SPECIAL ARTICLE

Cannabis Legalization and Detection of Tetrahydrocannabinol in Injured Drivers

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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.)

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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]

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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 information, 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 postlegalization 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-

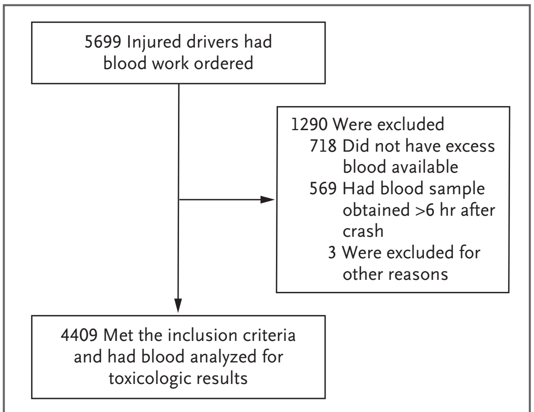

Figure 1. **Study Participants.**

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.

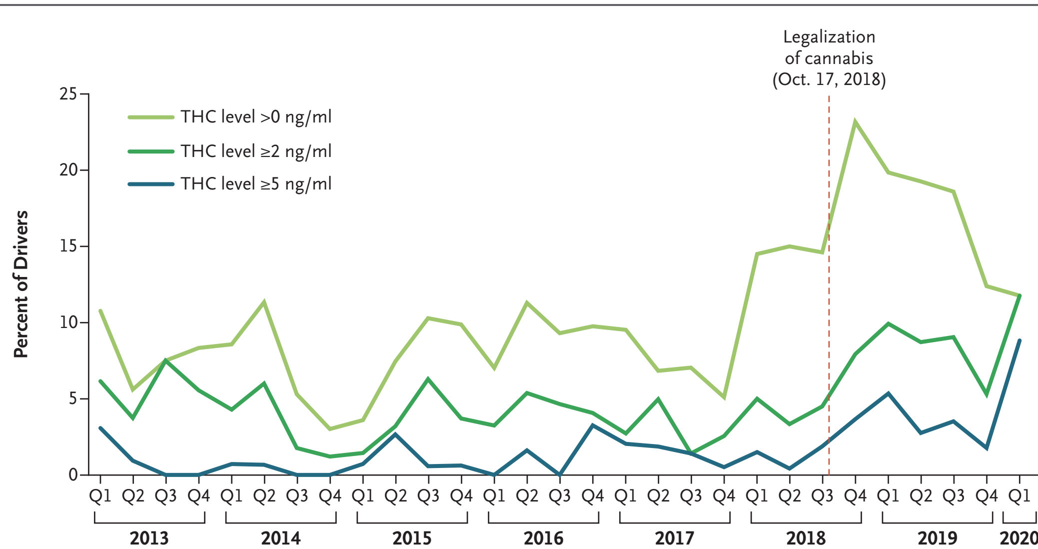

Figure 2. Quarterly Time Series Showing Tetrahydrocannabinol (THC) Levels in Moderately Injured Drivers.

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).

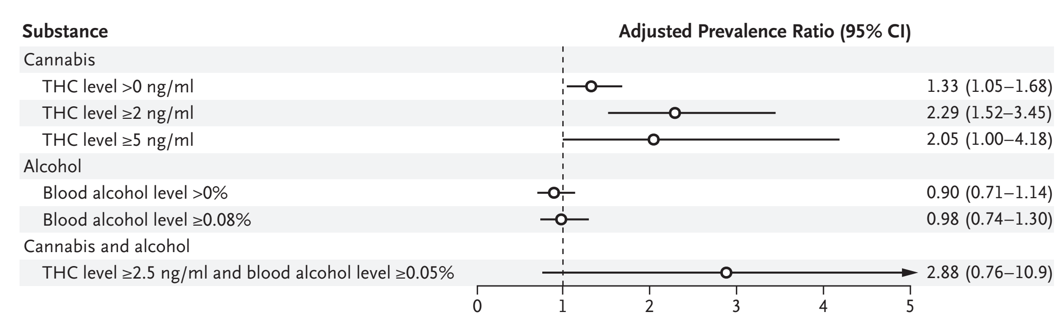

Figure 3. Adjusted Prevalence Ratios for Effects of Cannabis Legalization on Substance Use among Moderately Injured Drivers.

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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Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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