the ground next to them; was this because it was broken off, improperly attached or simply hanging from the handlebars? It was decided to include them in the helmet-wearing group since they did indeed have a helmet with them when the accident occurred.

Our patient population is limited to those patients who died at the scene or those that required hospitalization for their injuries. Cyclists with seemingly minor injuries who chose not to present themselves to the hospital are not included. It is uncertain how the differences in outcomes between helmeted and non-helmeted cyclists would be affected by the inclusion of these patients. It is plausible that, at lower velocities, helmet wearing is protective, as suggested by a recent biomechanical study.[11] It is therefore possible that certain mild TBIs may have been prevented by helmet use that we were unable to identify. A study that would take into account these avoided mild TBIs would be difficult to perform, due to the difficulty of recruiting minimally injured cyclists.

A strength of this study is the quality of all the information collected, all the cyclist death reports from the coroner's office, and the GCS scores that were reviewed by one of two experienced Physical Medicine and Rehabilitation physicians subspecialized in TBI (thus qualifying them as experts rendering the reliability of their GCS score more valid). Furthermore, all GCS scores were collected upon hospital arrival. Also, unlike other studies that included head and facial injuries that were not traumatic brain injuries, our sample only includes analysis of the three severities of TBI, defined using clinical parameters that followed expert consensus[39] as well as followed the recommendation guidelines.[40] This clinical approach was a strength because it allowed our findings to dbe applicable to clinical practice.

Conclusion

Our retrospective analysis contributes positively to the pre-existing literature by providing more specific information regarding the ability of bicycle helmets to protect against TBIs. It also further describes new characteristics of high-risk individuals for TBI from cycling accidents. These characteristics may be utilized by health care professionals to identify individuals at high risk of complications in a timelier manner. It also identifies subgroups that would most benefit from health promotion interventions by evaluating their demographics. Outcome differences in patients with TBI with and without helmets reinforce the need for increased helmet use and increased public health promotional measures.

Overall, not wearing a helmet was associated having worse Marshall Classifications, longer LOS in ICU and more neurosurgical interventions. There were no negative medical outcomes associated with wearing a helmet. Helmet wearing cyclists were underrepresented in our patient population compared to the general population of Montreal (25% vs 46%) which may be indicative of the decreased need for hospitalization for helmeted cyclists.

We believe that helmet wearing is protective against certain complications related to TBIs in cyclists and should be promoted. Ideally public health initiatives should be targeted to young, single men, the less educated, the unemployed, as well as include efforts to educate the elderly population due to their increased risk of death following TBIs.

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Disclosures

The authors have nothing to disclose.

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