State Medical Marijuana Laws and the Prevalence of Opioids Detected Among Fatally Injured Drivers

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Objectives. To assess the association between medical marijuana laws (MMLs) and the odds of a positive opioid test, an indicator for prior use.

Methods. We analyzed 1999–2013 Fatality Analysis Reporting System (FARS) data from 18 states that tested for alcohol and other drugs in at least 80% of drivers who died within 1 hour of crashing (n = 68,394). Within-state and between-state comparisons assessed opioid positivity among drivers crashing in states with an operational MML (i.e., allowances for home cultivation or active dispensaries) versus drivers crashing in states before a future MML was operational.

Results. State-specific estimates indicated a reduction in opioid positivity for most states after implementation of an operational MML, although none of these estimates were significant. When we combined states, we observed a significant overall association (odds ratio [OR] = 0.79; 95% confidence interval [CI] = 0.61, 1.03). However, age-stratified analyses indicated a significant reduction in opioid positivity for drivers aged 21 to 40 years (OR = 0.50; 95% CI = 0.37, 0.67; interaction P < .001).


Unfortunately, data on treatment efficacy is limited, in large part because of current federal scheduling. Regardless, severe or chronic pain is among the most common indications cited by medical marijuana patients. In theory, we would expect the adverse consequences of opioid use to decrease over time in states where medical marijuana use is legal, as individuals substitute marijuana for opioids. In a recent study of MMLs and opioid overdoses, state MMLs were associated with reductions in the annual rate of state-level opioid overdoses. The relationship between MMLs and other indicators of opioid use or adverse consequences needs to be further examined, as this relationship potentially identifies actionable points of intervention on a growing opioid epidemic (e.g., expanding eligible medical conditions for marijuana to include chronic pain).

One such indicator is the prevalence of opioid use. Although opioid use can be difficult to measure, tested opioid positivity in blood or urine is objective, and it provides a clear indicator of any prior opioid use, for medical or recreational purposes. Although we know of no representative general population data with tested opioid positivity among living participants, toxicological tests for substances among drivers fatally injured in car crashes represents a potential data source. Repeated annual panels of drivers killed in crashes in states with and without MMLs are available; in some states, data are uniformly collected for the majority of deceased drivers. Furthermore, states that do not

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have an MML but eventually pass one are more similar to states in which an MML has already been passed, reducing the possibility of bias in comparing MML and non-MML states.19 Thus, our aim was to empirically assess whether, among drivers who died within 1 hour of a traffic collision, crashing in a state with an MML was associated with a reduced likelihood of opioid positivity compared with crashing in a state that would eventually pass an MML but had not yet done so.

METHODS

We obtained study data from the Fatality Analysis Reporting System (FARS), which provides a census of all crashes on public roads that result in a traffic fatality. This includes data from police records, state administrative files, and medical records on the persons, vehicles, and circumstances related to each crash.20 To limit any false positive drug testing results, we restricted our sample to drivers who died within 1 hour of crashing from 1999 to 2013 (n = 215,384).

We excluded drivers younger than 15 years (n = 507) or with missing data on age (included categories = 15–20, 21–40, and ≥41 years) or gender (n = 50). In addition, although the FARS provides data for all states, toxicological testing of fatally injured drivers is inconsistently performed across states.21 States that do not perform drug and alcohol testing on the majority of their drivers may be selectively testing drivers that appear impaired.22 Thus, we restricted our analysis to include only states that tested at least 80% of fatally injured drivers (n = 70,683) from 1999 to 2013 (18 states; Table 1), a threshold consistent with previous studies.23–25 Although testing for New Mexico was above this threshold, because there were inexplicably low numbers of drivers testing positive for drugs, we deemed data from this state to be unreliable and excluded them.22 We also excluded drivers with missing outcome data (n = 2289; 3.2%). In total, we included 68,394 deceased drivers from 18 states.

Measures

Drug and alcohol test results. Blood or urine specimens were tested for drugs through gas–liquid chromatography, mass spectrometry, and radioimmunoassay techniques.27 For each driver, the FARS records up to 3 nonalcoholic drugs detected in the blood or urine. If multiple drugs are detected, the FARS records results in the following priority order: narcotics, depressants, stimulants, marijuana, and other.28 In accordance with the FARS coding manual,28 we based prior opioid use on the coding of any narcotic (codes 100–295). The FARS determines driver’s blood alcohol content and drug content separately; we coded blood alcohol content as negative, positive, or missing.

State medical marijuana laws. Because state MMLs vary in how medical marijuana is provided and made available,29 we coded only states that provided access to medical marijuana (through either one’s own or collective cultivation or through public or private dispensaries) as having an operational medical marijuana law, and we based operational dates on when access was made available. For example, New Hampshire and Illinois have effective dates within or immediately after our study period (2013 and 2014, respectively); however, because they did not allow home cultivation and dispensaries were not operational until after our study period, we coded these states as negative throughout. For states that implemented an operational MML during our study period, we coded MML status as positive for all years following the operational date of the MML. ("Never" indicates that the state never implemented any type of MML.)

<table>
<thead>
<tr>
<th>State</th>
<th>Effective Date</th>
<th>Operational Date</th>
<th>First Year Coded as Operational</th>
<th>MML Status (No.)</th>
<th>% of Drivers Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>Nov 96</td>
<td>Nov 96</td>
<td>1999</td>
<td>After (20,614)</td>
<td>92.3</td>
</tr>
<tr>
<td>Washington</td>
<td>Nov 98</td>
<td>Nov 98</td>
<td>1999</td>
<td>After (3,649)</td>
<td>91.1</td>
</tr>
<tr>
<td>Hawaii</td>
<td>Dec 00</td>
<td>Dec 00</td>
<td>2001</td>
<td>Before (38), After (388)</td>
<td>97.2</td>
</tr>
<tr>
<td>Colorado</td>
<td>Jun 01</td>
<td>Jun 01</td>
<td>2002</td>
<td>Before (687), After (2,273)</td>
<td>85.9</td>
</tr>
<tr>
<td>Vermont</td>
<td>Jul 04</td>
<td>Jul 04</td>
<td>2005</td>
<td>Before (122), After (2,649)</td>
<td>93.0</td>
</tr>
<tr>
<td>Montana</td>
<td>Nov 04</td>
<td>Nov 04</td>
<td>2005</td>
<td>Before (489), After (932)</td>
<td>89.8</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>Jan 06</td>
<td>Jan 06</td>
<td>2006</td>
<td>Before (2,679), After (2,255)</td>
<td>99.2</td>
</tr>
<tr>
<td>New Jersey</td>
<td>Oct 10</td>
<td>Dec 12</td>
<td>2013</td>
<td>Before (2,679), After (167)</td>
<td>93.0</td>
</tr>
<tr>
<td>Connecticut</td>
<td>Oct 12</td>
<td>Not operational</td>
<td>.</td>
<td>Before (1,616)</td>
<td>97.2</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>Jan 13</td>
<td>Not operational</td>
<td>.</td>
<td>Before (2,267)</td>
<td>82.0</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>Jul 13</td>
<td>Not operational</td>
<td>.</td>
<td>Before (889)</td>
<td>94.0</td>
</tr>
<tr>
<td>Illinois</td>
<td>Jan 14</td>
<td>Not operational</td>
<td>.</td>
<td>Before (5,803)</td>
<td>88.8</td>
</tr>
<tr>
<td>Maryland</td>
<td>Jun 14</td>
<td>Not operational</td>
<td>.</td>
<td>Before (2,504)</td>
<td>88.7</td>
</tr>
<tr>
<td>North Dakota</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>Never (710)</td>
<td>87.2</td>
</tr>
<tr>
<td>Ohio</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>Never (7,328)</td>
<td>85.2</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>Never (7,280)</td>
<td>80.5</td>
</tr>
<tr>
<td>Virginia</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>Never (4,775)</td>
<td>82.9</td>
</tr>
<tr>
<td>West Virginia</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>Never (2,328)</td>
<td>94.6</td>
</tr>
</tbody>
</table>

Note. "Majority testing" is defined as testing at least 80% of a state’s drivers who died within 1 hour of crashing.

Source. Fatality Analysis Reporting System.

MML effective dates are based on when (month and year) the law went into effect.

Operational dates are based on when (month and year) allowances for home cultivation or the presence of active dispensaries came into effect.

Numbers of drivers who died before and after the operational date of the MML. ("Never" indicates that the state never implemented any type of MML.)
the first half of the year (i.e., before July 1), we coded MML status as positive starting with that year. If the law became operational during the second half of the year, we coded MML status as positive starting with the subsequent year, as follows: Hawaii, 2001; Colorado, 2002; Vermont, 2005; Montana, 2005; Rhode Island, 2006; New Jersey, 2013. We coded California and Washington as positive for MML status for the entire study period. We considered the remaining states that had not yet passed an operational MML as negative throughout the study period (North Dakota, Ohio, Pennsylvania, Virginia, and West Virginia). Additionally, in the state-combined analysis, we controlled for whether the state had ever passed a medical marijuana law.19 This included the states with an operational MML at any point during the study period as well as states with laws that were not yet operational (Connecticut, Massachusetts, New Hampshire, Illinois, and Maryland).

State prescription drug monitoring program laws. Prescription drug monitoring programs (PDMPs) may confound any association between state MMLs and individual opioid use if PDMPs are associated with the timing of state MMLs and an independent cause of opioid use. To account for this, we used 4 time-varying measures of PDMP characteristics obtained from LawAtlas: (1) “PDMP mandatory,” which requires health professionals to report their prescribing; (2) “PDMP real-time,” which requires that prescribing data be updated at least once weekly; (3) “PDMP proactive,” which requires proactive identification of suspicious prescribing, dispensing, or purchasing; and (4) “PDMP oversight,” which requires an oversight board. These indicators have been used previously to characterize variations across PDMP programs.30 In this study, we compared the absence of all of these PDMP characteristics with the presence of 1 or of 2 or more of them.

State-Combined Analysis

First, to help characterize our study population, we ran cross-tabs between MML status and multiple driver and state-level characteristics. To assess the average impact of MML across states, we used a multilevel logistic regression with a random effect for state of crash and fixed effects for year of crash, presence of PDMP characteristics, and driver’s age category, gender, and blood alcohol content. The 2 main independent variables were operational MML status and whether the state had ever passed an MML (model 1). This specification allowed us to compare drivers crashing in states after an operational MML was implemented with drivers crashing in states before one was implemented. This reduced bias related to comparing states with and without an MML, as states that will eventually adopt an operational MML are more comparable to states with a current law than to states that have never passed a law.19 Furthermore, to test whether the effect of operational MML varied by age category, we included separate interaction terms between age category and the 2 main independent variables. We report the test of overall significance for the interaction between age category and operational MML status; if it is significant, we present age-stratified estimates.

RESULTS

Among our sample of 68 394 deceased drivers, approximately 41.8% were fatally injured in states that had an operational MML, 25.4% died in states before an operational law went into effect, and 32.8% died in states that had never passed an MML (Table 2). The mean age of all deceased drivers was approximately 41 years, and most (>75%) were male. There was also a relatively stable level of alcohol involvement across MML status, although there was more missing alcohol data for deceased drivers in states before an MML was operational (6.4%) than in states with an operational MML (2.1%) or in states that had never had an MML (3.7%). In addition, although nearly all states had some form of PDMP, the presence of PDMP characteristics appeared to vary by operational MML status (Table 2). Figure 1 displays trends in opioid positivity across the study years by the MML status of the state in which the deceased drivers crashed.

State-Specific Sensitivity Analysis

As a sensitivity analysis, we explored state-specific effects of an MML on opioid positivity using a “difference-in-difference” approach. In this method, state fixed effects are used to capture within-state changes in the outcome among the exposed group, which is then contrasted with the change in outcome observed among an unexposed control group. Under the assumption that the pre-intervention trend is similar in the 2 groups, any differences between states with and without an MML (measured or not) that may also influence opioid positivity (e.g., societal norms) is “differenced” out and does not bias effect estimates.31 Although statistical power is limited in such analyses, they are useful in showing state-specific effects, and can be used to compare results from other designs and modeling specifications. We conducted state-specific analyses on 4 states with at least 3 years of data before and after an MML became operational: Colorado (1999–2004), Montana (2002–2007), Vermont (2002–2007) and Rhode Island (2003–2008). For each comparison, besides the state of interest, we included as controls only those states in our sample that performed majority testing (i.e., ≥80% of drivers who died within 1 hour of crashing) and did not have an operational MML during each 6-year period. Each difference-in-difference analysis first used all eligible states and then repeated the analysis only in states that ever passed an MML, regardless of whether it was operational or not. Sample size limitations precluded the ability to obtain age-stratified estimates. Results are provided in Table A and Figure A (available as a supplement to the online version of this article at http://www.ajpjournal.org). We conducted all analyses using Stata SE version 13 (StataCorp LP, College Station, TX). The technical appendix (available as a supplement to the online version of this article at http://www.ajpjournal.org) provides information required to replicate our analyses.

State-Combined Analysis

In the overall sample, after we adjusted for driver’s age, gender, blood alcohol content, a state-level indicator of whether the state had ever passed a medical marijuana law, and PDMP characteristics, crashing in a state with an operational MML versus crashing in one where an MML was not yet operational was not associated with the odds of opioid
positivity (odds ratio [OR] = 0.79; 95% confidence interval [CI] = 0.61, 1.03; Table 3). Tests of interaction between an operational MML and age indicated that the association between MML and opioid positivity varied significantly by age ($\chi^2 = 48.7$; $P<.001$). After we adjusted for both individual and PDMP characteristics (Table 3), compared with drivers aged 21 to 40 years who crashed in states before an operational MML, drivers of the same age range who crashed in states with an operational MML had lower odds of opioid positivity (OR = 0.50; 95% CI = 0.37, 0.67). We observed no significant associations for other age groups.

**State-Specific Sensitivity Analysis**

Figure A plots the prevalence of opioid positivity for each MML state compared with the observed average among control states with no operational MML. For each state comparison (Table A), we contrast the count and percentage of opioid positivity before and after an operational MML was implemented (and the before-vs-after difference) with those of two overlapping controls groups: (1) controls in states that had performed majority testing (all eligible controls) and (2) controls only in states that had passed an MML. The difference-in-difference estimate signifies the estimated change in opioid positivity associated with an operational MML. For example, after we adjusted for state and year of crash as well as driver’s age, gender, and blood alcohol content, Montana experienced a 1.7% reduction (risk difference = –1.72; 95% CI = –5.5, 2.1) in opioid positivity after its MML became operational relative to the expected change in opioid positivity among states that had ever passed an MML (Table A). Although none of these state-specific estimates were significant, there were trends in all states toward a reduction in opioid positivity.

**DISCUSSION**

In this study, we assessed whether, among comparable samples, implementing an operational MML was associated with reductions in opioid positivity. We did this by comparing drivers crashing in states with an operational MML with drivers crashing in states before a future MML became operational. We performed this comparison in two disparate ways: by grouping drivers across states (i.e., the state-combined analysis) and by comparing before-versus-after trends.
in opioid overdose mortality.\textsuperscript{30} Few studies have previously attempted to explain this mechanism. One study assessed opioid use among a large representative sample,\textsuperscript{33} but it found no impact of MMLs on self-reported use. However, the survey question that captured opioid use only assessed “non-medical use” of pain medications, limiting the information on medication used legitimately for pain. It is possible that the weight of any benefit is mostly conferred on patients who have legitimate need for pain medications. For example, in 1 study conducted in Utah, the majority of opioid overdose decedents in 2008 and 2009 had previously been prescribed opioids for their own conditions.\textsuperscript{34}

Our findings in this study suggest that MMLs are associated with reductions in opioid positivity, an indicator for previous use, at least among drivers aged 21 to 40 years who died within 1 hour of crashing. For example, in 1 study conducted in Utah, the majority of opioid overdose decedents in 2008 and 2009 had previously been prescribed opioids for their own conditions.\textsuperscript{34} Although this degree of specificity did not allow us to explore other provisions of MMLs (e.g., criminal protection for patients), future studies should examine these as separate indicators with the potential to have disparate influences on substance use. Third, we accounted for the considerable state heterogeneity in both the measurement of our outcome (i.e., toxicological testing procedures) and trends in opioid use and opioid-related harms broadly. To correct for this in our state-combined analysis, we included a random intercept for state of crash and excluded states that did not perform majority testing. Furthermore, we also performed state-specific analyses that assessed within-state changes that eliminated most time-invariant sources of bias. Lastly, we observed consistent findings when making within-state and between-state comparisons, 2 models with varying assumptions.

Conclusions
Because of the uniqueness of our sample, it is worth noting again that our outcome is

\begin{table}[h]
\centering
\caption{Estimated Odds Ratios of Testing Positive For Opioids Among Drivers Who Died Within 1 Hour of Crashing: United States, 1999–2013}
\begin{tabular}{|l|l|}
\hline
Variable & OR \textsuperscript{a} (95\% CI) \\
\hline
Before an operational law was implemented (Ref) & 1 \\
\hline
After implementation, by age & \\
Overall & 0.79 (0.61, 1.03) \\
15-20 y & 0.95 (0.55, 1.64) \\
21-40 y & 0.50 (0.37, 0.67) \\
\geq 41 y & 1.04 (0.79, 1.37) \\
\hline
\end{tabular}
\end{table}

Note. CI = confidence interval; OR = odds ratio. For test of overall interaction of age-stratified estimates, $\chi^2 = 48.7$ ($P < 0.001$).

Source. Fatality Analysis Reporting System.

\textsuperscript{a}Multilevel model includes a random intercept for state of crash and adjusts for operational medical marijuana law (MML) status, driver’s age category (and the interaction with MML for age-stratified estimates), whether the state had ever passed an MML (and its interaction with age for age-stratified estimates), the presence of 1, $\geq 2$, or no prescription drug monitoring program characteristics, and year of crash, plus driver’s characteristics (gender and blood alcohol content).

within the same state (i.e., the state-specific analysis). We found that among 21- to 40-year-old deceased drivers, crashing in states with an operational MML was associated with lower odds of testing positive for opioids than crashing in MML states before these laws were operational. Although we found a significant association only among drivers aged 21 to 40 years, the age specificity of this finding coheres with what we know about MMLs: a minimum age requirement restricts access to medical marijuana for most patients younger than 21 years, and most surveyed medical marijuana patients are younger than 45 years.\textsuperscript{17,32} Although the uptake of medical marijuana has been historically concentrated among young adults, we would expect to see similar reductions in opioid use among older cohorts if medical marijuana is increasingly embraced by older generations.

Our findings among those aged 21 to 40 years are consistent with previous findings that MMLs are associated with a 25\% reduction in the annual rate of opioid overdose\textsuperscript{18} and that states permitting medical marijuana dispensaries experience a slight decrease in opioid treatment admissions and
opioid positivity (i.e., prior opioid use), which is not necessarily indicative of driving impairment. This study was not designed to assess whether opioids increase crash risk.

Instead, we assessed whether, among comparable samples, implementing an operational MML was associated with reductions in opioid positivity. Although previous studies have suggested that MMLs are associated with decreased opioid overdose mortality rates at the state level, our study suggests 1 plausible mechanism underlying this association: in states with MMLs, fewer individuals are using opioids. If these laws are actually causing reductions in opioid use—an explanation consistent with our results—then the hypothesis that MMLs reduce opioid-related overdoses and treatment admissions is more plausible. However, as states with MMLs move toward legalizing marijuana more broadly for recreational purposes, future studies are needed to assess the impact these laws may have on opioid use.

CONTRIBUTORS
J. H. Kim developed the study concept and design, collected and analyzed the data, interpreted the results, and drafted the article. J. Santana-Tenorio, C. Mauro, and J. Wrobleski collected and analyzed the data and interpreted the results. M. Ceredi, K. M. Keyes, D. Hasin, S. S. Martins, and G. Li helped develop the study concept and design and helped draft the article.

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HUMAN PARTICIPANT PROTECTION
Ethics approval was not needed for this work because it used publicly available, anonymized data.

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