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Chairperson, Legislative Council Legal and Social Issues Committee

Committee for Workplace Drug Testing Inquiry

Parliament House, Spring St

EAST MELBOURNE VIC 3002

Dear Chairperson,

I am writing to submit my response on behalf of MedReleaf Australia in accordance with the Terms of Reference provided by the Committee for the Workplace Drug Testing Inquiry in Victoria.

About MedReleaf Australia,

MedReleaf Australia is licensed to cultivate and manufacture medical cannabis by the Federal Government's Office of Drug Control (ODC) and also holds licenses to import, export, wholesale and distribute medical cannabis products. Australian-owned and operated, the company is backed by more than 50 years of pharmaceutical and healthcare expertise, driven by Research and Development, and strives to make improvements to the health of Australian patients. Built to service the Australian medical industry, including doctors, pharmacists, and allied health professionals. MedReleaf is also licensed to supply medical cannabis medicines into New Zealand.

MedReleaf has a strategic and exclusive partnership with Aurora Cannabis Enterprises (NYSE|ACB). Our Queensland based company is currently distributing the widest range of GMP medicinal cannabis products into the growing market in Australia.

MedReleaf Australia (MRA) is also a founding member of the Medical Cannabis Industry Association (MCIA) and supports the MCIA submission on this topic.

This submission seeks to address several important aspects outlined in the Terms of Reference, while also drawing attention to key findings and evidence from recent research on driving in a legal cannabis framework. Please refer to the attached studies in relation to this matter.

(1) **The Safety of Medicinal Cannabis for Driving:**

It is crucial to emphasize that medicinal cannabis is no less safe to drive with than other prescribed medications. The available scientific evidence supports that low levels of THC, especially in the blood of regular cannabis users, do not necessarily indicate recent use, and there is little population-level evidence that drivers with THC levels < 5 ng/ml are at an increased risk of collisions. It is essential to consider the research findings that indicate that alcohol remains a greater threat to road safety than prescribed medical cannabis.

(2) **Discrimination Towards Medical Cannabis Patients in Driving Laws:**

The current driving laws appear to be discriminatory towards medical cannabis patients. It is imperative that the inquiry examines whether these laws disproportionately impact this specific patient group and whether such discrimination is justified. The data presented in recent research highlights that the potential negative impact of cannabis use on driving is not significant at the population level compared to alcohol impairment.

(3) **Tasmania's Model for Medical Cannabis:**

Tasmania's approach to treating medical cannabis as other scheduled medications under the supervision of healthcare professionals, such as doctors and pharmacies, serves as a valuable model. This approach

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ensures patient safety and effective treatment while maintaining due process and natural justice in workplace settings.

In light of the key findings on driving in a legal cannabis framework please refer to the attached studies:

- A study has shown that legalizing medical cannabis reduces annual auto insurance premiums, suggesting a positive impact on road safety.

- Data from Canada indicates that drivers testing positive for THC are less common than those testing positive for alcohol, highlighting the continued greater threat posed by alcohol to road safety.

- A study from Canada showed no increase in traffic injuries post-legalization of recreational cannabis.

- Another study revealed no statistical significant increases in motor vehicle crash-related visits when comparing rates before and after medical authorization for cannabis, and found no significant differences between those authorised for cannabis and those who were not.

- A study from the New England Journal of Medicine indicates an increase in rates of moderately injured drivers testing positive for ≥5 ng/ml THC but highlights that cannabis driving impairment is only observed at higher THC levels, making the impact at the population level less significant compared to alcohol.

We refer to data from Canada as it is the largest federally legal jurisdiction for medical cannabis.

Given these findings, it is essential to consider the true impact of cannabis on road safety and base policies and regulations on scientific evidence. The rules and regulations should, at the very least, be as permissive as they are for alcohol, if not more so.

In conclusion, MedReleaf implores the Committee for Workplace Drug Testing Inquiry to take into account the evidence presented in this submission and the recent research on cannabis and driving. It is of utmost importance that the regulatory framework for workplace drug testing is fair, non-discriminatory, and based on scientific evidence, ensuring both employee rights and workplace safety.

We are available for further discussions or to provide additional information on this matter.

Sincerely,

[redacted]

Executive Director
MedReleaf Australia
[redacted]

SPECIAL ARTICLE

Cannabis Legalization and Detection of Tetrahydrocannabinol in Injured Drivers

Jeffrey R. Brubacher, M.D., Herbert Chan, Ph.D., Shannon Erdelyi, M.Sc., John A. Staples, M.D., Mark Asbridge, Ph.D., and Robert E. Mann, Ph.D.

ABSTRACT

BACKGROUND

The effect of cannabis legalization in Canada (in October 2018) on the prevalence of injured drivers testing positive for tetrahydrocannabinol (THC) is unclear.

METHODS

We studied drivers treated after a motor vehicle collision in four British Columbia trauma centers, with data from January 2013 through March 2020. We included moderately injured drivers (those whose condition warranted blood tests as part of clinical assessment) for whom excess blood remained after clinical testing was complete. Blood was analyzed at the provincial toxicology center. The primary outcomes were a THC level greater than 0, a THC level of at least 2 ng per milliliter (Canadian legal limit), and a THC level of at least 5 ng per milliliter. The secondary outcomes were a THC level of at least 2.5 ng per milliliter plus a blood alcohol level of at least 0.05%; a blood alcohol level greater than 0; and a blood alcohol level of at least 0.08%. We calculated the prevalence of all outcomes before and after legalization. We obtained adjusted prevalence ratios using log-binomial regression to model the association between substance prevalence and legalization after adjustment for relevant covariates.

RESULTS

During the study period, 4339 drivers (3550 before legalization and 789 after legalization) met the inclusion criteria. Before legalization, a THC level greater than 0 was detected in 9.2% of drivers, a THC level of at least 2 ng per milliliter in 3.8%, and a THC level of at least 5 ng per milliliter in 1.1%. After legalization, the values were 17.9%, 8.6%, and 3.5%, respectively. After legalization, there was an increased prevalence of drivers with a THC level greater than 0 (adjusted prevalence ratio, 1.33; 95% confidence interval [CI], 1.05 to 1.68), a THC level of at least 2 ng per milliliter (adjusted prevalence ratio, 2.29; 95% CI, 1.52 to 3.45), and a THC level of at least 5 ng per milliliter (adjusted prevalence ratio, 2.05; 95% CI, 1.00 to 4.18). The largest increases in a THC level of at least 2 ng per milliliter were among drivers 50 years of age or older (adjusted prevalence ratio, 5.18; 95% CI, 2.49 to 10.78) and among male drivers (adjusted prevalence ratio, 2.44; 95% CI, 1.60 to 3.74). There were no significant changes in the prevalence of drivers testing positive for alcohol.

CONCLUSIONS

After cannabis legalization, the prevalence of moderately injured drivers with a THC level of at least 2 ng per milliliter in participating British Columbia trauma centers more than doubled. The increase was largest among older drivers and male drivers. (Funded by the Canadian Institutes of Health Research.)

From the University of British Columbia, Vancouver (J.R.B., H.C., S.E., J.A.S.), Dalhousie University, Halifax, NS (M.A.), and the Centre for Addiction and Mental Health (R.E.M.) and the University of Toronto (R.E.M.), Toronto — all in Canada. Dr. Brubacher can be contacted at jeff.brubacher@ubc.ca or at the Department of Emergency Medicine, Faculty of Medicine, University of British Columbia, Diamond Health Care Centre, 2775 Laurel St., 11th Fl., Vancouver, BC, Canada V5Z 1M9.

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Cannabis is the second most commonly used recreational drug worldwide after alcohol,[1] and its legal status is rapidly changing. Cannabis has been legal for medical use in Canada since 2001 and for recreational use since October 2018. Internationally, recreational cannabis use is legal in South Africa and Uruguay as well as in 17 U.S. states, two U.S. territories, and the District of Columbia. The Canadian "Cannabis Act" (Bill C-45) aims to protect public health and safety by restricting access to cannabis for young people, reducing illicit activities related to cannabis, improving cannabis product safety, and increasing public awareness of health risks associated with cannabis. At the same time, the Government of Canada introduced Bill C-46, which aimed to prevent cannabis-impaired driving by establishing per se limits for whole-blood tetrahydrocannabinol (THC, the main psychoactive ingredient in cannabis) and expanding police powers to collect evidence of drug-impaired driving. Bill C-46 set penalties, including criminal charges, for drivers with a whole-blood THC level higher than 2 ng per milliliter (with more severe penalties for a THC level of >5 ng per milliliter or for a THC level of >2.5 ng per milliliter combined with a blood alcohol level of >0.05%).[2]

Cannabis use is associated with cognitive deficits and psychomotor impairment,[3,4] and there is evidence that it increases the risk of motor vehicle crashes, especially at higher THC levels.[5-7] As such, there is concern that legalization of cannabis might lead to an increase in cannabis-related motor vehicle crashes. The effects of cannabis legalization on road safety have been evaluated in several U.S. states, with mixed results. Some studies showed an increase in fatal collisions after cannabis legalization, but others did not, with results varying according to state and study methods.[8-11]

It is important to understand the effects of cannabis legalization on road safety in Canada. Unfortunately, prelegalization data on the prevalence of cannabis use among Canadian drivers were based on methods that have limited suitability for monitoring trends in cannabis use by drivers. Participant-reported surveys are subject to selection, recall, and reporting biases, and such surveys typically lack precision because they ask about drug use before driving during a given period (e.g., the previous month) instead of before a specific driving episode.[12] Roadside surveys are limited by the high percentage of drivers who decline to participate (20 to 30% in Canadian surveys).[13] Police reports on motor vehicle crashes often do not appropriately record previous cannabis use.[14] THC levels in coroner's reports do not reliably correspond to levels at the time of the collision owing to a delay in the testing of fatally injured drivers who survive the crash for a period of time[15] and substantial postmortem redistribution of THC in the body.[16-18]

A Quick Take is available at NEJM.org

Another way to monitor the prevalence of driving after cannabis use is to study injured drivers treated in the hospital after a collision.[19] Our research group has measured alcohol and drug levels, including THC levels, since 2011 in injured drivers treated at participating British Columbia trauma centers.[20] This research provides a unique opportunity to study the effect of cannabis legalization on the prevalence of cannabis use among injured drivers. Our primary objective was to investigate prelegalization as compared with postlegalization changes in the prevalence of injured drivers who test positive for cannabis (THC level >0) or exceed the Canadian per se limits (THC level of >2 ng per milliliter or >5 ng per milliliter). Increased availability of cannabis may be associated with a reduction in alcohol-related collisions if persons substitute cannabis for alcohol.[21] Conversely, there is concern that legalization will result in more drivers using cannabis in combination with alcohol. Our secondary objective was to investigate changes in the prevalence of injured drivers who consumed alcohol, alone or together with cannabis, before the crash.

METHODS

STUDY DESIGN AND OVERSIGHT

Detailed methods have been published previously.[22] In brief, we studied moderately injured drivers who were treated in a hospital after a motor vehicle crash. Moderate injury was defined pragmatically as meaning that blood tests were warranted for clinical assessment. We obtained excess blood that remained after clinical testing and froze it at −40°C for later toxicologic analysis. The study was approved by the University of British Columbia research ethics board. Because we used excess blood remaining after clinical use and had procedures to protect personal informa-

tion, the board approved waiver of informed consent.

INCLUSION CRITERIA

We prospectively studied drivers treated at four participating British Columbia trauma centers, all of which provided continuous data from January 2013 through March 2020 (temporary cessation of data collection owing to the coronavirus disease 2019 pandemic). All injured automobile drivers for whom blood samples were obtained as part of clinical care were included. Blood tests were performed routinely at all sites in all drivers with potentially serious injuries. Drivers with minor injuries after low-speed collisions did not undergo blood tests and were excluded. The decision to obtain blood was not based on suspicion of drug use; tests for cannabis and other drugs at participating hospitals are performed on urine. Toxicologic results from this study were not available to clinical staff. Most samples contained whole blood, and the remainder contained plasma. Research assistants reviewed emergency department (ED) records to identify all eligible drivers and obtained excess blood before it was discarded. Drivers were also excluded if the blood was obtained from the driver more than 6 hours after the crash or if no excess blood remained (blood was fully used for clinical analysis or discarded before being obtained by research assistants).

HEALTH RECORDS AND TOXICOLOGIC ANALYSIS

We reviewed medical records and recorded information on demographic characteristics, injury severity, and collision events. Broad-spectrum toxicologic testing on whole-blood samples was conducted at the British Columbia Provincial Toxicology Centre. Toxicologic testing detected alcohol, cannabinoids, other recreational drugs (cocaine, amphetamines [including designer drugs], and opiates), and psychotropic pharmaceuticals (including antihistamines, benzodiazepines, other hypnotic agents, and sedating antidepressants). The laboratory methods detected opium alkaloids (codeine and morphine), semisynthetic opioids (oxycodone and hydromorphone), and synthetic opioids (methadone and fentanyl). The limit of detection for THC was 0.2 ng per milliliter.

STATISTICAL ANALYSIS

The primary outcomes were binary indicator variables for a THC level greater than 0, a THC level of at least 2 ng per milliliter, and a THC level of at least 5 ng per milliliter. The secondary outcomes were binary indicators for a THC level of at least 2.5 ng per milliliter plus a blood alcohol level of at least 0.05%; a blood alcohol level greater than 0; and a blood alcohol level of at least 0.08%. We calculated the prevalence of all outcomes in the period before legalization (January 2013 through September 2018) and the period after legalization (November 2018 through March 2020) and report crude prevalence ratios for all injured drivers and for relevant subgroups, as defined below. We excluded drivers with crashes occurring during the month of legalization (October 2018) because the exact date of the crash was suppressed for privacy, which made it impossible to know which motor vehicle crashes occurred before legalization and which occurred after.

For each outcome, we obtained adjusted prevalence ratios using separate log-binomial regression models. The response variable was an indicator for whether the driver tested above the substance threshold. The models included the following predictors: legalization (pre- or post-legalization indicator), sex (male or female), age range (<30 years, 30 to 49 years, or ≥50 years), time of crash (night [6:01 p.m. to 6:00 a.m.] or day [6:01 a.m. to 6:00 p.m.]), type of crash (single-vehicle or multivehicle), injury severity (admission to hospital or discharge from the ED), hospital site, year of crash (treated as an annual linear trend), and season of crash (winter, spring, summer, or fall). There was no evidence of multicollinearity because all generalized variance inflation factors were less than 1.6. We estimated prevalence ratios and 95% confidence intervals for each predictor by exponentiating coefficient estimates from the model fit. We used log-binomial rather than logistic regression because the prevalence of cannabis use was not rare, especially in the period after legalization. However, we conducted sensitivity analyses to compare results from logistic, log-binomial, and Poisson regression with robust standard errors and found that all methods yielded similar results. We considered the clus-

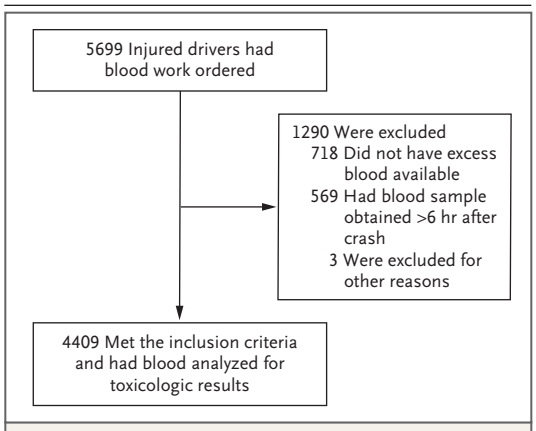

Figure 1. Study Participants.

tered nature of our multicenter data but chose to treat drivers coming from the same hospital site as a fixed effect, because this method produces unbiased estimates when the number of sites is small (≤5) and the sample size is large (≥2000).[23]

We performed exploratory analyses to assess the effect of cannabis legalization among various subgroups (with respect to age, sex, hospital site, and time, type, and severity of crash). For each subgroup, we updated the adjusted log-binomial model fit to include an interaction term between the legalization indicator and the covariate for the subgroup of interest. We estimated the legalization prevalence ratio in the subgroup by computing a linear combination of the legalization plus legalization-by-subgroup interaction coefficients from the model fit. Interactions were estimated separately for each covariate.

All statistical analyses were performed with the use of R software, version 4.0.3. All confidence intervals are reported without adjustments for multiplicity, so no statistical inferences may be drawn.

RESULTS

PARTICIPANTS

During the 7-year study period, 4409 drivers met the inclusion criteria and had blood analyzed for toxicologic results: 3550 before cannabis legalization, 70 during the month of legalization (excluded from analysis), and 789 after legalization (Fig. 1). Approximately two thirds of the sample (2728 of 4409 [61.9%]) were male, and the median age was 40 years. Most drivers (58.9%) were from the greater Vancouver area, one fifth (21.8%) were admitted to a hospital, and two thirds (66.7%) had blood obtained within 2 hours after the collision (mean, 116 minutes). Toxicologic results are provided in Table S1 in the Supplementary Appendix, available with the full text of this article at NEJM.org. Injured driver and crash characteristics were similar in the period before legalization and the period after legalization (Table 1). The prevalence of cannabis use varied over the course of the study (Fig. 2).

THC AND ALCOHOL LEVELS

Before legalization, THC was detected in 325 of 3550 drivers (9.2%), a THC level of at least 2 ng per milliliter in 136 (3.8%), and a THC level of at least 5 ng per milliliter in 38 (1.1%) (Table 2). After legalization, the values were 141 of 789 (17.9%), 68 (8.6%), and 28 (3.5%), respectively. Alcohol was detected in 409 of 3550 drivers (11.5%) before legalization and in 77 of 789 (9.8%) after legalization.

After legalization, there was an increase in the prevalence of moderately injured drivers with a THC level greater than 0 (adjusted prevalence ratio, 1.33; 95% confidence interval [CI], 1.05 to 1.68) and with a THC level of at least 2 ng per milliliter (adjusted prevalence ratio, 2.29; 95% CI, 1.52 to 3.45). Among moderately injured drivers with a THC level of at least 5 ng per milliliter, the adjusted prevalence ratio was 2.05 (95% CI, 1.00 to 4.18).

The largest increases in cannabis use (defined as a THC level of ≥2 ng per milliliter) were seen in drivers 50 years of age or older (adjusted prevalence ratio, 5.18; 95% CI, 2.49 to 10.78) and male drivers (adjusted prevalence ratio, 2.44; 95% CI, 1.60 to 3.74). Additional information on driver subgroups is provided in Table S3. There were no significant changes in the prevalence of drivers testing positive for alcohol, alone or in combination with THC (Fig. 3 and Table 2).

DISCUSSION

Recreational cannabis legalization was associated with an increased prevalence of moderately

Table 1. Characteristics of Injured Drivers and Motor Vehicle Crashes.*

Characteristic	Entire Study Period: Jan. 2013–Mar. 2020 (N=4409)	Before Legalization: Jan. 2013–Sept. 2018 (N=3550)	Legalization: Oct. 2018 (N=70)†	After Legalization: Nov. 2018–Mar. 2020 (N=789)
		number (percent)		
Male sex	2728 (61.9)	2182 (61.5)	47 (67.1)	499 (63.2)
Age group				
<30 yr	1106 (25.1)	906 (25.5)	8 (11.4)	192 (24.3)
30–49 yr	1559 (35.4)	1240 (34.9)	28 (40.0)	291 (36.9)
≥50 yr	1744 (39.6)	1404 (39.5)	34 (48.6)	306 (38.8)
Health authority				
Vancouver Coastal Health	2598 (58.9)	2074 (58.4)	33 (47.1)	491 (62.2)
Fraser Health Authority	865 (19.6)	672 (18.9)	9 (12.9)	184 (23.3)
Vancouver Island Health Authority	526 (11.9)	440 (12.4)	18 (25.7)	68 (8.6)
Interior Health Authority	420 (9.5)	364 (10.3)	10 (14.3)	46 (5.8)
Admitted to hospital	962 (21.8)	781 (22.0)	14 (20.0)	167 (21.2)
Time from collision to blood draw				
≤60 min	661 (15.0)	556 (15.7)	4 (5.7)	101 (12.8)
61–120 min	2278 (51.7)	1847 (52.0)	32 (45.7)	399 (50.6)
121–240 min	1147 (26.0)	892 (25.1)	20 (28.6)	235 (29.8)
241–360 min	323 (7.3)	255 (7.2)	14 (20.0)	54 (6.8)
Single-vehicle collision	1322 (30.0)	1064 (30.0)	24 (34.3)	234 (29.7)
Nighttime collision‡	1541 (35.0)	1243 (35.0)	18 (25.7)	280 (35.5)

* Percentages may not total 100 because of rounding.
† Data are for drivers with crashes occurring during the month of legalization.
‡ Night was defined as 6:01 p.m. to 6:00 a.m.

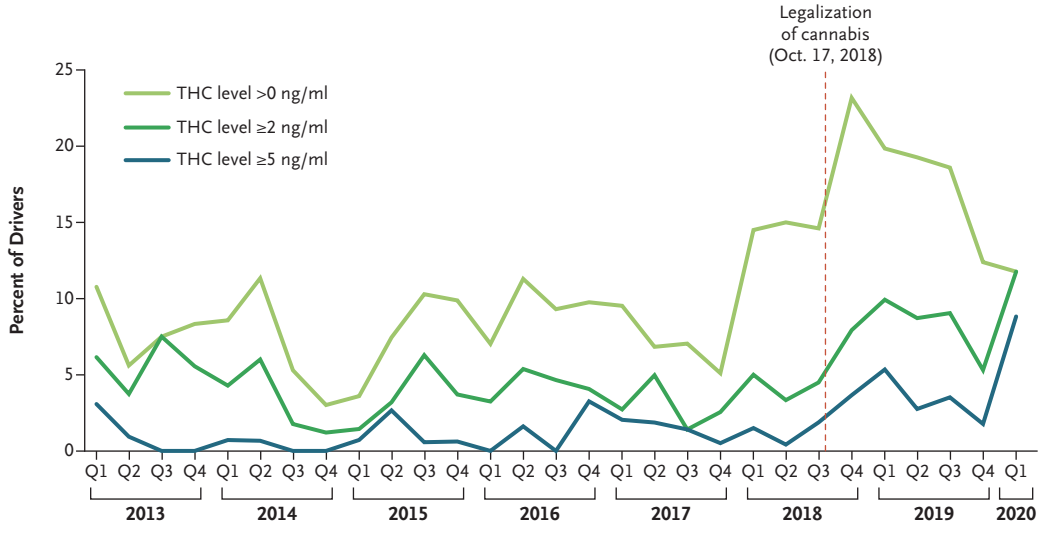

Figure 2. Quarterly Time Series Showing Tetrahydrocannabinol (THC) Levels in Moderately Injured Drivers.

Table 2. Substance Levels in Moderately Injured Drivers before and after Cannabis Legalization.*

Substance	Entire Study Period: Jan. 2013–Mar. 2020 (N=4409)	Before Legalization: Jan. 2013–Sept. 2018 (N=3550)	After Legalization: Nov. 2018–Mar. 2020 (N=789)	Prevalence Ratio: After vs. Before Legalization (95% CI)†	
				Crude‡	Adjusted§
		number (percent)			
Cannabis					
THC level = 0 ng/ml	3923 (89.0)	3225 (90.8)	648 (82.1)	—	—
THC level >0 ng/ml	486 (11.0)	325 (9.2)	141 (17.9)	1.95 (1.63–2.34)	1.33 (1.05–1.68)
THC level ≥2 ng/ml	209 (4.7)	136 (3.8)	68 (8.6)	2.25 (1.70–2.98)	2.29 (1.52–3.45)
THC level ≥5 ng/ml	69 (1.6)	38 (1.1)	28 (3.5)	3.32 (2.05–5.37)	2.05 (1.00–4.18)
Alcohol					
Blood alcohol level = 0%	3912 (88.7)	3141 (88.5)	712 (90.2)	—	—
Blood alcohol level >0%	497 (11.3)	409 (11.5)	77 (9.8)	0.85 (0.67–1.07)	0.90 (0.71–1.14)
Blood alcohol level ≥0.08%	399 (9.0)	331 (9.3)	64 (8.1)	0.87 (0.67–1.12)	0.98 (0.74–1.30)
Cannabis and alcohol					
THC level >0 ng/ml and blood alcohol level >0%	103 (2.3)	75 (2.1)	24 (3.0)	1.44 (0.92–2.27)	0.84 (0.49–1.45)
THC level ≥2.5 ng/ml and blood alcohol level ≥0.05%	24 (0.5)	17 (0.5)	7 (0.9)	1.85 (0.77–4.45)	2.88 (0.76–10.9)

* Date on prevalence during the month of legalization (October 2018) are provided in Table S2 in the Supplementary Appendix. THC denotes tetrahydrocannabinol.
† Confidence intervals (CIs) have not been adjusted for multiplicity; no statistical inferences may be drawn.
‡ Shown are Wald confidence intervals (excluding the month of legalization).
§ Adjusted prevalence ratios were obtained from a log-binomial regression model that was adjusted for annual trend (year), season (winter, spring, summer, or fall), sex (male or female), age group (<30, 30 to 49, or ≥50 years), health authority (Vancouver Coastal Health, Fraser Health Authority, Vancouver Island Health Authority, or Interior Health Authority), injury severity (admission to hospital or discharge from emergency department), time of collision (daytime or nighttime), and type of collision (single-vehicle or multivehicle).

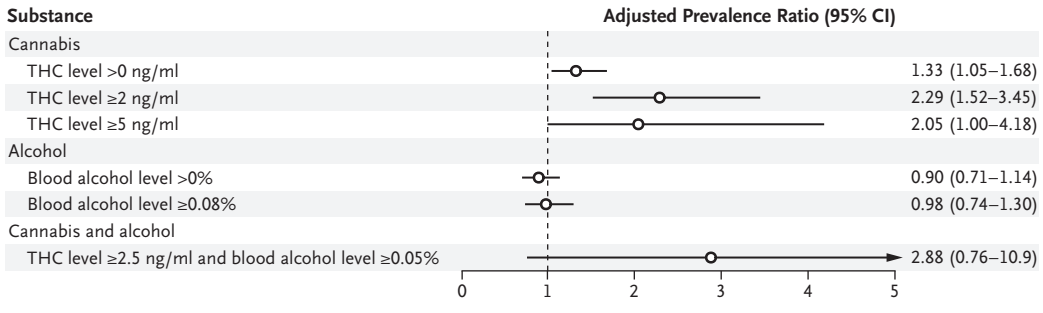

Figure 3. Adjusted Prevalence Ratios for Effects of Cannabis Legalization on Substance Use among Moderately Injured Drivers.

Shown is the ratio of postlegalization prevalence to prelegalization prevalence, with adjustment for annual trend (year), season (winter, spring, summer, or fall), sex (male or female), age group (<30, 30 to 49, or ≥50 years), regional health authority (Vancouver Coastal Health, Fraser Health Authority, Vancouver Island Health Authority, or Interior Health Authority), injury severity (admission to hospital or discharge from emergency department), time of collision (daytime or nighttime), and type of collision (single-vehicle or multivehicle). Confidence intervals have not been adjusted for multiplicity; no statistical inferences may be drawn.

injured drivers who tested positive for THC (adjusted prevalence ratio, 1.33), for a THC level of at least 2 ng per milliliter (adjusted prevalence ratio, 2.29), and for a THC level of at least 5 ng per milliliter (adjusted prevalence ratio, 2.05). This troubling increase occurred despite the simultaneous introduction of traffic laws designed to deter cannabis-impaired driving. According to Statistics Canada, the percentage of Canadian adults reporting cannabis use increased from 14.9% before legalization to 16.8% afterward (from 18.2% to 19.1% in British Columbia).[24] Our finding of a much larger increase in the prevalence of drivers testing positive for THC raises the possibility that, in addition to more persons using cannabis after legalization, people who do use it are more likely than before legalization to drive afterward. Figure 2 suggests that these trends began after the federal announcement of forthcoming legalization but before the law came into force. This "transition period" probably produced public perceptions that cannabis use was already legal or that laws against its use would not be enforced, a finding observed previously in Canada.[25] We caution that the presence of THC, especially at low concentrations, does not necessarily mean that the collision was caused by cannabis. Although the odds of causing a collision are increased among drivers with a THC level higher than 5 ng per milliliter, there is little evidence of increased risk at a THC level of less than 5 ng per milliliter.[6,26]

Our findings complement previous research suggesting that cannabis legalization increases the prevalence of drivers using cannabis. In Washington State, the proportion of THC-positive drivers involved in fatal collisions approximately doubled after the legalization of cannabis in 2012 and remained elevated through at least 2017.[27,28] That research used coroner's data and relied heavily on imputation to address missing data. A Colorado report, which did not account for time trends or missing values, also noted an increase in "marijuana-related traffic deaths" after cannabis legalization.[29] Our findings are also consistent with a survey from Washington State that showed a significant increase in cannabis use during the first 4 years after cannabis legalization (rising from 25.0% to 31.7% of survey respondents).[30]

The greatest increase in THC prevalence occurred among drivers 50 years of age or older (adjusted prevalence ratio, 5.18). This observation is consistent with other research showing increased cannabis use in older adults. A review of cannabis prevalence studies showed an increasing trend in cannabis use in the past 20 years among persons older than 50 years of age, with the greatest increase among persons 65 years of age or older.[31] Similarly, in the years before legalization in Ontario, adults older than 50 years of

age accounted for an increasing proportion of cannabis users.[32] Before legalization, older drivers may have been more strongly deterred by cannabis prohibition than younger drivers, even if they had used it when they were younger. Now that cannabis is legal, they may be returning to recreational use, using it for medical purposes, or both.[33] This apparent increase in driving after cannabis use by older adults is worrisome. Most information about cannabis pharmacology and its effects on behavior is derived from studies involving younger adults. The cognitive and psychomotor abilities that are required for safe driving decline with age,[34,35] which suggests that older drivers may be more vulnerable to the impairing effects of cannabis. This, combined with the potential for more severe injuries in older drivers after a collision,[36,37] suggests that the increase in cannabis use among older drivers could result in increases in collision-related injuries.

Postlegalization increases in cannabis use by drivers must be interpreted in the context of traffic laws intended to deter cannabis-impaired driving.[13,38-40] At the federal level, Bill C-46 allows police to demand a roadside oral fluid sample from drivers whom they reasonably suspect have drugs in their body and to demand a blood sample if they have reasonable grounds to believe a driver committed a drug-impaired driving offense within the past 3 hours. The British Columbia Motor Vehicle Act was amended with new penalties (fines and driver's license suspension) to deter cannabis-impaired driving, especially for new drivers. The substantial increase in injured drivers testing positive for THC suggests that the new federal and provincial laws do not deter everyone from driving after using cannabis. This may be because police have difficulty identifying drivers who have used cannabis,[14] which limits their ability to gather evidence of a cannabis-related driving offense. If drivers who use cannabis are not prosecuted, the laws will have limited deterrent effect.

The collision risk that is associated with cannabis appears to be less than that with alcohol,[6,26] and it has been suggested that the increased availability of cannabis could be associated with an overall reduction in the incidence of collisions if drivers substitute cannabis for alcohol.[21] However, we found no evidence of a decreased prevalence of moderately injured drivers with a blood alcohol level higher than 0.08% after cannabis legalization (adjusted prevalence ratio, 0.98; 95% CI, 0.74 to 1.30). This finding is consistent with a Washington State survey that showed no significant change in alcohol use after legalization.[30]

Strengths of our study include the use of multicenter prospective data over a prolonged study interval, a large sample size, and additional measurement of alcohol and other potentially impairing drugs. Our study also has limitations. Outcomes were prespecified but not preregistered. There was a mean interval of 116 minutes from collision until blood samples were obtained. As such, measured THC levels were lower than actual levels at the time of the collision. This limitation would probably not alter our conclusions because the mean intervals were similar before legalization and after legalization (Table 1). Our findings apply to moderately injured drivers treated in large urban trauma centers and may not apply to collisions causing minor injury, fatal collisions, or collisions occurring in remote areas. Our results may not generalize to other provinces with different patterns of cannabis use or norms regarding impaired driving. Cannabis use in British Columbia (before and after legalization) is higher than the national average, but the percentage of persons driving after using cannabis may be lower than in other provinces.[13,38-40]

After cannabis legalization in Canada, the prevalence of injured drivers with a THC level of at least 2 ng per milliliter in British Columbia more than doubled (adjusted prevalence ratio, 2.29). The increase was largest among older drivers (adjusted prevalence ratio, 5.18) and male drivers (adjusted prevalence ratio, 2.44). There was no significant change in the prevalence of injured drivers who tested positive for alcohol. Our findings confirm the effect that cannabis legalization has had on cannabis-related driving and point to the need for continued surveillance of postlegalization effects. Despite laws tailored to regulate road safety after legalization, our results suggest that more work is needed to increase the deterrent effect of traffic laws that target driving after cannabis use. Efforts to improve public knowledge of the harmful effects of cannabis use on driver safety are also warranted.

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Injury Epidemiology

ORIGINAL CONTRIBUTION Open Access

Cohort study of medical cannabis authorization and motor vehicle crash-related healthcare visits in 2014–2017 in Ontario, Canada

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Abstract

Background: With increasing numbers of countries/jurisdictions legalizing cannabis, cannabis impaired driving has become a serious public health concern. Despite substantive research linking cannabis use with higher rates of motor vehicle crashes (MVC), there is an absence of conclusive evidence linking MVC risk with medical cannabis use. In fact, there is no clear understanding of the impact of medical cannabis use on short- and long-term motor vehicle-related healthcare visits. This study assesses the impact of medical cannabis authorization on motor vehicle-related health utilization visits (hospitalizations, ambulatory care, emergency department visits, etc) between 2014 and 2017 in Ontario, Canada.

Methods: A matched cohort study was conducted on patients authorized to use medical cannabis and controls who did not receive authorization for medical cannabis – in Ontario, Canada. Overall, 29,153 adult patients were identified and subsequently linked to the administrative databases of the Ontario Ministry of Health, providing up to at least 6 months of longitudinal follow-up data following the initial medical cannabis consultation. Interrupted time series analyses was conducted to evaluate the change in rates of healthcare utilization as a result of MVC 6 months before and 6 months after medical cannabis authorization.

Results: Over the 6-month follow-up period, MVC-related visits in medical cannabis patients were 0.50 visits/10000 patients ($p = 0.61$) and − 0.31 visits/10000 patients ($p = 0.64$) for MVC-related visits in controls. Overall, authorization for medical cannabis was associated with an immediate decrease in MVC-related visits of − 2.42 visits/10000 patients ($p = 0.014$) followed by a statistically significant increased rate of MVC-related visits (+ 0.89 events/10,000 in those authorized medical cannabis) relative to controls in the period following their authorization($p = 0.0019$). Overall, after accounting for both the immediate and trend effects, authorization for medical cannabis was associated with an increase of 2.92 events/10,000 (95%CI 0.64 to 5.19) over the entire follow-up period. This effect was largely driven by MVC-related emergency department visits (+ 0.80 events/10,000, $p < 0.001$).

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Conclusions: Overall, there was an association between medical cannabis authorization and healthcare utilization, at the population level, in Ontario, Canada. These findings have public health importance and patients and clinicians should be fully educated on the potential risks. Continued follow-up of medically authorized cannabis patients is warranted to fully comprehend long-term impact on motor vehicle crash risk.

Keywords: Medical cannabis, Motor vehicle crash, Healthcare utilization, Public health

Background

Since 2001, Canadians have been allowed to legally possess cannabis for medical purposes with a health care provider's authorization(Alberta, 2017). With non-medical cannabis legalization in Canada and certain states in the United States, there is rising public concern about cannabis-impaired driving/driving under the influence of cannabis (DUIC) (Valleriani, 2017). Past fatality studies (Andrews et al., 2015; Callaghan et al., 2013; Fischer et al., 2016; Romano et al., 2017) resulting from motor vehicle crashes (MVC) suggest higher risk of MVC is associated with general cannabis consumption, however, there is a lack of robust evidence (Rogeberg and Elvik, 2016) surrounding MVC risk for medical cannabis users at the population level.

Previous research on cannabis use and MVC risk have shown mixed results -with a continued debate in the literature on whether or not this association is significant. Clinical studies have reported common physiological effects (both acute and long-term exposure of cannabis use) on the brain that have been found to impair driving ability (Neavyn et al., 2014; Ogourtsova et al., 2018; Wright and Metts, 2016). Evidence suggests that the risk of being involved in a motor vehicle crash increases approximately two-fold when a person drives immediately after smoking cannabis (Hartman and Huestis, 2013) and that acute cannabis intoxication may be associated with an increased MVC risk (Rogeberg and Elvik, 2016). In Canada, statistical data has shown that the percentage of fatally injured drivers from testing positive for cannabis, has generally increased over time (Foundation, T. I. R, 2018). Conversely, higher levels of tetrahydrocannabinol (THC) in the blood has been correlated with higher rates of MVC and impaired driving behaviors, but not at lower levels (Brubacher et al., 2019; Bonar et al., 2019). Further, other studies have shown a nonsignificant association between traffic accidents and cannabis use (Hostiuc et al., 2018; Hansen et al., 2018). In other jurisdictions where medical cannabis has been legalized (i.e. Colorado), an increased rate of MVCs has been reported; whereas the rate remained the same in states without cannabis legalization (Salomonsen-Sautel et al., 2014).

To address the evidence gap, research is needed on whether medical use of cannabis is associated with a higher risk of MVC. Although cannabis would be expected to have a similar potential for MVC in these patients, our study examines whether these medical cannabis patients represent a different subset of the cannabis using population with potentially different patterns of risk behaviors. While past studies on causal interpretation between medical cannabis impairment and motor vehicle crashes present mixed results - a majority of cohort studies are limited due to small sample sizes (Bonar et al., 2019; Ogourtsova et al., 2018), are outdated (Walsh and Mann, 1999; Asbridge et al., 2005), express high publication bias (Hostiuc et al., 2018); do not differentiate between medical and recreational cannabis (Azofeifa et al., 2015; Li et al., 2012; Masten and Guenzburger, 2014), rely heavily on self-reported measures (Richer and Bergeron, 2009), and have loss of participants to follow up over time (Callaghan et al., 2013) who are using medical cannabis.

Thus, we conducted a large cohort study of adults authorized to obtain medical cannabis - to assess whether medical cannabis use has any association on healthcare utilization due to MVC. In this paper, we hypothesized that there is an association between medical authorization for cannabis and MVC-related healthcare utilization in comparison to controls.

Methods

Study design

A matched cohort study was conducted on patients authorized to use medical cannabis and controls who did not receive authorization for medical cannabis – in Ontario, Canada. This retrospective longitudinal matched cohort study is part of a larger study assessing the health outcomes of medical cannabis among patients who received medical authorization (Eurich et al., 2020).

Study population

Inclusion Criteria

All adult patients authorized for medical cannabis [inhaled (smoked or vaporized) or orally consumed (oils) cannabis] that attended specialized cannabis clinics in Ontario (Canada) between April 24, 2014 and March 31, 2017. These individuals were ≥ 18 years of age, of any sex and ethnicity, and had received medical cannabis authorization for a variety of acute and chronic health conditions. Patients may choose to seek assessment for medical cannabis through the clinic via a self-referral or by a physician referral. The index date for each patient

was the first recorded date of medical cannabis authorization at the clinics (Table 1).

Exclusion Criteria

Adult patients who received medical cannabis authorization but were unable to be matched with at least one control, those who were non-eligible to Ontario Health Insurance Plan at baseline and those with invalid or duplicate identifiers were excluded. Patients who had less than 6 months administrative data before the index date and less than 6 months after, were also excluded. This restriction was to ensure we had sufficient health data to determine trends in health care utilization. Further, through sensitivity analysis, we excluded patients having less than 12 months data before the index date and less than 12 months data after.

Table 1 Characteristics of patients with six months follow-up before and six months after the index date included in interrupted time series analyses analysis ($n = 27657$[a])

Characteristic	Unauthorized for medical cannabis (*N* = 17,732)	Authorized for medical cannabis (*N* = 9925)	*p*-value
Age			
< 21	143 (0.8%)	78 (0.8%)	0.9957
21 to 30	1855 (10.5%)	1063 (10.7%)	
31 to 40	3553 (20.0%)	1993 (20.1%)	
41 to 50	3876 (21.9%)	2135 (21.5%)	
to 60	4545 (25.6%)	2562 (25.8%)	
61 to 70	2527 (14.3%)	1414 (14.3%)	
71 to 80	891 (5.0%)	491 (5.0%)	
> 80	342 (1.9%)	189 (1.9%)	
Sex			
Female	8054 (45.4%)	4462 (45.0%)	0.4576
Male	9678 (54.6%)	5463 (55.0%)	
Nearest Census based neighborhood income quintile			
1	3963 (22.4%)	2212 (22.3%)	0.9939
2	3785 (21.4%)	2103 (21.2%)	
3	3347 (18.9%)	1893 (19.1%)	
4	3490 (19.7%)	1959 (19.7%)	
5	3147 (17.8%)	1758 (17.7%)	
Rural	1891 (10.7%)	797 (8.0%)	< 0.0001
Diagnosis codes			
Diabetes	1945 (11.0%)	1132 (11.4%)	0.2680
Congestive heart failure	97 (0.6%)	64 (0.6%)	0.3051
COPD	2028 (11.4%)	1187 (12.0%)	0.1933
Asthma	3438 (19.4%)	1965 (19.8%)	0.4096
Cancer	1250 (7.1%)	726 (7.3%)	0.4110
Musculoskeletal issues	7791 (43.9%)	4377 (44.1%)	0.7931
Neurologic disorders	2564 (14.5%)	1515 (15.3%)	0.0702
Pain	401 (2.3%)	280 (2.8%)	0.0040
Behavioural issues	3313 (18.7%)	1929 (19.4%)	0.1259
Fatigue	188 (1.1%)	139 (1.4%)	0.0120
Metabolic disease	2132 (12.0%)	1286 (13%)	0.0236
Anxiety at baseline	4313 (24.3%)	4867 (49.0%)	< 0.0001

[a]29153 adult patients were identified and subsequently linked to the administrative databases of the Ontario Ministry of Health providing up to at least 6 months of longitudinal follow-up data following the initial medical cannabis consultation. All data was released as de-identified data
COPD Chronic obstructive pulmonary disease

Matched Controls

Each authorized medical cannabis patient was matched at the time of the case index up to 3 controls based on age (± 1 years), sex, Local Health Integration Network location, income quartile, and history of diabetes, heart disease, chronic obstructive pulmonary disease, asthma, cancer, musculoskeletal issues, neurological issues, pain, behavioral issues, fatigue, malnutrition, and metabolic disease based on any related ICD-9/10 codes within the previous 5 years. Matching was completed with replacement and thus an unauthorized patient could have been utilized for 1 or more authorized patients, although no controls was selected more than once. To be considered as unauthorized, no record of a referral to a participating cannabis clinic was allowed. After matching, a pseudo-index date equal to the authorized patient was assigned so that the distribution of index dates is the same as the authorized patients.

Data source

All data for both cannabis users and matched controls were obtained from the provincial administrative health databases collected and housed by Ontario's Institute for Clinical Evaluative Sciences. The ICES Data Repository consists of record-level, coded and linkable health data sets. It encompasses publicly funded administrative health services records for the Ontario population eligible for universal health coverage.

All adult patients seeking assessment at specialized cannabis clinics (between April 2014–March 2017) in Ontario, Canada were eligible. Informed consent was provided by the patient at the time of first intake, which allows data to be collected and used for clinical and research purposes. As part of the authorization and intake process, each patient seeking medical cannabis meets with a trained counselor who performs and initial assessment and collects relevant data. All patients must provide sociodemographic information and disclose their primary medical complaints that constitute their rationale for requesting a medical cannabis authorization. Following their initial intake interview, the patient is referred to a physician who makes their assessment based on the self-reported information, the patient's health record, and any additional assessments conducted by the physician. Initial referral to the clinics can be a self-referral by the patients or by a medical professional.

Overall, 29,153 adult patients were identified and subsequently linked to the administrative databases of the Ontario Ministry of Health hospitalizations and emergency department visits providing up to at least 6 months of longitudinal follow-up data following the initial medical cannabis consultation. These data were provided by the ICES administrative databases in Ontario and all data was released as de-identified data. Research ethics approval was obtained from the University of Alberta Health Research Ethics Board (PRO 00083651) and Veritas Research Ethics Board (Ontario) (16111–13:21:103–01-2017).

Outcomes

All types of healthcare resources utilization that was related or potentially due to motor vehicle crashes were considered in this study (hospitalizations or emergency department visits). The combined endpoint of MCV-related hospitalizations or emergency department was our variable of interest. For this endpoint, if a patient had an emergency department visit that directly lead to a hospitalization only 1 event was counted in the model. For the individual assessments of MVC-related hospitalization or emergency department visits, each was considered as mutually exclusive for analyses. This included ICD-10 codes V40-V69 (Appendix 1); MVC related to buses were not included (V70-V79).

Study sample

In total, 29,153 patients attended a cannabis clinic and provided consent. Of these patients, 9925 medically authorized cannabis patients having at least 6 months follow-up data before and after the index date were matched to 17,732 controls (Fig. 1). In each group, at least 2/3 of the patients were aged 60 years or less, and the majority were men (55%). Musculoskeletal issues, anxiety, neurologic disorders, and asthma were the most predominant morbidities. Morbidities were well balanced between the two groups due to the matched study design although slightly fewer patients authorized for medical cannabis resided in a rural area (8% vs 10.7%) and were more likely to have a history of anxiety (49% vs 24.3%) ($p < 0.001$ for each).

Statistical analysis

All data are expressed descriptively using means (standard deviations) or proportions as appropriate. To assess the effect of medical cannabis use on motor vehicle-related visits, interrupted time series (ITS) analyses assessed the trend in MVC in the 6 months before and 6 months after the authorization of cannabis (Wagner et al., 2002). Each outcome was assessed in 30-day windows for each patient (i.e., total number of occurrences in the month) which represents the time series before and after the change point (i.e. authorization for medical cannabis). Two parameters defined the time series – a level (immediate change in y-intercept) and trend (change in slope over time). The model accounts for the pretreatment trend differences between those authorized medical cannabis and

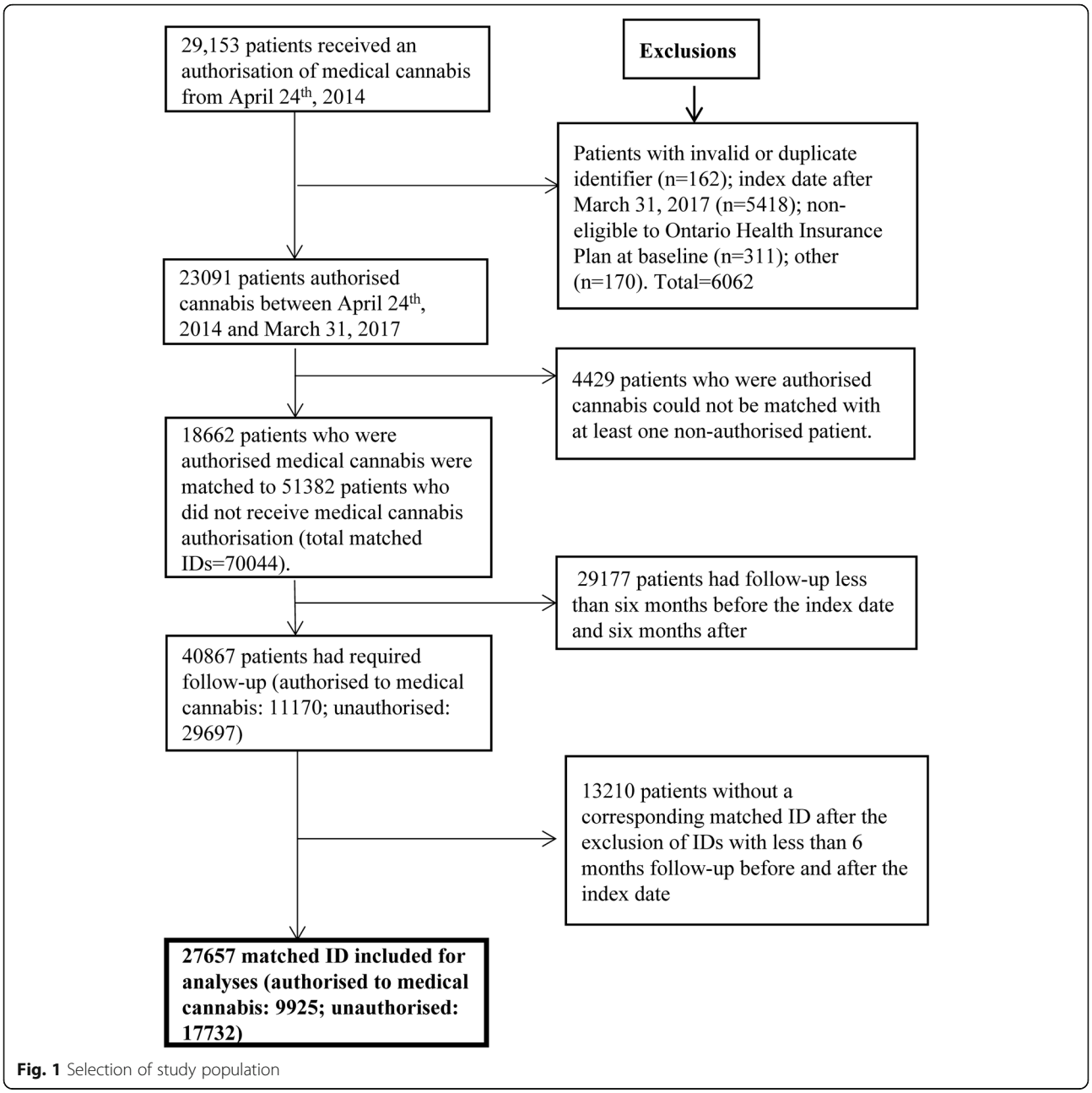

Fig. 1 Selection of study population

controls. First the number of motor vehicle-related visits within each 30-day window are summated for the controls and medically authorized cannabis users separately. Then, the difference in motor vehicle-related visit outcomes between authorized and unauthorized patients is modeled using the standard controlled ITS approach (Zhang et al., 2009). The average pretreatment effect is then projected into the posttreatment period as the best estimate of the counterfactual—what motor vehicle-related visits would have been in the absence of authorization for medical cannabis (Linden, 2015; Bernal et al., 2017).

By modeling the outcomes in this manner, a clear interpretation of effects can be observed: the trend in those authorized for medical cannabis; the trend in those not authorized; and the joint trend of those authorized relative to those unauthorized; as opposed by just relative effects between authorized and those unauthorized where the true drivers of any differences may be difficult to interpret. In addition, the overall absolute effects of medical cannabis authorization on MVC was calculated, which summarizes both the immediate level change (i.e., within a month) and change in trend over the 6 months

Table 2 Cannabis motor vehicle crash healthcare utilization – six months before and six months after authorization for medical cannabis

Outcome	Cannabis Population Difference in mean number of visits/admissions per 10,000 patients from 6 months before to 6 months after medical cannabis			Matched Controls Difference in mean number of visits/admissions per 10,000 patients from 6 months prior to 6 months after index date		
	Before	After	Change	Before	After	Change
Hospitalization or Emergency Department visit as a result of motor vehicle crashes	46	48	+ 2	32	34	+ 2
Hospitalization visit as a result of motor vehicle crashes	6.05	2.02	−4.03	2.82	0.56	−2.26
Emergency Department visit as a result of motor vehicle crashes	40	46	+ 6	29	33	+ 4

with the multivariate delta method used to the construct 95% confidence intervals around the estimate.

Sensitivity analysis

To assess the effect of longer exposure to medical cannabis on motor vehicle-related visits, we extended the follow-up to 12 months before the index date and after exposure by repeating the ITS analysis for all outcomes. However, it is important to note that this additional extension period led to the exclusion of patients who did not have sufficient data 12 months prior or 12 months after (or in the matched controls). As the number of patients included in this analysis was significantly smaller, we considered this as an exploratory analysis.

In addition, we conducted a sensitivity analysis to exclude 0.1 and 0.6, as these codes relate to passengers. Patients involved in motor vehicle collisions involving cannabis and other substances sometimes indicate that they were a passenger as opposed to a driver to avoid any repercussion for the accident from law enforcement. As such, we elected to include all passenger codes in the main analysis.

Results

In the 6 months before authorization, there were 46 MVC-related health care visits/admissions per 10,000 patients among those authorized for medical cannabis and 32 MVC-related health care visits/admissions per 10,000 patients among those not authorized for medical cannabis

Table 3 Interrupted time series analysis of healthcare utilization due to motor vehicle crash six months before and six months after authorization of medical cannabis compared to those unauthorized ($n = 27{,}657$)

Outcome	Authorized Medical Cannabis				Unauthorized Controls				Difference			
	Immediate Level Change*		Temporal Trend change**		Immediate Level Change*		Temporal Trend Change**		Immediate Level Change*		Temporal Trend Change**	
	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/10, 000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*P*-value
Motor-vehicle related hospitalization or ED visit	−3.15	0.3988	0.50	0.61	−2.38	0.2879	−0.31	0.64	−2.42	0.0138	0.89	0.0019
Absolute Effect Motor-vehicle related hospitalization or ED visit									**Events/10,000 patients** 2.92		**95% Confidence Intervals** 0.64–5.19	
Motor-vehicle related hospitalization	−1.97	0.0365	0.22	0.2753	−0.91	0.0749	−0.068	0.5782	−1.10	0.7322	−0.0081	0.9898
Absolute Effect Motor-vehicle related hospitalization									**Events/10,000 patients** − 1.15		**95% Confidence Intervals** (− 14.63–12.33)	
Motor-vehicle related ED	− 1.91	0.5108	0.64	0.4184	−1.42	0.4661	−0.18	0.7384	−0.90	0.2907	0.80	0.0001
Absolute Effect Motor-vehicle related ED visit									**Events/10,000 patients** 3.92		**95% Confidence Intervals** (2.65–5.19)	

*change in the month following the authorization of cannabis or the index date
**change in slope in the six months following the authorization of cannabis or the index date
ED Emergency department

(Table 2). Following medical cannabis authorization, an immediate (level change) change of − 3.15 MVC-related health care visits/admissions per 10,000 patients occurred whereas in controls − 2.38 MVC-related health care visits/admissions per 10,000 patients occurred (Neither change was statistically significant ($p = 0.39$ and $p = 0.29$, respectively). Furthermore, with respect to changes in trend, amoung those authorized for medical cannabis, MVC-related visits after 6 months was 0.50 visits per 10,000 patients; and MVC-related visits in controls was − 0.31 visits per 10,000 patients. Neither change was statistically significant ($p = 0.61$ and $p = 0.64$, respectively) (Table 3); and also shown by the ITS analysis in the difference in monthly proportions of healthcare utilization between cases and controls (Fig. 2). When evaluating the difference in events amoung those authorized medical cannabis to controls, an immediate decrease in MVC -related visits of − 2.42 events per 10,000 in those authorized medical cannabis was observed (level change) $p = 0.0138$). This was followed by an increase of MVC-related visits of 0.89 events per 10,000 in those authorized medical cannabis (over the 6 months relative to controls − trend change), which was statistically significant ($p = 0.0019$) (Table 3). After accounting for both the immediate (level) and temporal (trend) effects, authorization of medical cannabis was associated with an absolute increase of 2.92 events/10,000 (95%CI 0.64 to 5.19) over the entire follow-up period.

Stratified analyses by type of MVC-related visit suggests that emergency department visits contributed to the majority of the difference observed between those authorized medical-cannabis compared to controls. Indeed, although no statistical difference was observed with respect to MVC-related hospitalizations immediately (level change) or during the follow-up (trend change) or immediately in MVC-related emergency department visits (level change), an increase of MVC-related emergency department visits was observed of 0.80 events per 10,000 in those authorized medical cannabis during the follow-up (over the 6 months relative to controls; trend change, $p = 0.0001$) No clinically important differences were noted for either age or sex (Appendix 2 and 3).

Additional sensitivity analyses

After exclusion of 0.1 and 0.6 (codes relating to passengers), following medical cannabis authorization, MVC-related visits in medical cannabis patients after 6 months was 0.46 visits per 10,000 patients; and MVC-related visits in controls was − 0.57 visits per 10,000 patients - with neither change statistically significant ($p = 0.54$ and $p = 0.32$, respectively) (Table 4). After accounting for both the immediate and temporal effects, the absolute effect of medical cannabis authorization was a non-statistcially significant increase of 2.34 events/10,000 (95%CI: − 25.06-29.74) over the 6-month follow-up period.

When we extended our analysis out to 12 months, in the 12 months before authorization, there were 121 MVC-related health care visits/admissions per 10,000 patients among those authorized medical cannabis and

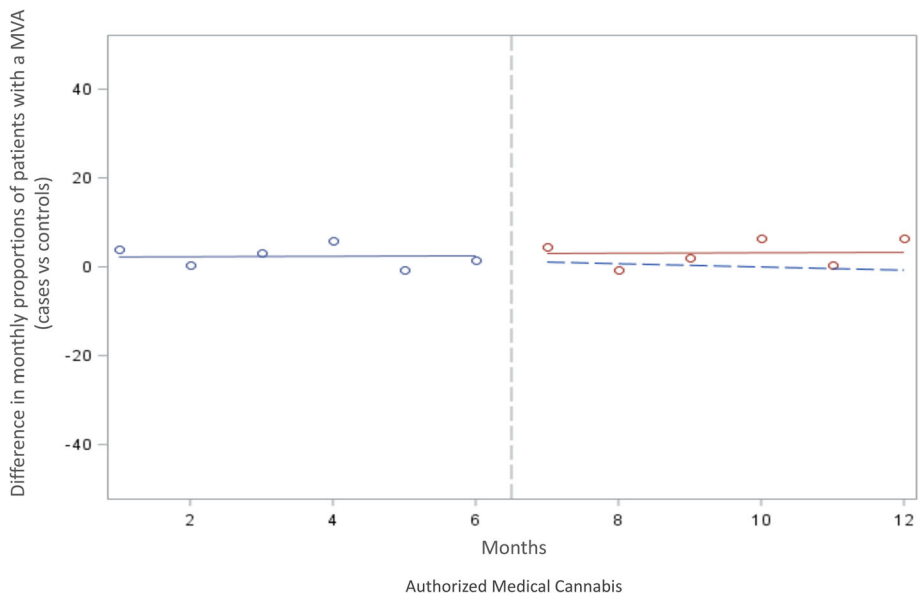

Fig. 2 Interrupted Time Series Analyses: Difference in motor vehicle-related health care utilization by patients after authorization of medical cannabis compared to those unauthorized ($n = 27,657$). Legend:. *Healthcare utilization includes all hospitalizations and hospital visits. *Solid lines represent the pre trend (blue) and post trends (red) after authorization for medical cannabis. *Dashed line (blue) represents the counterfactual trend expected if no change occurred due to medical cannabis authorization

Table 4 Sensitivity Analyses (Exclusion of 0.1 & 0.6 Codes): Interrupted time series analysis of healthcare utilization due to motor vehicle crash six months before and six months after authorization of medical cannabis compared to those unauthorized ($n = 27,657$)

Outcome	Authorized Medical Cannabis				Unauthorized Controls				Difference				Absolute Difference	
	Immediate Level Change*		Temporal Trend change**		Immediate Level Change*		Temporal Trend Change**		Immediate Level Change*		Temporal Trend Change**		Combined Level and Trend Changes	
	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*P*-value	Events/ 10,000 patients	95% Confidence intervals
Motor-vehicle related hospitalization or ED visit	−2.50	0.3745	0.46	0.5358	−0.23	0.9196	−0.57	0.3239	−0.95	0.9229	0.55	0.8284	2.34	−25.06 to 29.7
Motor-vehicle related hospitalization	−1.56	0.0857	0.08	0.7079	−0.64	0.0586	−0.0063	0.9369	−0.65	0.4911	0.28	0.3066	1.02	−2.96 to 4.99
Motor-vehicle related ED	−0.85	0.7276	0.39	0.5517	0.53	0.8388	−0.63	0.2613	3.20	0.2904	0.35	0.7655	5.29	−6.60 to 17.17

65 MVC-related health care visits/admissions per 10,000 patients among those not authorized medical cannabis (Table 5). Following medical cannabis authorization, MVC-related visits in medical cannabis patients after 12 months was 0.33 visits per 10,000 patients; and MVC-related visits in controls was 0.21 visits per 10,000 patients - with neither change statistically significant ($p = 0.70$ and $p = 0.60$, respectively) (Table 6). However, when comparing those authorized medical cannabis to controls, MVC-related visits of − 0.11 events per 10,000 in those authorized medical cannabis (over the 12 months relative to controls) was observed which was also not statistically significant ($p = 0.56$) (Table 6). After accounting for both the immediate and temporal effects, the absolute effect of medical cannabis authorization was a non-statistcially significant increase of 4.32 events/10,000 (95%CI − 0.73 to 9.37) over the entire 12-month follow-up period. Finally, no associations were observed with respect to either MVC-related hospitalizations or emergency department visits in stratified analyses when comparing those authorized medical cannabis to controls.

Discussion

This population-based study of patients authorized for medical cannabis showed an overall absolute increase (overall level and trend effects) in MVC-related visits of 2.92 per 10,000 people (compared to controls) within the first 6 months, which was largely driven by increases in MVC-related emergency department visits. However, no statistical differences in MVC-related healthcare utilization were observed in the subgroup of patients followed for up to 1 year, although the overall absolute effects were higher than the 6-month data (absolute events of 4.32 per 10,000 people). The clinical relevance of these findings at the individual level is unclear but may have important implications from a public health perspective.

The majority of previous studies of medical cannabis and MVC risk have shown inconsistent results. Certain studies report high correlation between medical cannabis/recreational cannabis use and MVC risk (Richer and Bergeron, 2009; Wright and Metts, 2016). Bonar et al. (2019) reported that DUIC behavior was higher in medical cannabis patients authorized for chronic pain than those in the general population of individuals who were reported to drive after the use of cannabis (Bonar et al., 2019). Recent Canadian reports on MVC and cannabis (Foundation, T. I. R, 2018; Alberta, 2017) indicate a general increase of fatally injured drivers who tested positive of cannabis from 2000 to 2015. Recent meta-analyses of epidemiological studies (Rogeberg and Elvik, 2016; Hartman and Huestis, 2013) including Li et al. (Li et al., 2012) also showed a significant increase of MVC risk as a result of cannabis consumption. Conversely, other meta-analyses report that the association between medical cannabis use and MVC risk is nonsignificant (Hostiuc et al., 2018) – and that only higher levels of cannabis were associated with higher MVC risk (Brubacher et al., 2019). Notably, other ITS studies (Hamilton et al., 2014) focused on recreational use and/or impairment without strictly focusing on solely medical use (Ogourtsova et al., 2018). Indeed, Masten et al. (Masten and Guenzburger, 2014) reported that medical cannabis laws may not necessarily be linked with increased MVC rates. Likewise, Neavyn et al. (Neavyn et al., 2014) reported the importance of distinguishing between medical cannabis and recreational cannabis to fully understand its effects on MVC-risk associated behavior. These discrepancies may explain the difference in outcomes associated with medical cannabis use and MVC risk among the various study populations.

The strength of our study is that it is currently the largest Canadian population-based study completed with population-based matched controls. However, our study is not without limitations. First, this is an observational study and potential spectrum bias is a concern as our cohort is based on patients who have individually sought authorization for medical cannabis. This population may not be representative of all individuals who are using

Table 5 Cannabis motor vehicle crash healthcare utilization – one year before and one year after authorization for medical cannabis

Outcome	Cannabis Population Difference in mean number of visits/admissions per 10,000 patients from 1 year before to 1 year after medical cannabis			Matched Controls Difference in mean number of visits/admissions per 10,000 patients from 1 year prior to 1 year after index date		
	Before	After	Change	Before	After	Change
Hospitalization or Emergency Department visit as a result of motor vehicle crashes	121	95	−26	65	50	−15
Hospitalization visit as a result of motor vehicle crashes	3.3	9.8	+ 6.5	0	2.5	+ 2.5
Emergency Department visit as a result of motor vehicle crashes	118	85	−33	65	47	−18

Table 6 Interrupted time series analysis of healthcare utilization due to motor vehicle crash one year before and one year after authorization for medical cannabis compared to those unauthorized ($n = 7065$)

Outcome	Authorized Medical Cannabis				Unauthorized Controls				Difference				Absolute change	
	Immediate Level Change*		Temporal Trend change**		Immediate Level Change*		Temporal Trend Change**		Immediate Level Change*		Temporal Trend Change**		Combined Level and Trend Changes	
	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	95% Confidence intervals
Motor-vehicle related hospitalization or ED visit	4.19	0.0294	0.33	0.1731	−0.84	0.7191	0.21	0.5973	4.77	0.0034	−0.11	0.5627	4.32	−0.73 to 9.37
Motor-vehicle related hospitalization	0.040	0.9728	0.15	0.3594	0.28	0.5182	−0.0082	0.8915	−0.24	0.8662	0.19	0.6389	-1.15	-14.61 to 12.63
Motor-vehicle related ED	4.82	0.0705	0.27	0.4309	−0.84	0.7191	0.21	0.5973	3.37	0.5935	0.23	0.7575	3.92	2.65 to 5.19

*change in the month following the authorization of cannabis or the index date
**change in slope in the six months following the authorization of cannabis or the index date
ED Emergency department

cannabis for medical purposes but obtained it through other (legal or illegal) avenues.

Among the limitations, we were not able to match all the cannabis cohort patients to at least one control as noted (about 19% were not matched and were excluded from the analysis). It is unclear how this could have affected the results. This issue has probably led to an underestimation of the MVC events as the excluded patients were more likely to be older and had higher rates of morbidities. However, there is no reason to believe that the relative effects would be affected as similar characteristics would be expected in controls if matched. Although controls did not have any records of a referral to a participating cannabis clinic, it is possible these patients could have been using recreational cannabis which we could not capture. If so, this misclassification bias would have led to an underestimation of the MVC effects of cannabis in our analyses. We also have no information on patients which may have declined consent for data collection, and thus, we can make no assumptions about this group of patients or how they may have affected our results. Although patients were authorized to use medical cannabis, we cannot ensure the products were consumed as authorized by physicians or if patients elected to use alternative agents than what was authorized. Moreover, there is no method of determining if medical cannabis was in a patient's system at the time of an MVC. Third, not all MVCs result in healthcare resource utilization and our data do not capture MVCs that did not result in injury or were less severe, thus, we only investigated major crashes resulting in healthcare utilization; not minor crashes. Lastly, we do not know whether the association may change depending on if the MVC was caused by the authorized user or someone else. As this information is from law-enforcement agencies (not available to researchers), we only focused on the user coming into the hospital/ED as a result of an MVC.

Conclusions

Overall, this study suggests an association between medical cannabis authorization and MVC-related healthcare utilization in Ontario medical cannabis users. The clinical relevance of these findings at the individual level is unclear but may have important implications from a public health perspective. Although some may consider the risk small, a policy requiring physicians to discuss the risks of medical cannabis use while driving, should be warranted for patients who are authorized for medical cannabis. Users of medical cannabis should continue to use this medication with caution when interacting with their environments and follow all instructions concerning its use during the operation of motor vehicles.

Appendix

Table 7 Health conditions and ICD-10 codes defining the Motor-vehicle-related hospitalizations (MVC)

Condition	ICD-10
Car occupant injured in transport crash	V40*-V49*
Occupant of pick-up truck or van injured in transport crash	V50-V59
Occupant of heavy transport vehicle injured in transport crash	V60-V69

*The following fourth-character subdivisions are for use with categories V40-V48

.0 Driver injured in nontraffic crash
.1 Passenger injured in nontraffic crash
.2 Person on outside of vehicle injured in nontraffic crash
.3 Unspecified car occupant injured in nontraffic crash
.4 Person injured while boarding or alighting
.5 Driver injured in traffic crash
.6 Passenger injured in traffic crash
.7 Person on outside of vehicle injured in traffic crash
.9 Unspecified car occupant injured in traffic crash

Legend:
ICD-10 International Classification of Diseases, Tenth Revision.

Table 8 Stratification of Authorized and Unauthorized Adult Patients by Age, Sex, Rural/Urban

Outcome	Authorized				Unauthorized				Difference			
	Immediate change*		Temporal change**		Immediate change*		Temporal change**		Immediate change*		Temporal change**	
	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/10, 000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*p*-value	Events/ 10,000 patients	*P*-value
Motor-vehicle related hospitalization or ED visit	−3.15	0.3988	0.50	0.6102	−2.38	0.2879	−0.31	0.6405	−2.42	0.0138	0.889	0.0019
Age												
< 30	2.42	0.7479	−1.99	0.3082	1.45	0.7717	−2.59	0.0807	3.36	0.7622	−0.037	0.9897
31 to 60	−2.69	0.3049	1.23	0.0796	−3.57	0.1370	0.42	0.4885	0.52	0.9550	0.56	0.8143
> 60	−3.27	0.2696	−0.27	0.7182	0.47	0.9126	−0.54	0.6747	−5.09	0.6128	0.23	0.9432
Sex												
Male	−0.99	0.7140	−0.60	0.5060	−4.30	0.0419	−1.24	0.0327	18.94	0.5903	7.14	0.5987
Female	4.31	0.3496	1.67	0.2653	1.28	0.5981	1.10	0.1297	23.83	0.4015	7.43	0.7924
Urban/Rural												
Urban	−3.08	0.3364	0.087	0.9152	−2.13	0.2959	−0.19	0.7328	−5.12	0.2229	1.50	0.0403
Rural	0.71	0.9469	3.08	0.2923	1.16	0.7347	−0.39	0.6666	−6.83	0.6224	2.69	0.2782

Legend:
ED Emergency visi

Table 9 ICD codes by Case and Control in Motor-Vehicle Crashes

MVC ICD DX code	Control	Case
V405	3	3
V430	3	3
V431	0	1
V434	1	1
V435	159	141
V436	40	46
V437	1	0
V439	9	5
V445	4	14
V446	0	1
V455	1	0
V460	1	0
V465	1	0
V470	3	4
V471	1	1
V475	20	18
V476	1	2
V480	1	1
V481	0	3
V482	1	2
V483	1	0
V484	6	5
V485	11	9
V486	4	8
V489	1	2
V490	0	1
V493	0	1
V494	10	12
V495	7	4
V496	2	4
V498	2	0
V499	9	17
V505	1	0
V530	1	0
V532	0	1
V535	8	4
V536	0	3
V539	0	1
V545	0	2
V546	1	0
V575	1	1
V581	0	1
V584	6	3
V585	1	1
V586	3	1
V594	1	0
V595	0	1
V596	1	0
V599	1	0
V645	1	0
V675	1	0
V681	0	1
V684	1	2
V685	3	1
V687	1	0
V698	0	1
TOTAL	335	333

Legend:
ICD International Classification of Diseases.

Table 10 Matched authorized versus unmatched authorized cannabis patients

Characteristics	Authorized cannabis patients matched to a control (18662)	Authorized cannabis patients not matched to a control ($n = 4429$)
Age		
< 21	120 (0.64)	23 (0.52)
21–30	1974 (8.55)	240 (5.42)
31–40	3606 (19.32)	547 (12.35)
41–50	3822 (20.48)	843 (19.03)
51–60	4846 (25.97)	1165 (26.30)
61–70	2858 (15.31)	878 (19.82)
71–80	1050 (5.63)	491 (11.09)
> 80	386 (2.07)	242 (5.46)
Sex (males)	10,132 (54.29)	2124 (47.96)
Rural (yes)	1798 (9.63)	519 (11.72)
Asthma	3691 (19.78)	1737 (39.22)
Musculoskeletal disorders	8256 (44.24)	3032 (68.46)
behavioural disorders	3582 (19.19)	2152 (48.59)
Cancer	1828 (9.80)	1387 (31.32)
COPD	2353 (12.61)	1706 (38.52)
Diabetes	2215 (11.87)	1518 (34.27)
Fatigue	279 (1.50)	1003 (22.65)
Metabolic disease	2609 (13.98)	2361 (53.31)
Neurlogic disorders	2892 (15.50)	2146 (48.45)
Pain	615 (3.30)	1397 (31.54)

Abbreviations

CIHI: Canadian institutes of health research; ICES: Institute for clinical evaluative sciences; ITS: Interrupted time series; MVC: Motor vehicle crashes; SPOR: Strategy for patient-oriented research; THC: Tetrahydrocannabinol

Acknowledgments

DTE affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and if relevant) have been explained.

Authors' contributions

DTE, JRBD, JGH, EH designed the study and DTE and JRBD acquired the data. DTE and JKMS analyzed the data. CL and DTE drafted the manuscript. All other authors revised it critically for important intellectual content and approved the final version to be published. All authors are accountable for the work and integrity of the work. The corresponding author and guarantor accepts full responsibility of the work and/or conduct of the study, had access to the data and controlled the decision to publish. DTE attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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Availability of data and materials

The dissemination of data results to study participants and or patient organizations in this research project is not possible/applicable. The dissemination of data results to study participants and or patient organizations in this research project is not possible/applicable as the data is de-identified. Moreover, the data is not available as only the researchers authorized by ICES have access to the data.

Declarations

Ethics approval and consent to participate

Research ethics approval was obtained from the University of Alberta Health Research Ethics Board (PRO 00083651) and Veritas Research Ethics Board (Ontario) (16111–13:21:103–01-2017). Informed consent was provided by the patient at the time of first intake, which allows data to be collected and used for clinical and research purposes. These data were provided by the Institute for Clinical Evaluative Sciences (ICES) administrative databases in Ontario and all data was released as de-identified data.

Consent for publication

This study made use of de-identified data from the ICES Data Repository, which is managed by the Institute for Clinical Evaluative Sciences with support from its funders and partners: Canada's Strategy for Patient-Oriented Research (SPOR), the Ontario SPOR Support Unit, the Canadian Institutes of Health Research and the Government of Ontario. The opinions, results and conclusions reported are those of the authors. No endorsement by ICES or any of its funders or partners is intended or should be inferred. Parts of this material are based on data and information compiled and provided by CIHI. However, the analyses, conclusions, opinions and statements expressed herein are those of the author, and not necessarily those of CIHI.

Competing interests

JRBD is a former board member for a major cannbis company. JGH has worked as a paid advisor and speaker for Canadian Cannabis Clinics. JRBD has a financial interest in Aurora Cannabis Inc. DTE and JRBD hold a Mitacs Grant with Aurora as a partner. Mitacs is a national, not-for-profit organization that works with universities, private companies, and both federal and provincial governments, to build partnerships and administer research funding that supports industrial and social innovation in Canada. DTE does not have any past or present financial interest in the companies involved. CL, DV, JKMS, and EH have no conflicts of interest to declare.

Moreover, the above mentioned entities, research funders and companies listed were not involved in any aspect of the design or write-up of the study and all analysis was performed independent from the funders and companies.

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RESEARCH REPORT

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High-'n'-dry? A comparison of cannabis and alcohol use in drivers presenting to hospital after a vehicular collision

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Abstract

Design: This was a prospective observational study.

Background and Aims: The characteristics of cannabis-involved motor vehicle collisions are poorly understood. This study of injured drivers identifies demographic and collision characteristics associated with high tetrahydrocannabinol (THC) concentrations.

Setting: The study was conducted in 15 Canadian trauma centres between January 2018 and December 2021.

Cases: The cases (n = 6956) comprised injured drivers who required blood testing as part of routine trauma care.

Measurements: We quantified whole blood THC and blood alcohol concentration (BAC) and recorded driver sex, age and postal code, time of crash, crash type and injury severity. We defined three driver groups: high THC (THC ≥ 5 ng/ml and BAC = 0), high alcohol (BAC ≥ 0.08% and THC = 0) and THC/BAC-negative (THC = 0 = BAC). We used logistic regression techniques to identify factors associated with group membership.

Findings: Most injured drivers (70.2%) were THC/BAC-negative; 1274 (18.3%) had THC > 0, including 186 (2.7%) in the high THC group; 1161 (16.7%) had BAC > 0, including 606 (8.7%) in the high BAC group. Males and drivers aged less than 45 years had higher adjusted odds of being in the high THC group (versus the THC/BAC-negative group). Importantly, 4.6% of drivers aged less than 19 years had THC ≥ 5 ng/ml, and drivers aged less than 19 years had higher unadjusted odds of being in the high THC group than drivers aged 45–54 years. Males, drivers aged 19–44 years, rural drivers, seriously injured drivers and drivers injured in single-vehicle, night-time or weekend collisions had higher adjusted odds ratios (aORs) for being in the high alcohol group (versus THC/BAC-negative). Drivers aged less than 35 or more than 65 years and drivers involved in multi-vehicle, daytime or weekday collisions had higher adjusted odds for being in the high THC group (versus the high BAC group).

Funding information
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Conclusions: In Canada, risk factors for cannabis-related motor vehicle collisions appear to differ from those for alcohol-related motor vehicle collisions. The collision factors associated with alcohol (single-vehicle, night-time, weekend, rural, serious injury) are not associated with cannabis-related collisions. Demographic factors (young drivers, male drivers) are associated with both alcohol and cannabis-related collisions, but are more strongly associated with cannabis-related collisions.

KEYWORDS
Alcohol, cannabis, motor vehicle collisions, risk factors, tetrahydrocannabinol, THC

INTRODUCTION

Cannabis is the second most commonly used recreational drug in the world after alcohol [1]. Tetrahydrocannabinol (THC), the primary active compound in cannabis, results in slowed reaction time, impaired attention and impaired fine motor skills, making it more difficult to drive straight without 'weaving' [2, 3]. There is epidemiological evidence that drivers with THC concentration ≥ 5 ng/ml are at increased risk of crashing, although the risk is lower than for alcohol [4, 5]. The prevalence of driving after using cannabis has increased in some countries [6, 7], and there is concern that this trend may accelerate as more jurisdictions legalize recreational cannabis [8, 9]. For example, the prevalence of injured drivers with high THC levels in Canada approximately doubled after recreational cannabis was legalized in 2018 [10]. Several factors probably contributed to this increase, which occurred despite new traffic laws designed to prevent cannabis-impaired driving (e.g. introduction of *per se* limits for THC). Many drivers believe that cannabis does not impair driving ability and the perceived risk associated with cannabis use is decreasing [11]. Further, the police have difficulty enforcing laws against cannabis-impaired driving because they seldom identify drivers who used cannabis [12]. Effective education and enforcement programmes to prevent cannabis-impaired driving are needed. Developing such programmes requires knowledge of risk factors for cannabis-impaired driving, especially cases that result in a collision.

There are substantial limitations to prior research on the characteristics of cannabis-involved collisions. Much of this research uses coroner's data; however, postmortem THC concentrations do not reliably correspond with concentrations at time of collision, due to a delay in testing fatally injured drivers who survive the crash for a period of time [13] and postmortem redistribution of THC [14–16]. Roadside surveys provide useful information on substance use by drivers, but typically measure THC in oral fluid (blood is the preferred biological specimen) and generally have high refusal rates, which could bias results if drivers who use cannabis are less likely to participate. Further, almost all previous research characterizes THC as 'present or absent' without consideration of THC concentration. However, low THC concentration does not necessarily indicate recent use of cannabis [17], and there is scant evidence that drivers with blood THC levels < 5 ng/ml are at increased risk of crashing [4, 5]. Some people who regularly use large amounts of cannabis have detectable THC levels that persist for days or even weeks after last use [17]. This phenomenon means that temporal patterns of cannabis use by drivers may be obscured in studies that report the prevalence of drivers with detectable THC levels; a low but detectable level of THC could be from cannabis use days earlier. A more informative approach would be to report on drivers with higher blood THC concentration levels (i.e. THC ≥ 5 ng/ml); THC > 5 ng/ml indicates recent use in occasional cannabis users [18] and in most, but not all, frequent users [17–19]. Further, there is evidence that drivers with THC ≥ 5 ng/ml have increased collision risk, whereas this evidence is lacking for drivers with THC < 5 ng/ml [4, 5].

The aim of this study is to identify characteristics of cannabis-involved collisions and contrast with alcohol-related collisions. Our objectives are to: (1) identify driver and collision factors associated with high THC concentrations in injured drivers; (2) identify factors associated with high BAC in injured drivers; and (3) compare factors in drivers with high THC concentrations versus high alcohol concentrations.

METHODS

This study was approved by institutional research ethics boards (REBs) at all participating sites. This report uses data collected between January 2018 and December 2021 from an ongoing prospective study of moderately injured drivers treated in 15 Canadian emergency departments (EDs) after a crash. Moderate injury was defined pragmatically as meaning that blood work (blood count or electrolyte measurement) was required for clinical assessment. Because we used excess blood remaining after clinical use and had procedures to protect personal information, the REB approved waiver of consent. Detailed methods have been published previously [4, 20, 21]. As the analysis presented in this study was not pre-registered, the results should be considered exploratory.

Study setting

Participating EDs function within regional trauma centres in eight Canadian provinces. According to the 2021 National Census, the total census subdivision of these cities is 10.5 million, which is more than a quarter of the entire Canadian population (38.25 million) [22].

Study procedures

We prospectively identified drivers treated for injuries at participating EDs following a motor vehicle collision (MVC). Injured automobile drivers who had blood obtained within 6 hours of a collision are eligible. Clinicians at participating hospitals obtain blood samples to guide trauma management when there is the evidence that the driver may have severe injuries. This assessment is based on the mechanism of injury (high speed collision, major damage to vehicle) and clinical evidence that the driver is injured (bleeding, unstable vital signs). Drivers with minor injuries after low-risk collisions (e.g. neck stiffness that develops gradually after a low-speed 'fender-bender') do not require blood tests. The decision to obtain blood tests is not based on clinical suspicion of drug use because toxicology testing at participating hospitals is conducted on urine, not on blood. Further, clinicians do not receive the toxicology results from this study. Research assistants identified eligible drivers and obtained excess blood before it was discarded. We froze blood for later toxicology analysis. We excluded drivers with minor injuries who did not require blood work, cases where blood samples were obtained more than 6 hours after the crash and cases with no excess blood available. Research assistants review the medical records of all eligible drivers and record basic demographic, medical and collision information.

Toxicology analysis

The BC Provincial Toxicology Centre conducted broad-spectrum toxicology testing for alcohol, cannabinoids and other recreational drugs (cocaine, amphetamines including designer drugs and opiates), as well as psychotrophic pharmaceuticals (including antihistamines, benzodiazepines, other hypnotics and sedating antidepressants). Detection limits were 0.2 ng/ml for THC and 1 ng/ml for other drugs. In most cases, samples consisted of whole blood. In a small number of cases, only plasma specimens were obtained. In this case, plasma results were adjusted to equivalent whole blood results according to international standards [23, 24].

Analysis

We considered the following demographic and collision risk factors: sex, age range (< 19, 19–24, 25–34, 35–44, 45–54, 55–64, 65–74, ≥75 years), residential postal code (urban delivery area, rural delivery area), time of day in 4-hour blocks (06:01–10:00, 10:01–14:00, 14:01–18:00, 18:01–22:00, 22:01–02:00, 02:01–06:00), day of week (weekend, Friday after 6 p.m. until midnight Sunday, or holiday; weekday), year (2018, 2019, 2020, 2021), season (Spring, Summer, Autumn, Winter), crash type (single-vehicle, multi-vehicle) and injury severity (admitted to hospital, discharged from ED). Postal codes with a zero in the second digit were considered rural, based on Canada Post's classification of delivery areas [25]. We also reported descriptive statistics for the following toxicological factors: presence of stimulants, presence of sedatives and presence of opioids.

We classified drivers as high THC (THC ≥ 5 ng/ml and BAC = 0), high alcohol (BAC ≥ 0.08% and THC = 0) and THC/BAC-negative (THC = 0 and BAC = 0). We fitted three mixed-effects logistic regression models. The first model had high THC as the outcome (THC ≥ 5 ng/ml versus THC = 0 among drivers with BAC = 0) and addressed objective 1; the second model had high alcohol as the outcome (BAC ≥ 0.08% versus BAC = 0 among drivers with THC = 0) and addressed objective 2. To compare factors associated with membership in the high THC versus high alcohol group (objective 3), the third model had high THC as an outcome and was restricted to drivers in either the high THC or the high alcohol group.

The models included a random intercept term for hospital site to account for correlation arising between drivers in the same region. All potential predictors (age, sex, postal code type, time of day, day of week, year, season, type of collision, injury severity) were included in the models as fixed effects. As there were fewer drivers in the high THC group compared with the high alcohol group, we simplified categorizations of age group and time of day in models 1 and 3 to reduce the number of parameters and avoid model convergence issues. In particular, drivers aged less than 25 years were combined into a single age group. We ran additional logistic regression models with only one independent variable at a time to calculate unadjusted odds ratios (uORs) associated with granular age and time of day categories in the high THC group.

Four predictors had missing values (6.0% for postal code, 2.0% for time of day, 1.7% for injury severity and < 0.1% for type of collision), and 7.2% of all injured drivers had at least one missing predictor. We used multiple imputation (MI) with fully conditional specification via the 'mice' package in R to handle missing data [26]. Binary incomplete predictors (postal code, type of collision and injury severity) were imputed using a logistic model with hospital site as a random intercept. Time of day was imputed using a proportional odds logistic regression model with hospital site as a fixed effect, as the mice package does not currently support mixed models for ordered data. All imputation models included gender, exact age (in years), postal code, year, season, alcohol level (BAC = 0, 0 < BAC < 0.08%, BAC ≥ 0.08%) and THC level (THC = 0, 0 < THC < 5 ng/ml, THC ≥ 5 ng/ml). The following auxiliary variables were associated with incomplete predictors and included in select imputation models: time between crash and blood draw (for injury severity and postal code), an indicator for whether medications were given (for injury severity) and an indicator for whether head computerized tomography (CT) scan was performed during the emergency visit (for injury severity and postal code). We generated 10 imputed data sets using 30 iterations. Convergence was verified using trace plots of estimates throughout iterations. The outcome models for high alcohol, high THC and high THC versus high alcohol were fitted to each imputed data set, and then estimates were pooled according to Rubin's Rule [27]. We also performed a sensitivity analysis using complete cases. Models were checked for multicollinearity using generalized variance inflation factors, which were all less than two. We report pooled adjusted odds ratios (aORs) and 95%

confidence intervals (95% CIs) for all potential predictors. *P*-values were computed using likelihood ratio tests comparing nested models with and without the predictor of interest.

All analyses were performed in R version 4.0.3 [28]. *P*-values < 0.05 were considered statistically significant. No adjustments were made for multiple comparisons.

TABLE 1 Characteristics of included drivers and collisions.

	All drivers	BAC/THC-negative (THC = 0 and BAC = 0)	High alcohol (BAC ≥ 0.08% and THC = 0)	High THC (THC ≥ 5 ng/ml and BAC = 0)
Group size	6956 (100.0%)	4882 (100.0%)	606 (100.0%)	186 (100.0%)
Sex				
Male	4703 (67.6%)	3099 (63.5%)	457 (75.4%)	144 (77.4%)
Age group (years)				
< 19	237 (3.4%)	163 (3.3%)	14 (2.3%)	8 (4.3%)
19–24	919 (13.2%)	494 (10.1%)	92 (15.2%)	38 (20.4%)
25–34	1609 (23.1%)	951 (19.5%)	207 (34.2%)	65 (34.9%)
35–44	1152 (16.6%)	784 (16.1%)	124 (20.5%)	32 (17.2%)
45–54	1045 (15.0%)	815 (16.7%)	76 (12.5%)	12 (6.5%)
55–64	1026 (14.7%)	805 (16.5%)	72 (11.9%)	18 (9.7%)
65–74	574 (8.3%)	495 (10.1%)	16 (2.6%)	12 (6.5%)
≥ 75	394 (5.7%)	375 (7.7%)	5 (0.8%)	1 (0.5%)
Postal code				
Urban delivery area	5672 (81.5%)	4088 (83.7%)	449 (74.1%)	152 (81.7%)
Rural delivery area	867 (12.5%)	525 (10.8%)	112 (18.5%)	24 (12.9%)
Unknown	417 (6.0%)	269 (5.5%)	45 (7.4%)	10 (5.4%)
Crash				
Single-vehicle	2875 (41.3%)	1656 (33.9%)	448 (73.9%)	86 (46.2%)
Multi-vehicle	4078 (58.6%)	3224 (66.0%)	157 (25.9%)	100 (53.8%)
Unknown	3 (0.0%)	2 (0.0%)	1 (0.2%)	0 (0.0%)
Time				
Daytime (06:01–18:00)	4197 (60.3%)	3263 (66.8%)	165 (27.2%)	113 (60.8%)
Night-time (18:01–06:00)	2621 (37.7%)	1528 (31.3%)	420 (69.3%)	73 (39.2%)
Unknown	138 (2.0%)	91 (1.9%)	21 (3.5%)	0 (0.0%)
Time in 4-hour blocks				
06:01–10:00	1024 (14.7%)	783 (16.0%)	45 (7.4%)	24 (12.9%)
10:01–14:00	1299 (18.7%)	1039 (21.3%)	35 (5.8%)	37 (19.9%)
14:01–18:00	1874 (26.9%)	1441 (29.5%)	85 (14.0%)	52 (28.0%)
18:01–22:00	1334 (19.2%)	876 (17.9%)	135 (22.3%)	45 (24.2%)
22:01–02:00	816 (11.7%)	426 (8.7%)	178 (29.4%)	16 (8.6%)
02:01–06:00	471 (6.8%)	226 (4.6%)	107 (17.7%)	12 (6.5%)
Unknown	138 (2.0%)	91 (1.9%)	21 (3.5%)	0 (0.0%)
Day				
Weekday	4470 (64.3%)	3349 (68.6%)	277 (45.7%)	117 (62.9%)
Weekend or holiday	2486 (35.7%)	1533 (31.4%)	329 (54.3%)	69 (37.1%)
Injury severity				
Discharged	4347 (62.5%)	3188 (65.3%)	334 (55.1%)	117 (62.9%)
Admitted	2493 (35.8%)	1613 (33.0%)	256 (42.2%)	69 (37.1%)
Unknown	116 (1.7%)	81 (1.7%)	16 (2.6%)	0 (0.0%)

Abbreviations: BAC, blood alcohol concentration; THC, tetrahydrocannabinol.

RESULTS

During the course of the study, 17 379 injured drivers were screened and 6956 met inclusion/exclusion criteria (Supporting information, Figure S1). The most common reasons for exclusion were: (i) no blood tests ordered (n = 7746), (ii) blood obtained more than 6 hours after crash (n = 1554) and (iii) excess blood not available (n = 1061). Table 1 shows the characteristics of included drivers; additional information is provided in Supporting information, Table S1. Supporting information, Table S2 compares characteristics of included and excluded drivers. Two-thirds of included drivers (67.6%) were male and the median age was 40 years [interquartile ratio (IQR) = 28–57]. Most collisions occurred during the day (60.3%), and most were multi-vehicle crashes (58.6%). One-third (35.8%) of drivers required overnight hospital admission. Just over two-thirds of included drivers (70.2%) tested negative for both alcohol and THC (BAC/THC-negative group). Seventeen per cent of all drivers (1161/6956) tested positive for alcohol, 873 (12.6%) had BAC ≥ 0.08% and 606 (8.7%) were in the high alcohol group (BAC ≥ 0.08% and THC = 0). Eighteen per cent of all drivers (1274/6956) tested positive for THC, 246 (3.5%) had THC ≥ 5 ng/ml and 186 (2.7%) were in the high THC group (THC ≥ 5 ng/ml and BAC = 0). Forty-one drivers (0.6%) had both BAC ≥ 0.08% and THC ≥ 5 ng/ml. Of the 237 drivers aged less than 19 years, 11 (4.6%) had THC ≥ 5 ng/ml and 26 (3.0%) had BAC ≥ 0.08% (Supporting information, Table S1).

TABLE 2 Pooled risk factor associations for high THC (THC ≥ 5 ng/ml and BAC = 0) versus BAC/THC-negative.

	High THC versus BAC/THC-negative (THC ≥ 5 ng/ml and BAC = 0 versus BAC = 0 and THC = 0)				
		Unadjusted[b]		Adjusted[b,c]	
	Count (%) with outcome[a]	uOR[d] (95% CI)	*P*-value[d]	aOR[d] (95% CI)	*P*-value[d]
Sex					
Male	144/3243 (4.4%)	1.94 (1.37, 2.75)	*P* < 0.0001	1.94 (1.36, 2.78)	*P* = 0.0002
Female (ref.)	42/1825 (2.3%)	(ref.)		(ref.)	
Age group (years)					
< 25	46/703 (6.5%)	3.70 (2.32, 5.90)	*P* < 0.0001	3.90 (2.42, 6.27)	*P* < 0.0001
25–34	65/1016 (6.4%)	3.77 (2.43, 5.86)		4.08 (2.62, 6.36)	
35–44	32/816 (3.9%)	2.25 (1.36, 3.72)		2.41 (1.45, 4.00)	
45–64 (ref.)	30/1650 (1.8%)	(ref.)		(ref.)	
≥ 65	13/883 (1.5%)	0.81 (0.42, 1.55)		0.84 (0.44, 1.62)	
Postal code					
Urban (ref.)	160/4464 (3.6%)	(ref.)	*P* = 0.83	(ref.)	*P* = 0.77
Rural	26/604 (4.3%)	0.95 (0.60, 1.50)		0.93 (0.58, 1.50)	
Crash					
Single-vehicle	86/1743 (4.9%)	1.50 (1.11, 2.02)	*P* = 0.01	1.31 (0.96, 1.79)	*P* = 0.10
Multi-vehicle (ref.)	100/3325 (3.0%)	(ref.)		(ref.)	
Time					
Daytime (ref.)	113/3431 (3.3%)	(ref.)	*P* = 0.04	(ref.)	*P* = 0.71
Night-time	73/1637 (4.5%)	1.38 (1.02, 1.87)		1.06 (0.77, 1.45)	
Day					
Weekday (ref.)	117/3466 (3.4%)	(ref.)	*P* = 0.13	(ref.)	*P* = 0.39
Weekend or holiday	69/1602 (4.3%)	1.27 (0.94, 1.71)		1.15 (0.84, 1.57)	
Injury severity					
Discharged (ref.)	117/3374 (3.5%)	(ref.)	*P* = 0.51	(ref.)	*P* = 0.26
Admitted	69/1694 (4.1%)	1.11 (0.81, 1.53)		1.21 (0.87, 1.67)	

Note: This table shows pooled unadjusted (uOR) and adjusted odds ratios (aOR) with 95% confidence intervals (95% CI) from a mixed-effects logistic regression model where the outcome is high THC = 1 and BAC/THC-negative = 0.

Abbreviations: BAC, blood alcohol concentration; THC, tetrahydrocannabinol.

[a]Estimates from imputed data sets were pooled according to Rubin's Rule.

[b]Models (both adjusted and unadjusted) include a random intercept for hospital site. The pooled intraclass correlation coefficient (ICC) was 0.07 for the adjusted model.

[c]Although estimates are not shown, adjusted models also include season and year as fixed effects.

[d]*P*-values were obtained via likelihood ratio tests comparing models with and without the variable of interest.

Table 2 and Figure 1 show risk factors for membership in the high THC group. The key findings are that, among drivers with BAC = 0 and THC either 0 or ≥ 5 ng/ml, males and drivers aged less than 45 years have higher odds of having THC ≥ 5 ng/ml (versus THC = 0). In an unadjusted model with age group only, drivers aged 19 years had higher unadjusted odds than drivers aged 45–54 years of being in the high THC group (uOR = 3.03; 95% CI = 1.22–7.53).

Table 3 and Figure 2 show risk factors for membership in the high alcohol group. The key findings are that, among drivers with THC = 0 and BAC either 0 or ≥ 0.08%, males, drivers aged 19–44 years, rural drivers, seriously injured drivers (requiring hospital admission) and drivers involved in single-vehicle crashes, night-time crashes or weekend/holiday crashes had higher odds having high BAC, whereas drivers aged less than 19 years or more than 64 years had lower odds.

Supporting information, Table S3 and Figure S2 show risk factors for membership in the high THC group among drivers in either the high THC group or high alcohol group. The main findings are that, among drivers with either THC ≥ 5 ng/ml and BAC = 0 or BAC ≥ 0.08% and THC = 0, drivers aged less than 35 or more than 65 years had higher odds of having high THC, whereas drivers involved in single-vehicle crashes or night-time crashes had lower odds.

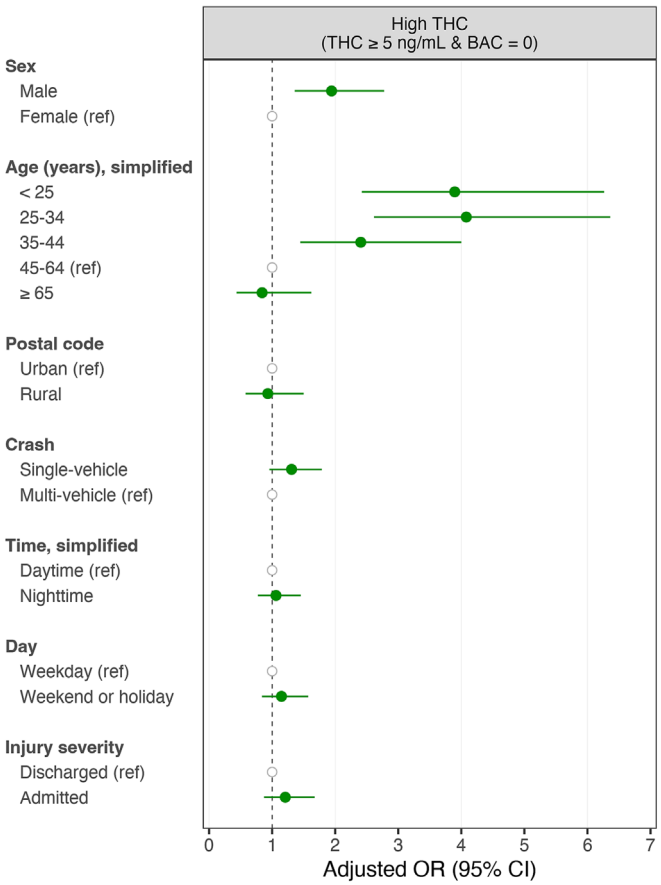

FIGURE 1 Risk factors for membership in high tetrahydrocannabinol (THC) group [THC ≥ 5 ng/ml and blood alcohol concentration (BAC) = 0].

Sensitivity analyses on complete cases yielded similar results (Supporting information, Figure S2).

DISCUSSION

We prospectively studied 6956 moderately injured drivers treated in 15 Canadian trauma centres and analyzed their blood to measure alcohol, THC and other impairing substances. Consistent with recent Canadian research [29, 30], we found that more drivers tested positive for THC (18.3%) than for alcohol (16.7%). However, it is important to note that low THC levels do not necessarily represent recent use because THC, especially at low levels, can be detected in the blood of regular cannabis users for days after last use [17]. Further, there is little evidence at the population level that drivers with THC < 5 ng/ml are at increased risk of collisions [4, 5]. Drivers with THC ≥ 5 ng/ml may be at increased risk of crashing, but the risk is lower than for drivers with BAC ≥ 0.08% [4, 5, 31]. In this sample, there were more than three times as many drivers with BAC ≥ 0.08% (12.6%) than with THC ≥ 5 ng/ml (3.5%), suggesting that alcohol remains a greater threat to road safety.

A large body of research shows that drinking and driving are more common in males and in younger drivers. Consistent with this research, we found that male drivers were more likely than female drivers to have high BAC and that drivers aged 19–44 years were more likely to have high BAC than drivers aged 45–54 years. The youngest group of drivers (aged less than 19 years) had significantly lower odds than reference drivers (aged 45–64 years) of being in the high alcohol group. This finding probably reflects the impact of anti-drinking and driving education campaigns that target young drivers combined with zero tolerance laws for drinking and driving in novice drivers in most provinces. Unfortunately, we found that 3.0% of drivers in this age group had BAC ≥ 0.08%, which is very concerning, given the high risk of crashing in young drinking drivers [32].

The demographics of drivers who use cannabis are less well-established than for drinking drivers, although it appears that cannabis use is also more common in male drivers and in younger drivers [30]. Consistent with this research, we found that male drivers and drivers aged less than 45 years had higher odds of being in the high THC group. We were particularly interested in THC use in drivers aged less than 19 years. Even when not impaired, young inexperienced drivers are at higher risk of crashing, per distance driven, than middle-aged drivers [33, 34]. There is little research on the impairing effects of cannabis in this age group but, as is the case with alcohol [32], it is likely that young drivers are particularly susceptible to the impairing effects of cannabis and at higher risk of collision after using it. We hoped to find that cannabis use would be uncommon in young drivers, because Canadian law does not permit cannabis use before the age of 18 and because most provinces have zero-tolerance laws for cannabis use in novice drivers (generally aged less than 19 years). Contrary to this expectation, we found that 4.6% of drivers aged less than 19 years had THC ≥ 5 ng/ml (Supporting information, Table S1). Further, in an unadjusted model with age group only, drivers aged less than 19 years

TABLE 3 Pooled risk factor associations for high alcohol (BAC ≥ 0.08% and THC = 0) versus BAC/THC-negative.

	High alcohol versus BAC/THC-negative (BAC ≥ 0.08% and THC = 0 versus BAC = 0 and THC = 0)				
		Unadjusted[b]		Adjusted[b,c]	
	Count (%) with outcome[a]	uOR[d] (95% CI)	*P*-value[d]	aOR[d] (95% CI)	*P*-value[d]
Sex					
Male	457/3556 (12.9%)	1.66 (1.37, 2.02)	*P* < 0.0001	1.29 (1.03, 1.60)	*P* = 0.02
Female (ref.)	149/1932 (7.7%)	0.09 (0.07, 0.12)			
Age group (years)					
< 19	14/177 (7.9%)	0.89 (0.49, 1.62)	*P* < 0.0001	0.49 (0.25, 0.93)	*P* < 0.0001
19–24	92/586 (15.7%)	1.99 (1.44, 2.76)		1.51 (1.06, 2.16)	
25–34	207/1158 (17.9%)	2.42 (1.83, 3.21)		2.04 (1.50, 2.78)	
35–44	124/908 (13.7%)	1.74 (1.28, 2.36)		1.66 (1.19, 2.32)	
45–54 (ref.)	76/891 (8.5%)	(ref.)		(ref.)	
55–64	72/877 (8.2%)	0.96 (0.69, 1.35)		1.06 (0.73, 1.53)	
65–74	16/511 (3.1%)	0.35 (0.20, 0.61)		0.40 (0.22, 0.71)	
≥ 75	5/380 (1.3%)	0.14 (0.06, 0.36)		0.19 (0.07, 0.48)	
Postal code					
Urban (ref.)	484/4788 (10.1%)	(ref.)	*P* = 0.0003	(ref.)	*P* = 0.0004
Rural	122/700 (17.4%)	1.60 (1.25, 2.04)		1.69 (1.28, 2.24)	
Crash					
Single-vehicle	449/2106 (21.3%)	5.27 (4.34, 6.40)	*P* < 0.0001	4.19 (3.40, 5.16)	*P* < 0.0001
Multi-vehicle (ref.)	157/3382 (4.6%)	(ref.)		(ref.)	
Time					
06:01–10:00 (ref.)	46/844 (5.5%)	(ref.)	*P* < 0.0001	(ref.)	*P* < 0.0001
10:01–14:00	38/1094 (3.5%)	0.61 (0.39, 0.96)		0.63 (0.39, 1.01)	
14:01–18:00	90/1556 (5.8%)	1.03 (0.70, 1.49)		1.05 (0.71, 1.55)	
18:01–22:00	141/1035 (13.6%)	2.64 (1.85, 3.78)		2.10 (1.45, 3.05)	
22:01–02:00	183/620 (29.5%)	6.86 (4.83, 9.74)		5.24 (3.62, 7.58)	
02:01–06:00	108/340 (31.8%)	7.80 (5.30, 11.48)		4.44 (2.94, 6.69)	
Day					
Weekday (ref.)	277/3626 (7.6%)	(ref.)	*P* < 0.0001	(ref.)	*P* < 0.0001
Weekend or holiday	329/1862 (17.7%)	2.57 (2.16, 3.05)		2.07 (1.71, 2.52)	
Injury severity					
Discharged (ref.)	347/3604 (9.6%)	(ref.)	*P* = 0.02	(ref.)	*P* = 0.01
Admitted	259/1884 (13.7%)	1.24 (1.03, 1.49)		1.34 (1.09, 1.66)	

Note: This table shows pooled unadjusted (uOR) and adjusted odds ratios (aOR) with 95% confidence intervals (95% CI) from a mixed-effects logistic regression model where the outcome is high alcohol = 1 and BAC/THC-negative = 0.

Abbreviations: BAC, blood alcohol concentration; THC, tetrahydrocannabinol.

[a]Estimates from imputed data sets were pooled according to Rubin's Rule.

[b]Models (both adjusted and unadjusted) include a random intercept for hospital site. The pooled intraclass correlation coefficient (ICC) was 0.02 for the adjusted model.

[c]Although estimates are not shown, adjusted models also include season and year as fixed effects.

[d]*P*-values were obtained via likelihood ratio tests comparing models with and without the variable of interest.

had higher odds of being in the high THC group (uOR = 3.03) than drivers aged 45–54 years. These findings are concerning; they suggest that current Canadian laws are not effective in deterring young people from using cannabis and driving. It is possible that public messaging about the risks of driving after using cannabis has not successfully reached its intended audience [35, 36]. Further research is required to identify and evaluate measures designed to prevent cannabis-impaired driving in this high-risk age group.

Collision factors were more strongly associated with high alcohol levels than with high THC levels. Drivers involved in single-vehicle (versus multi-vehicle) collisions, night-time (versus daytime) collisions or weekend/holiday (versus weekday) collisions and drivers involved

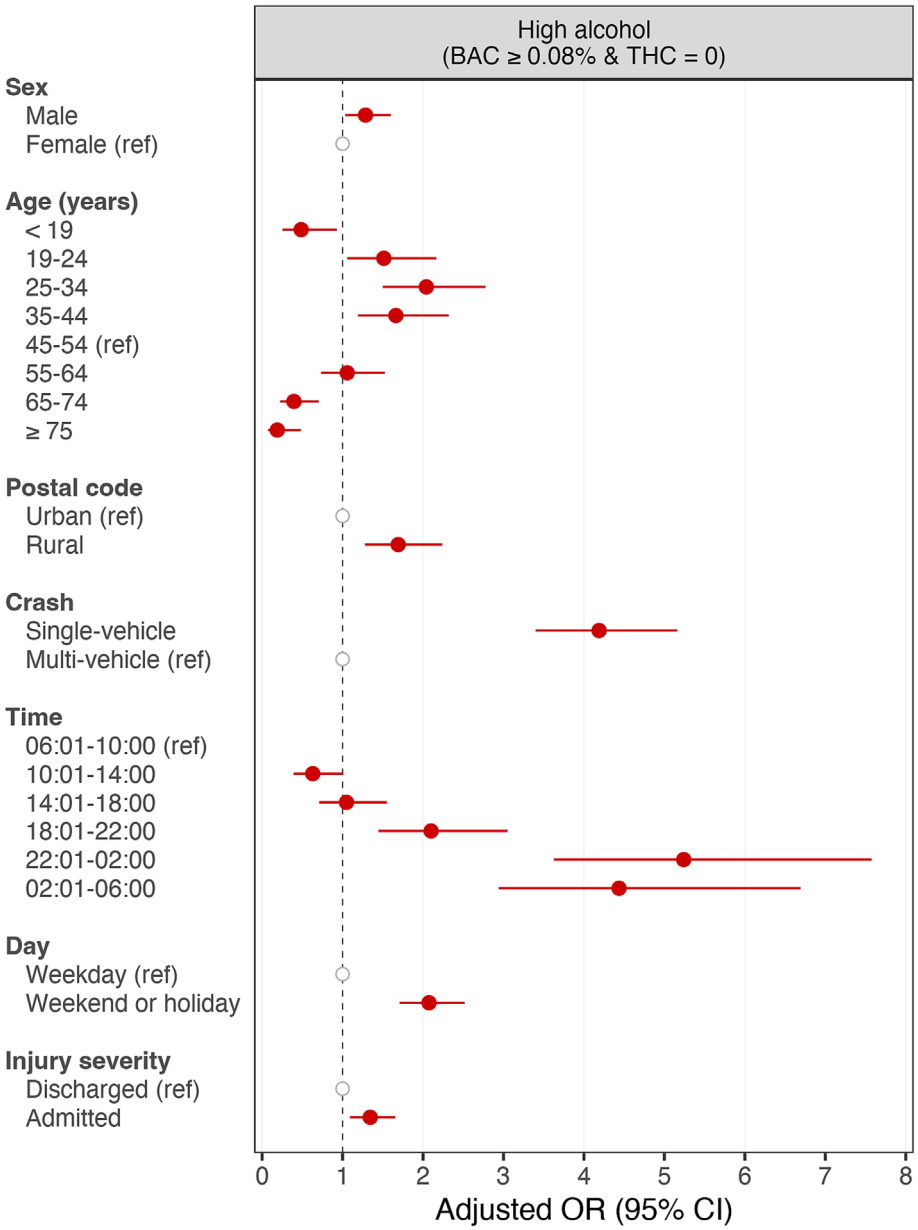

FIGURE 2 Risk factors for membership in high alcohol group [blood alcohol concentration (BAC) ≥ 0.08% and tetrahydrocannabinol (THC) = 0].

in serious injury collisions (versus those discharged home from the ED) all had higher odds of being in the high alcohol group. This suggests that proxy measures for alcohol-impaired driving, such as single-vehicle night-time crashes [37], are not reliable indicators of cannabis-impaired driving. These differences should also be considered when developing enforcement measures that target cannabis-impaired driving; traditional night-time sobriety checks that deter alcohol-impaired driving [38], for example, may be less effective for deterring cannabis-impaired drivers. The strong associations between alcohol and single-vehicle collisions probably reflect the strong impairing effects of alcohol (resulting in increased risk of collision even in low-volume traffic), together with the fact that alcohol use is more common at night when fewer vehicles are on the roads. In the adjusted analysis, none of these collision factors were associated with increased odds of drivers being in the high THC group. The fact that single-vehicle collisions were strongly associated with BAC ≥ 0.08% but not with THC ≥ 5 ng/ml is probably because of the more modest collision risk associated with cannabis [4, 5, 31], combined with the fact that drivers with high THC concentrations were found both during the day (when traffic is heavier and multi-vehicle collisions are more common) and at night.

Strengths

This study has several important strengths. Blood tests were obtained to guide trauma management and we conducted toxicology testing on all drivers for whom excess blood was available. This process minimized the selection bias that would occur if we reviewed medical records and recorded toxicology results from tests ordered by

clinicians. Further, we received REB approval for waiver of consent because we used 'left-over' blood samples and had strict measures to protect personal information; waiver of consent allowed us to avoid the refusal bias that would occur if drivers who used drugs or alcohol were less likely to participate. As THC concentrations decline rapidly after smoking cannabis, another strength of our study is that blood samples were obtained shortly after the collision, with a median time of 94 minutes. We included drivers treated in 15 trauma centres from across Canada, making our results more generalizable than if we had included only a few hospitals. Data were collected prospectively over a 4-year period, which mitigates the risk of having results skewed by transient events that may temporarily impact substance use, such as celebrations centred around cannabis legalization.

Limitations

Our study also has some limitations. Our methods did not allow us to interview drivers (this would require informed consent and make it probable that drivers who used cannabis or alcohol would be more likely to decline to participate). As a result, we do not know when cannabis was last used by the driver, the route of ingestion (e.g. inhaled or ingested) or the driver's pattern of cannabis use. As our methods excluded minor collisions that did not require blood tests and off-road vehicle crashes, our findings may not apply to these crashes. The study period included the COVID-19 pandemic, which may have impacted drug and alcohol use in some drivers due to stay-at-home orders, closures or reduced hours of bars and changes in how police enforced traffic laws (e.g. reduced use of breathalyzers due to concerns of spreading an airborne disease).

CONCLUSIONS

We studied crash-involved drivers and identified driver and crash characteristics associated with high THC or high alcohol levels. The odds of having THC ≥ 5 ng/ml was increased in male drivers and in drivers aged less than 45 years, including drivers aged less than 19 years, but not in night-time or weekend drivers, single-vehicle crashes, seriously injured drivers or rural drivers. We found increased odds of having BAC ≥ 0.08% in male drivers, drivers aged 19–44 (but not drivers aged less than 19 years), rural drivers, seriously injured drivers, drivers involved in single-vehicle crashes and drivers involved in night-time or weekend crashes.

AUTHOR CONTRIBUTIONS

Jeff Brubacher: Conceptualization; funding acquisition; methodology; project administration; supervision; writing—original draft. **Herbert Chan:** Data curation; methodology; project administration; writing—review and editing. **Shannon Erdelyi:** Data curation; formal analysis; methodology; writing—review and editing. **Yue Yuan:** Project administration; writing—review and editing. **Raoul Daoust:** Project administration; writing—review and editing. **Christian Vaillancourt:** Project administration; writing—review and editing. **Brian H. Rowe:** Project administration; writing—review and editing. **Jacques Lee:** Project administration; writing—review and editing. **Eric Mercier:** Project administration; writing—review and editing. **Paul Atkinson:** Project administration; writing—review and editing. **Phillip Davis:** Project administration; writing—review and editing. **Davis Clarke:** Project administration; writing—review and editing. **John Taylor:** Project administration; writing—review and editing. **Andrew Macpherson:** Project administration; writing—review and editing. **Marcel Emond:** Project administration; writing—review and editing. **Durr Al-Hakim:** Project administration; writing—review and editing. **Chrystal Horwood:** Project administration; writing—review and editing. **Ian Wishart:** Project administration; writing—review and editing. **Kirk Magee:** Project administration; writing—review and editing. **Jagadish Rao:** Project administration; writing—review and editing. **Jeffrey Eppler:** Methodology; project administration; writing—review and editing.

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DECLARATION OF INTERESTS

None.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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