


Driving under the influence: a multi-center evaluation of vehicular crashes in the era of cannabis legalization

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ABSTRACT

Background Eleven states have instituted laws allowing recreational cannabis use leading to growing public health concerns surrounding the effects of cannabis intoxication on driving safety. We hypothesized that after the 2016 legalization of cannabis in California, the use among vehicular injury patients would increase and be associated with increased injury severity.

Methods San Diego County's five adult trauma center registries were queried from January 2010 to June 2018 for motor vehicle or motorcycle crash patients with completed toxicology screens. Patients were stratified as toxicology negative (TOX-), positive for only THC (THC+), only blood alcohol >0.08% (ETOH+), THC+ETOH, or THC+ with any combination with methamphetamine or cocaine (M/C). County medical examiner data were reviewed to characterize THC use in those with deaths at the scene of injury.

Results Of the 11,491 patients identified, there were 61.6% TOX-, 11.7% THC+, 13.7% ETOH+, 5.0% THC+ETOH, and 7.9% M/C. THC+ increased from 7.3% to 14.8% over the study period and peaked at 14.9% post-legalization in 2017. Compared with TOX- patients, THC+ patients were more likely to be male and younger. THC+ patients were also less likely to wear seatbelts (8.5% vs 14.3%, $p<0.001$) and had increased mean Injury Severity Score (8.4±9.4 vs 9.0±9.9, $p<0.001$) when compared with TOX- patients. There was no difference in in-hospital mortality between groups. From the medical examiner data of the 777 deaths on scene, 27% were THC+.

Discussion THC + toxicology screens in vehicular injury patients peaked after the 2016 legalization of cannabis. Public education on the risks of driving under the influence of cannabis should be a component of injury prevention initiatives.

Level of evidence III, Prognostic

BACKGROUND

Of the 33 states in the USA that have legalized marijuana, 11 have instituted laws allowing for use of recreational cannabis. In these states, cannabis use has increased significantly compared with states that have not legalized cannabis.¹ There is evidence showing that cannabis has therapeutic properties in the treatment of chronic pain, as an antiemetic in the treatment of chemotherapy-induced nausea and vomiting, and for improving patient-reported

multiple sclerosis spasticity symptoms.²⁻⁴ Further, as recreational and medicinal cannabis becomes more popular, it is increasingly viewed as harmless.^{5 6} However, cannabis use can lead to impairment of learning, memory, and attention.^{2 7-12}

Recent evidence suggests that there may be an association between cannabis use and an increased risk of motor vehicle crashes.^{2 13 14} Several studies have demonstrated an association between cannabis intoxication and impaired driving ability, as well as increased risk of motor vehicle crashes, fatal collisions, and driver culpability.¹⁵⁻¹⁸ A study conducted in Hawaii demonstrated that THC-positive patients were less likely to use protective devices.¹⁹ Cannabis positivity in trauma patients has also been shown to be associated with increased hospital length of stay, intensive care unit days, ventilator days, and a greater number of operative interventions.^{20 21} Conversely, studies by Movig and Longo reported that marijuana intoxication may not even be associated with an increased risk of motor vehicle crashes.^{22 23}

In 2016, the recreational use of cannabis was legalized in California. With a lack of consensus on the risks related to operating a vehicle while under the influence of cannabis, and increasing legalization, it is imperative to define the relationship between cannabis use and vehicular crashes. The goal of this study is to describe, among those patients undergoing toxicology screening, the prevalence of cannabis positivity after vehicular crashes in San Diego County and to assess associations between cannabis use and outcomes in injured patients. We hypothesized that after the 2016 legalization, cannabis use would increase in vehicular injury patients and be associated with increased injury severity.

METHODS

Five San Diego County trauma center registries were queried from January 2010 to June 2018 for motor vehicle (MVC) or motorcycle crash (MCC) patients with completed toxicology screens. All patients 16 years and older meeting these criteria were included in the study. For the purposes of this study, toxicology screening constituted having both blood and urine results completed. A blood alcohol level of >0.08% was considered positive and any urine toxicology positive for THC was considered positive. Patients were stratified into five groups: negative

blood alcohol and urine screening (TOX-), THC positive only (THC+), alcohol positive only (ETOH+), THC and alcohol positive (THC+ETOH), or anyone who tested positive for any combination of toxicology with methamphetamine or cocaine (M/C). Annual toxicology screening rates were obtained from each of the five participating trauma centers. Of note, routine urine toxicology screening included THC, methamphetamines and cocaine at all institutions over the entire study period.

Patient variables included admission age, sex, and race/ethnicity. The data point “race/ethnicity” includes race and ethnicity combined into one categorical data point. Within the dataset, the category Asian/other includes the races Asians, Pacific Islanders, American Indians, and Alaskan Natives; Black includes non-Hispanic Blacks; Hispanic includes race defined as other with Hispanic ethnicity; White includes Non-Hispanic Whites; and Unknown is no race or ethnicity listed. Age and sex were reported as ascribed in the electronic health record. Injury-related data collected included date of injury, mechanism of injury (MVC or MCC), protective equipment (seatbelt and helmet use), and Injury Severity Score (ISS). Additional variables collected included operations and in-hospital mortality.

In addition, San Diego County medical examiner data from 2011 to 2018 were acquired to analyze THC positivity in people who died at the scene of vehicular crashes (MVC or MCC). Patient demographics (age, sex, race) and year of injury were also acquired. This dataset was analyzed separately from the hospital datasets.

The year 2010 was not available from the medical examiner, which is why the dates do not align with the trauma center dataset. However, we chose to include the additional year in the hospital dataset to increase the ability to show trends over time in relation to cannabis legislation and outcomes. The ability to demonstrate differences in the positive outcomes for this study increased with more patients included in our sample.

Ethics

Institutional Review Board (IRB) approval and data use agreements were obtained for all sites. The University of California, San Diego Human Research Protections Program, ID#1 81 506X, served as the central IRB for all centers including UC San Diego School of Medicine and Palomar Medical Center. Additional approvals were obtained for Scripps Hospitals by the Scripps IRB, IRB-15-6721, and Sharp Memorial through the Sharp Center for Research IRB #1912801. This study was approved as exempt from requiring individual patient consent due to the minimal risk and retrospective nature of the study.

Statistical analysis

The cohort as a whole was described with basic summations and percentages. To examine for potential predictors of THC + toxicology, univariate analyses were performed. Age and ISS are skewed hence represented by median values with IQRs; Kruskal-Wallis non-parametric test was used to assess differences in the ISS and age between the study groups. For Kruskal-Wallis analyses, post hoc pairwise comparisons were performed with Bonferroni correction for multiple tests. Pearson χ^2 was used to assess for differences between groups for categorical variables sex, race, mechanism, use of safety devices, operative interventions, and mortality. Using TOX- as the reference group, binomial logistic regressions were used to characterize the association of THC positivity differences between study groups adjusting for other variables in the model; including for sex, mechanism, seatbelt use, helmet use, operative interventions and mortality.

Table 1 Cohort demographics

Characteristic	Number of patients	
Total no	11,491	
Age (median/LQ-UQ)	34	24–51
Sex (male)	7427	65.5%
Race/ethnicity		
Asian/other	1518	13.2%
Black	968	8.4%
Hispanic	3814	33.2%
Unknown	245	2.1%
White	4945	43.0%
Mechanism		
MV occupant	8443	73.5%
Seatbelt	6512	77.1%
No seatbelt	1023	12.1%
Other/unknown	908	10.8%
Motorcycle	3048	26.5%
Helmet	2697	88.5%
No helmet	281	9.2%
Unknown	70	2.3%
ISS (median/LQ-UQ)	5	2–11
ICU admissions	2412	21%
Operations	2950	25.7%
Outcome (mortality)	170	1.5%

ICU, intensive care unit; ISS, Injury Severity Score; LOS, length of stay; MV, motor vehicle.

Multivariate logistic regression was used to assess for toxicology results as predictors of our primary outcome measure injury severity. ISS of 1–8 was used as the reference range to compare the subgroup ISS ranges of 9–14, 15–25, and >25. TOX- was the reference group for the toxicology +subgroups.

Pearson correlations were used to assess differences in any THC positivity rate over time in increments of months as well as before and after legislation in 2016. Time-series regression analysis was performed to further assess the significance. To assess the impact of the January 2016 legalization on THC use over time, a linear regression was performed to assess percent positivity by including an interaction term for pre/post legislation by month.

Statistical analysis was conducted using SPSS Statistics V.26.0.0.0.

RESULTS

Trauma center data

There were 11,491 patients from five trauma centers included in the study who had toxicology screening performed at admission. Overall, the average rate of toxicology screening during the study period was 59.4% SD 3.3%. This rate changed during the course of the study, starting at 58.7% in 2010 with a steep increase to 67.0% in 2018. However, the intervening years had minimal change compared with the 2010 rate of 58.7%, ranging from screening rates of 56.8% to 60.7%. Vehicular injury patients included in the study were predominantly male (65.5%) with 73.5% involved in an MVC and 26.5% MCC (table 1).

Toxicology screening found that 61.6% were identified as TOX-, 11.7% THC+, 13.7% ETOH+, 5.0% THC +ETOH, and 7.9%M/C. Compared with TOX- patients with a median age of 38 years (LQ-UQ 25–56), THC + patients were younger with a median age of 27 years (LQ-UQ 21–39), $p < 0.001$. The highest proportion of patients under the age of 35 were in the THC + and THC +ETOH groups (68.2% and 77.9%, respectively), which are

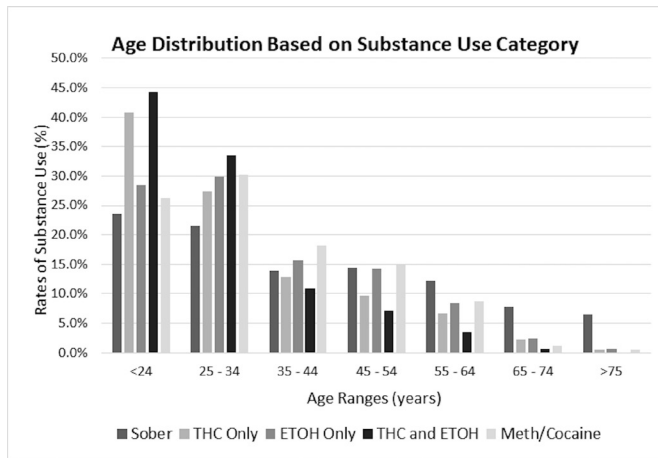


Figure 1 Age distribution for all toxicology subgroups.

both significantly higher than TOX- patients under the age of 35 at 45.1%, $p < 0.001$. **Figure 1** depicts the age distribution for all subgroups, with youngest patients in the THC+ and THC + ETOH groups. THC + patients were also more likely to be male than TOX- patients (74.0% vs 59.7%; $p < 0.001$). Across all groups, White patients were the most prevalent, followed by Hispanic then Black; the distributions within the different toxicology study groups can be found in **table 2**.

THC+ patients were more likely than TOX- to be in a MCC (33.8% vs 28.6%, $p < 0.001$) and less likely to wear a helmet (7.7% vs 8.6%, $p = 0.053$). In addition, in comparison with TOX- patients, THC+ patients were less likely to wear seatbelts (8.5% vs 14.3%, $p < 0.001$). There was no difference in in-hospital mortality. The comparisons of mechanism of injury, seatbelt use, helmet use, ISS, and operations for TOX- patient with all other toxicology subgroups are listed in **table 2**.

The semiannual percentage of TOX- patients decreased during the study period from 68.4% to 54.2% (**figure 2A**). THC+ and M/C increased during the study period with the percentage of THC+ patients increasing from 7.3% in 2010 to 14.8% in 2018. The percentage of THC+ ETOH patients remained consistent over (**figure 2B**). THC positivity in the entire study population was assessed in a time-series analysis and demonstrated an increased Pearson correlation coefficient after legislation in 2016 (0.591, $p < 0.001$), suggesting an increase in use over time. The Pearson correlation coefficient for increased THC positivity on a monthly basis is even stronger at 0.723, $p < 0.001$ (R^2 for the time series = 0.523). Time-series linear regression demonstrates an increase per month of 0.125% ($B = 0.125$) or 1.5% increase each year, $p > 0.001$, demonstrating THC+ toxicology significantly increased during the study period. To assess the impact of THC legalization in January 2016 on THC positivity, a linear regression using an interaction term for pre/post legislation by month was performed. However, there was not a significant differential change in the rate of THC+ toxicology after the 2016 legislation, $B = 0.683$, $p = 0.923$ ($R^2 = 0.524$). In summary, these data demonstrate a persistent and significant increase in THC+ rates over time; however, this rate was not accelerated by legalization.

Multivariate analysis of ISS, using ISS 1-8 as the reference range to ISS 9-14, ISS 15-24, and ISS ≥ 25 , did not demonstrate THC + compared with TOX- to be an independent predictor after adjusting for sex, age, race, year, payor, mechanism, and institution. However, ETOH+, THC + ETOH, and M/C subgroups all had increased odds of ISS 9-14, 15-24, and ≥ 25 when compared with TOX- patients (**figure 3**). The AUOC for each regression analysis is as follows: ISS 9-14 = 0.666, ISS 15-24 = 0.694, and ISS ≥ 25 = 0.712.

Medical examiner data

Data from the San Diego County Medical Examiner demonstrated 777 deaths at the scene during the study period; of those patients, 26.6% were THC+. The THC + people were significantly younger,

Table 2 Patient demographic by toxicology screen classification

Characteristic	TOX-†	THC only	ETOH only	THC and ETOH	Cocaine/meth					
Total no	7078	61.6%	1345	11.7%	1580	13.7%	578	5.0%	910	7.9%
Age (median/LQ-UQ)	28	25-56	27	21-39*	31	24-45*	26	22-33*	32	24-45*
Sex (male)	4224	59.7%	995	74.0%*	1076	68.1%*	445	77.0%*	687	75.5%*
Race/ethnicity										
Asian/other	1074	15.2%	150	11.2%	166	10.5%	61	10.6%	67	7.4%
Black	520	7.3%	160	11.9%	126	8.0%	54	9.3%	108	11.9%
Hispanic	2376	33.6%	382	28.4%	539	34.1%	182	31.5%	335	36.8%
White	2967	41.9%	615	45.7%	716	45.3%	261	45.2%	386	42.4%
Unknown	141	2.0%	38	2.8%	32	2.0%	20	3.5%	14	1.5%
Mechanism										
MV occupant	5052	71.4%	891	66.2%*	1323	83.7%*	483	83.6%*	694	76.3%*
Seatbelt	4185	82.8%	677	76.0%*	878	66.4%*	310	64.2%*	462	66.6%*
No seatbelt	429	8.5%	127	14.3%*	236	17.8%*	98	20.3%*	133	19.2%*
Unknown	438	8.7%	87	9.8%*	209	15.8%*	75	15.5%*	99	14.3%*
Motorcycle	2026	28.6%	454	33.8%	257	16.3%	95	16.4%	216	23.7%
Helmet	1821	89.9%	402	88.5%	219	85.2%*	81	85.3%*	174	80.6%*
No helmet	157	7.7%	39	8.6%	35	13.6%*	14	14.7%*	36	16.7%*
Unknown	48	2.4%	13	2.9%	3	1.2%*	0	0.0%*	6	2.8%*
ISS (median/LQ-UQ)	5	2-10	5	2-11*	5	2-12*	5	3-14*	6	4-13*
Operations	1685	24%	376	28%*	399	25.3%	164	28.4%*	326	35.8%*
Mortality	111	1.6%	18	1.3%	18	1.1%	11	1.9%	12	1.3%

* $p < 0.05$.
†TOX- is the reference category.
ISS, Injury Severity Score.

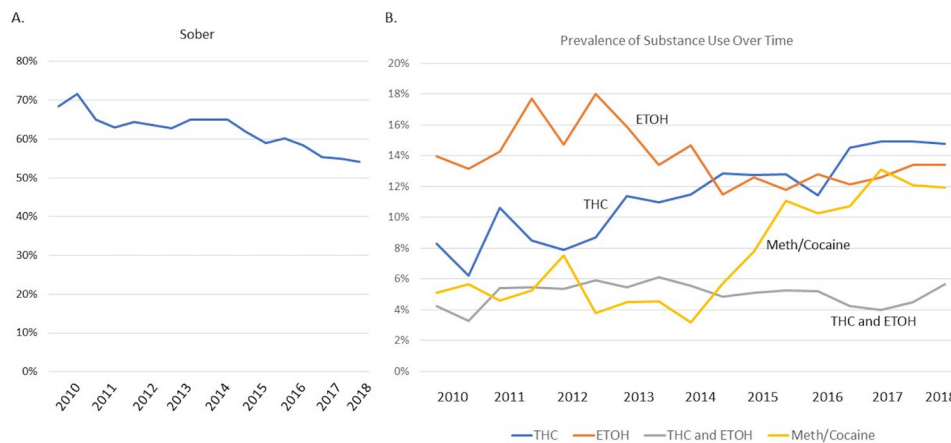


Figure 2 Distribution of toxicology results per year, depicting the change in positivity by subgroups: TOX–, THC+, ETOH+, THC +ETOH, and M/C.

more likely to be male, and in an MVC (table 3). The annual incidence of THC associated with deaths at the scene for MVC/MCC trended up from 20.8% in 2011 to 27.9% in 2018 with a peak in 2017 at 32.7% (figure 4).

DISCUSSION

Cannabis positive toxicology screens are increasing in vehicular injury patients admitted to the five trauma centers that participated in this study. Patients testing positive for cannabis were younger, less likely to wear seatbelts, and had elevated ISS compared with TOX– vehicular injury patients. Our seven-and-a-half-year study period allows for close analysis of trends in trauma patients through changes in legislation. Although the changes are likely multifactorial, the peak in THC+ trauma patients the year after recreational cannabis legalization in 2016 demonstrates that changes in legislation related to the legality and availability of cannabis likely has an impact on drug usage trends. The impact of legalization on drug use trends has been previously seen in California with the legalization of medical marijuana in 2006 being associated with an increase in cannabinoid prevalence in drivers in fatal accidents after accounting for national trends in driver cannabinoid prevalence.²⁴

Recent evidence suggests that states that legally permit medical cannabis dispensaries experience an increase in use prevalence among adults aged 21 years and older as well as an increase in average THC levels.²⁵ A study conducted in Washington state found the proportion of THC + daytime drivers increased from 8% before retail sales to 23% 6 months after retail sales.²⁶ Similarly, an analysis of trauma admissions in Colorado found that marijuana detection on urine drug screen increased significantly in the years after legalization.²⁷

In this report, we analyzed how the toxicology reports of trauma patients correlated with mechanism of injury and how the results of these drug screenings impacted injury severity. We surveyed data from the five adult trauma centers that compose the San Diego County Trauma System. These trauma centers serve individuals from a wide range of socioeconomic and demographic backgrounds. THC + patients were more likely to be young males and were less likely to wear seatbelts, which is in agreement with the characteristics of THC + patients described in similar reports.²⁰ Overall, THC or any other positive toxicology was associated with an increased ISS compared with TOX–, although the odds of having an increased ISS was higher in the THC +ETOH patients than ETOH + patients for

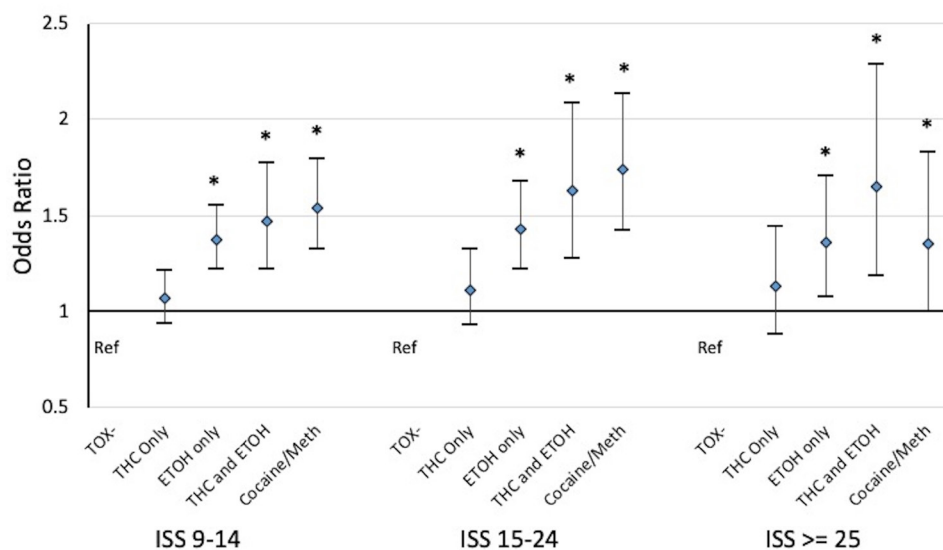


Figure 3 Odds of increased injury severity for intoxicated patients compared with toxicology-negative patients. Each ISS category is compared with ISS 1–8 and the regressions are adjusted for age, gender, race, year of admission, payor, mechanism, and institution. *p>0.05. Ref, reference category.

Table 3 Deaths on scene by THC positivity

	THC-		THC+		P value
Total no	570	73.4%	207	26.6%	
Age (median/LQ-UQ)	35	24-54	27	22-37	<0.001
Sex (male)	425	74.6%	178	86.0%	<0.001
Race/ethnicity					<0.001
Asian/other	52	9.1%	9	4.3%	
Black	36	6.3%	21	10.1%	
Hispanic	182	31.9%	45	21.7%	
White	277	48.6%	118	57.0%	
Other	23	4.0%	14	6.8%	
Mechanism					<0.001
MV occupant	383	67.2%	158	76.3%	
Motorcycle	187	32.8%	49	23.7%	

all ISS categories. This suggests that the combined use of alcohol and THC may have a synergistic effect on driver impairment, translating to worse injuries.^{14 28}

The use of medical cannabis in our study population is unknown. However, a study on a cohort of young individuals in LA found fewer individuals were medical cannabis patients after legalization.²⁹ As our study population was similarly young, it is reasonable to think that an increase in medical cannabis use did not account for the rise in THC+ patients. In addition, the significance of medical versus non-medical use does not impact our findings as the possession of a medical marijuana card does not correlate with driving under the influence of cannabis.³⁰

There is an unclear link between the concordant rise of M/C+ patients and the rise of THC + patients found in our study. Previous studies have suggested cannabis use predicts the use of illicit drug use; however, recreational marijuana legalization in Colorado and Washington was not associated with an increase in substance use disorder treatment admission.^{31 32} There may be local-regional reasons why this occurred in our study including our regional increasing homeless population, drug trafficking, and a known epidemic of methamphetamine use just across the border from us.^{33 34} Further studies are needed to understand this correlation.

Although there was a persistent and significant increase in THC+ rates over time, this rate was not accelerated after legalization and in fact in our series appears to plateau. The impacts of legalization are influenced by information diffusion which begins during the arduous process of legalization. By the time the law was enacted,

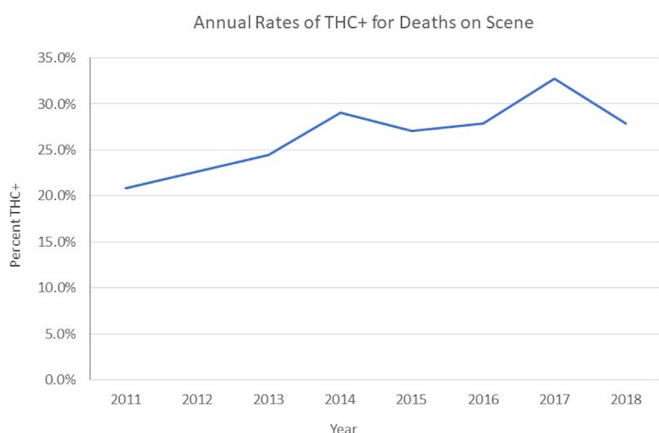


Figure 4 Rate of cannabis positivity per year for deaths on scene after vehicular crashes.

individual behaviors may have already changed, explaining the plateau.³⁵

The long-term impact of legalization on THC+ trauma patients is difficult to predict as studies on the association between cannabis laws and cannabis use have reported inconsistent results.³⁶ Regardless, the nearly doubling in THC+ patients during our study period is concerning as THC+ drivers put themselves and everyone else on the road in danger. THC can impair critical abilities necessary for safe driving, including slowed reaction time, problems with road tracking, lane position variability, and decreased cognitive performance and executive functions as well as divided attention.³⁷

Data from the San Diego County Medical Examiner were analyzed to evaluate the extent of THC+ toxicology in patients who died at the scene of injury. We found that during the entire study period, 26.6% of deaths at the scene of injury had THC+ toxicology. This cohort of fatalities is important to analyze as they are not represented in mortality data from individual trauma centers. A previous study analyzed the effect of marijuana legalization on MVC fatalities in Washington and Colorado, finding that crash fatality rates did not differ from states that had not legalized marijuana.³⁸ Medical Examiner data also demonstrated that there was an association between THC+ vehicular deaths and a younger, predominantly male population. The young male population is known to engage in more per-capita violations and experience more per-capita injuries and fatalities than older cohorts and females.³⁹

Limitations of this study include the lack of a legal threshold for driver impairment while under the influence of cannabis. In addition, cannabinoids can exist in the blood stream for several days after drug discontinuation in heavy cannabis users, and it is unknown what impact these residual levels have on the user's physiological profile and level of impairment.^{40 41} For those patients who did have positive toxicology, we do not have data regarding timing of use and the crashes. Not all patients had a toxicology screen performed, and there was variability in the screening rates between institutions. These institutional differences, combined with the variation in toxicology screening over time, introduce the risk of selection bias which could have influenced these outcomes making generalization of these results difficult. Finally, motor vehicle and motorcycle crash injuries have the potential for different injury patterns and severity, and combining these mechanisms to assess roadway vehicular crashes could have influenced these outcomes. A larger prospective study would overcome many of these limitations and be the ideal way to study the association of cannabis use with vehicular crashes and injury severity.

These data should be used to fuel injury prevention initiatives starting with targeted public education, focusing on the under 35 age group, who are at the highest risk for being under the influence of cannabis at the time of injury. Educational campaigns should focus on the risks of driving under the influence of any substance, including cannabis, which may be negatively synergistic with other intoxicants. It is key that drug testing is developed for law enforcement to be able to screen for cannabis use in the field, facilitating their ability to enforce policy regarding driving intoxicated. Further studies are needed to address the question of how positive toxicology screens relate to timing of cannabis use, cannabis levels in the blood, and the relation of those blood levels to acute intoxication and impairment. Studies like these are important for increasing awareness of the dangers associated with cannabis use.

Contributors JMB: data acquisition and analysis, interpretation of data, drafting of article. TWC: study design, data analysis and interpretation, drafting of article and critical revision. AMS: data acquisition, analysis and interpretation, critical revision of article. LR: data acquisition, interpretation of data, drafting of article. RS: data acquisition, critical revision of article. JS: data acquisition, critical revision of article. DW: data acquisition, critical revision of article. VB: data acquisition, critical revision

of article. WLB: data acquisition, drafting of article and critical revision. LNG: overall content and guarantor, study design, data analysis and interpretation, drafting of article and critical revision.

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