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Geographic variation and trends in opioid-involved crash deaths in Maryland: 2006–2017

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ABSTRACT

The objective of this study was to describe trends in the prevalence of opioids in driver fatalities and examine geographic variation in opioid-involved crashes at a county level. Using comprehensive toxicological data from the Office of the Chief Medical Examiner in Maryland, we examined the prevalence of opioids in all motor vehicle crash fatalities in Maryland between 2006–2017 and tested for trends to assess the statistical significance of changes in the prevalence of prescription opioids detected in these drivers over time. Opioid-involved crash deaths accounted for 10.0% of all driver deaths during the study period. The prevalence of opioids detected in fatally injured drivers increased from 8.3% in 2006 to 14.1% in 2017, ($Z = -1.9$, $p < .05$). The trends in opioid deaths do not follow broader trends in motor vehicle crash deaths; opioid-involved crashes appear to be increasing while overall motor vehicle crashes appear to be decreasing over the same period. To determine if the increase in opioid-involved crash deaths was the result of changes in pain management related to injuries sustained from the crash, we analyzed a subgroup of cases where death occurred at the scene of the crash. Within this group, there was no statistically significant increase in opioid-involved crashes during the study period. Opioid prevalence was higher in middle aged, and white drivers, and in crashes occurring in rural counties. Geographic distribution of opioid-involved crash deaths reflect broader patterns of opioid deaths overdose across the state. Irrespective of the timing of the deaths, of the drivers testing positive for opioids, 28% had elevated blood alcohol concentrations (‡ 0.01 g/dL), and 45% tested positive for other drugs.

1. Introduction

Opioid overdose and motor vehicle crashes are leading causes of injury-related death in the U.S. (Centers for Disease Control and Prevention, 2016). An emerging body of literature is examining the link between the two. While opioids account for the majority of drug overdoses in the United States (Rudd et al., 2016), data from the Centers for Disease Control and Prevention (CDC) indicates overdose deaths are increasing across all drug types, both opioid and nonopioid (Centers for Disease Control and Prevention, 2016). In 2016, the most recent year for which data are available, 37,461 people died on U.S. roadways— representing the second successive year crash deaths have increased in the U.S. following a decade of a declining trend (National Highway Traffic Safety Administration, 2017). Part of the increase may be attributable to an increase in drugged driving, which encompasses opioids, among other drugs (National Highway Traffic Safety Administration, 2017; Governors Highway Saftey Association, 2017).

Despite the magnitude of the public health burden, little is known about the extent to which this worsening trend in opioid abuse is contributing to motor vehicle accidents. Prescription opioids are known to impair reaction time, alertness, attention, and concentration during driving (Manchikanti and Singh, 2008; Verster et al., 2006; Menefee et al., 2004; Rudisill et al., 2016), which supports a direct toxicological link between opioid use and impaired driving. Previous research has established a significant increased risk of motor vehicle crashes resulting from opioid-impaired driving (Manchikanti and Singh, 2008; Verster et al., 2006; Menefee et al., 2004; Rudisill et al., 2016). One study has drawn an association between opioids and motor vehicle fatalities, finding a significant increase in the prevalence of opioids in fatal crashes across six states (Stanford Chihuri and Li, 2017). However, less is understood about the demographic and geographic variation in opioid-involved motor vehicle crash fatalities.

The State of Maryland has been disproportionately affected by opioid-overdose deaths (Centers for Disease Control and Prevention,

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2018a), in addition to an increasing number of crash deaths over recent years (Centers for Disease Control and Prevention, 2018a; Maryland Department of Transportation, 2018). Recent analyses suggest drugged driving deaths are not evenly distributed across U.S. states. In one analysis of 2001–2016 data, opioid-involved motor vehicle crash deaths were found to be clustered in the Appalachian region and the northeast (Rookey, 2018). However, these analyses did not account for differences in driving exposure or distinguish between drivers who had been administered opioid-analgesics as pain relief resulting from the injuries of the crash itself, compared to those who had used opioids prior to driving. Nevertheless, these findings suggest the need for a closer examination of the geographic variation in opioid-involved crash deaths.

Using data from the Office of the Chief Medical Examiner in Maryland, the objective of this study was to describe the characteristics of drivers involved in opioid-involved crashes, examine trends in the prevalence of opioids in driver fatalities over time and explore the geographic variation in opioid involved crashes at a county level. The Office of the Medical Examiner in Maryland is distinctive because all deaths occurring across the state are processed at a centralized facility in Baltimore, including toxicological testing of tissues and database management. This offers a degree of consistency and quality control that is not typical for a state of this geographic size. Therefore, these data offer a unique opportunity to examine the issue of opioid-impaired driving deaths in the state.

2. Methods

2.1. Data sources

2.1.1. Office of the chief medical examiner in Maryland

The analysis uses data obtained by the Chief Medical Examiner's Office for all fatally injured drivers in Maryland who were autopsied. To arrange the data into a useable format several steps were taken, which included applying exclusions, identifying positive toxicology results, classifying substances, and calculating frequency tables by year of analysis. The Chief Medical Examiner's office uses gas chromatography and mass spectrometry for screening and enzyme-linked immunosorbent assay (ELISA) for confirmation of opioids in urine where samples are available. No minimum cutoff was used for the concentration of opioids. The data, as received from the Medical Examiner's Office, contained 5713 unique case identifiers. The data range spanned from April 2004 to January 2018. Complete years of data were required for the analysis, resulting in the elimination of 79 cases from 2004, 181 cases from 2005 and 87 cases from 2018. Deaths that involved non-roadway vehicles including: boats, aircraft, ATVs, construction equipment, farm vehicles, bicycles, and trains were also excluded. Intentional deaths (as determined by the medical examiner) were also excluded, such as homicide and suicide cases. After applying these exclusions, the total cases decreased from 5713 to 3149.

To identify and exclude cases where opioids may have been administered to treat injuries sustained in the crash that resulted in their death we generated a subsample of drivers that died at the scene of the crash. In such cases, the likelihood of pain management is likely to be considerably lower than those whose died hours or days following a crash. The rationale for examining these cases is that it may approximate the true or underlying prevalence of opioid use in the general population. This generated a subsample of 1931 cases.

In order to identify substances involved in crashes, the frequency of positive toxicology results were examined. To calculate frequencies by substance, cases with positive toxicology were identified using data of all substances detected during toxicological screening. The Maryland Medical Examiner screens cases for 120 substances. Of these substances, 17 were identified as opioids (see footnote for exact listing).[1]

2.1.2. U.S. census data

Supplemental data were incorporated to provide comparisons to the broader Maryland population, and to adjust the spatial analysis by population. The population data were obtained from United States Census Bureau data for Maryland.

2.1.3. Maryland highway safety office

Data for vehicle miles travelled were obtained from the Maryland State Highway Administration and are calculated as the total daily miles of vehicle travel based on traffic data counts collected through permanent automatic traffic recorders on public roadways. These data were averaged from 2006 to 2016; 2016 vehicle miles travelled were the most recently available data at the time of the study.

2.1.4. CDC data

County-level data for opioid overdose deaths for Maryland were obtained from the CDC's Wide-ranging Online Data for Epidemiologic Research (WONDER) database (Centers for Disease Control and Prevention, 2018b). These data were used to test the correlation between opioid overdose deaths and opioid-involved driver fatalities in Maryland from 2006 to 2017.

2.1.5. Analysis

To analyse the data, several statistical techniques were used. Chi-square tests were used to compare subpopulations in the data. The Cochran-Armitage trend test was used to assess trends in the data. A one-sided trend test was used for the trend test examine changes in opioid-involved driver fatalities given the prior research in this area; for the subgroup analysis by select demographic factors, however, a two-sided trend test was used. In addition, incidence rates of opioid-involved fatalities were calculated for each year in the dataset. Lastly, incidence rates were calculated by county to present spatial analysis results. The Spearman Rank Correlation test was used to compare these results to all opioid overdose deaths in Maryland at a county level. All statistical analyses were performed using R. The proposed analyses were reviewed by the Johns Hopkins Institutional Review Board who determined they do not qualify as human subjects research under DHHS regulations 45 CFR 46.102, and does not require IRB oversight.

3. Results

3.1. Demographic distribution of opioid- and non-opioid involved crash deaths

During the study period, January 2006 through December 2017, there were 3149 fatally injured drivers in Maryland identified through the Office of the Chief Medical Examiner, of which 1989 screened positive for any substance (63.1%) and 316 drivers (10.0%) screened positive for opioids at the time of death (Table 1). Among all fatally injured drivers, 79.2% were male, and 20.8% were female; these proportions were roughly equivalent between those with opioids and those without opioids in their system. The race and age of fatally injured drivers differed between those who screened positive for opioids and those who did not. Significant differences were observed in the population characteristics for vehicle deaths involving opioids as compared to those that did not involve opioids. Opioid-involved crashes were significantly higher proportion among Caucasians; 81.6% of opioid-involved crashes versus 58.5% in non-opioid involved crashes. Opioid-involved crashes among African Americans were 17% lower compared

[1] The substances classified as opioids include the following: 'Codeine", 'Morphine', 'Methadone', 'Oxycodone', 'Fentanyl', 'Hydrocodone', 'Oxymorphone', 'Hydromorphone', 'Furanyl fentanyl', 'Despropionyl fentanyl', 'Dihydrocodeine', 'Tramadol', 'Propoxyphene', 'Norpropoxyphene', '6-Monoacetylmorphine, 'Norbuprenorphine', 'Buprenorphine', 'U-47700"

Table 1
Descriptive Statistics.

Characteristic	Non-Opioid Cases	Opioid Cases	Total column
Gender*			
Female	579 [20.4%]	75 [23.7%]	654 [20.8%]
Male	2254 [79.6%]	241 [76.3%]	2495 [79.2%]
Race**			
Caucasian	1657 [58.5%]	258 [81.6%]	1915 [60.8%]
African American	918 [32.4%]	48 [15.2%]	966 [30.7]
Hispanic	156 [5.5%]	4 [1.3%]	160 [5.1%]
Asian	47 [1.7%]	1 [0.3%]	48 [1.5%]
Other	55 [1.9%]	5 [1.6%]	60 [1.9%]
Total	2,833 [100%]	316 [100%]	3149 [100%]

* Chi-square = 2.15 (p-value = 0.142).
** Chi-square = 57.97 (p-value < .001).

to non-opioid-involved crashes, and the prevalence of opioids in crash deaths among Hispanics was four percent lower compared to all other crashes. A Pearson's chi-squared test showed a statistically significant difference in the distribution by racial category, comparing the opioid and non-opioid cases (p-value < .001).

Significant differences were also observed in the age distribution of opioid versus non-opioid involved crashes. Broadly, the age distribution of crash deaths in Maryland was significantly different from the overall Maryland population (p-value < .0005), as obtained from Maryland Census data (United States Census Bureau, 2010). Significant differences were also observed between the age distribution of opioid-involved and non-opioid involved crashes (p-value = 0.02). Among the 15-19-yer-old age group, the proportion of opioid-involved crash deaths was lower relative to non-opioid-involved deaths. The proportion of opioid-involved crash deaths relative to non-opioid crash deaths was higher by more than one percentage point for those between 30–34, 45–49, and 50–54. This difference was statistically significant for the 50–54 age group (p-value = .02).

3.2. Trends in opioid-involved crash deaths

Fig. 1 shows the percentage of all motor vehicle fatalities in Maryland that involved opioids, by year between 2006 and 2017. The trendline shows a slightly increasing trend, and the percent of opioid cases is 8.3 percent in 2006 and reaches 14.1 percent in 2017. This contrasts with the general decline in motor vehicle driver fatalities in the data corresponding to the same period (data not shown). The Cochran-Armitage test for trend showed a statistically significant increase in opioid-involved crash deaths during the study period (Z = −1.9, p-value = .03). Of particular note, fentanyl-involved crash deaths increased significantly over the study period (Z = −6.2, p-value < .01). Prior to 2015, the number of cases involving fentanyl ranged from 0 to 3 per year; however, in 2017 the number of cases involving fentanyl increased to 14 cases. Subgroup analysis revealed there were no statistically significant changes in opioid-involved deaths by gender or urbanicity over this time period. In terms of race, there was a statistically significant decrease in the proportion of white drivers in opioid-involved crash deaths (Z = 2.4, p-value = .02).

3.3. Fatalities occurring at the scene of a motor vehicle crash

Maryland Emergency Medical Services (EMS) personnel routinely administer fentanyl to those who have been seriously injured in a crash (Maryland EMS, 2018). In order to account for opioid-administration due to injuries resulting from a crash, we also analysed the trend for fatalities occurring at the scene the crash (where opioids for pain relief are unlikely to be administered) and compared these to the remaining crash deaths. Fig. 2 shows no significant increase trend in deaths occurring at the scene of a crash shows a non-significant result (Z = −0.3; p-value = .36). A significant increasing trend was observed for those deaths that occurred after the crash itself (i.e. not at the scene) (Z = −2.7; p-value < .01). Of particular note, fentanyl-involved crash deaths increased significantly for deaths occurring at the scene of a crash (Z = −3.7, p-value < .01). The remaining results presented in this paper are for opioid-involved crash deaths occurring at the scene of the crash.

Geographic variation in opioid- and non-opioid involved crash deaths: Maryland is notable for its variation in population density and rurality. In Figs. 3, 4 and 5 we present the counts, rates (by population) and rates (by vehicle miles travelled) of opioid-involved crash deaths and non-opioid crash deaths by county.

3.4. Crash counts

Generally, counts of opioid and non-opioid-involved crash deaths by county corresponded to the most populous counties (Fig. 3). For example, Baltimore County has the largest number of opioid-involved deaths from 2006 to 2017 (20% of all opioid involved motor vehicle fatalities in Maryland). Baltimore County also accounts for around 14% of Maryland's population, and is its third most populous county (see map on the left). Prince George's county has the highest rate of non-opioid involved driver fatalities, accounting for 18 percent of non-opioid involved driver fatalities and 15% of the total population (map on the right). However, there were exceptions such as Montgomery

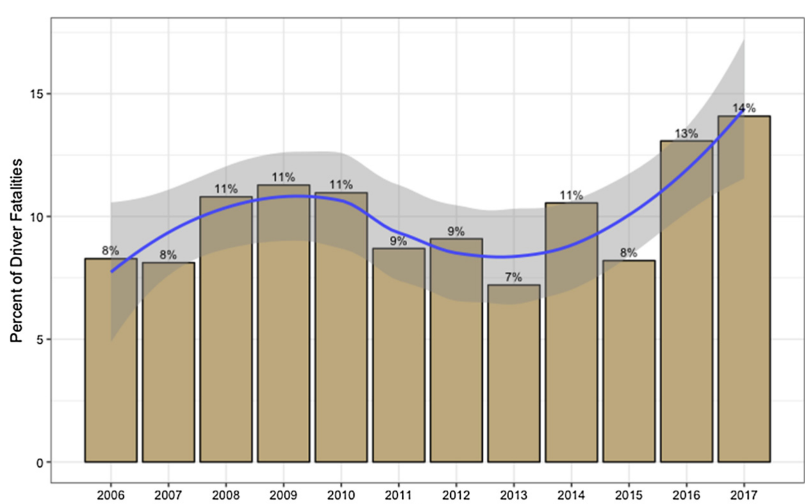

Fig. 1. Percent of Motor Vehicle Fatalities Involving Opioids.

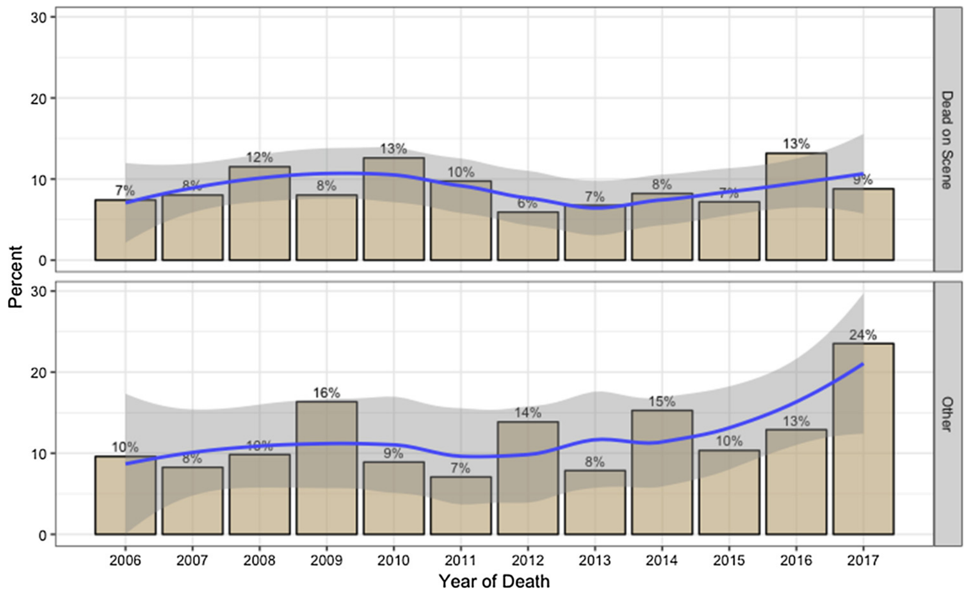

Fig. 2. Prevalence of Opioids by Year and Time of Death.

county which is the most populous county in Maryland, but had few opioid-involved driver fatalities, whereas Cecil county is a much less populated, but had more cases of opioid-involved driver fatalities than many surrounding counties. The counts of opioid-involved crash deaths by county are strongly correlated to the counts of overall opioid overdose deaths in the county (Spearman's rho = .77, p-value < .01) which suggests opioid-involved driver fatalities largely reflect broader patterns of opioid deaths.

3.5. Crash rates (by population)

After adjusting for population, Maryland's rural counties have the highest rates of fatalities of opioid-involved fatalities (Fig. 4). These counties include Cecil, Kent, Queen Anne's, and Caroline, of which Cecil, which has the highest rates per 100,000 people (17 opioid-involved driver fatalities per 100,000 people). Among non-opioid involved cases, the figure is similar in highlighting more rural counties, however the contrast between rural and urban counties is not as stark as for the figure for opioid-involved cases.

3.6. Crash rates (by vehicle miles travelled)

An additional geographic characteristic not captured by accounting for the population size is the exposure to driving. One commonly used measure for exposure is Vehicle Miles Travelled (VMT). In Fig. 5, Counties with the higher death rates by vehicle miles travelled correspond to Maryland's more rural counties for both opioid and non-opioid involved cases. Similar to opioid-involved crash rates by population, rural counties, such as Cecil and Kent, appear to be over-represented in opioid-involved crash deaths relative to the non-opioid deaths.

4. Discussion

This research presents for the first time, a multidimensional perspective of the opioid-involved crash deaths in Maryland. Using a distinctive data source that allowed for a nuanced analytical approach, the findings provide new insight into the nature and distribution of opioid-involved deaths in this state. When examining all crash deaths, we found evidence of a significant increase in the prevalence of opioid-involved deaths on Maryland's roadways. However, when the analysis was restricted to include deaths occurring at the scene of the crash, no significant change in the prevalence of opioid was detected. The observed increase in all opioid-involved crash deaths may reflect practices in pain management at the crash scene or following a crash. This suggests that the prevalence of opioid-involved crash deaths may be artificially increased by administration of opioid analgesics for pain in crash victims. Future studies may consider constricting the definition of cases to those deaths that occurred on the scene. We also found that the presence of opioids was higher among drivers who were middle aged, and white drivers. Finally, we found that in drivers who died in Maryland, almost two-thirds (63.1%) had positive toxicological results for alcohol or other drugs.

Prior research examining trends in prescription opioids in drivers in fatal crashes in 6 U.S. states found the prevalence increased from 1.0% in 1995 to 7.2% in 2015 (Stanford Chihuri and Li, 2017). This work did not demonstrate a similar increasing trend, which could be for several

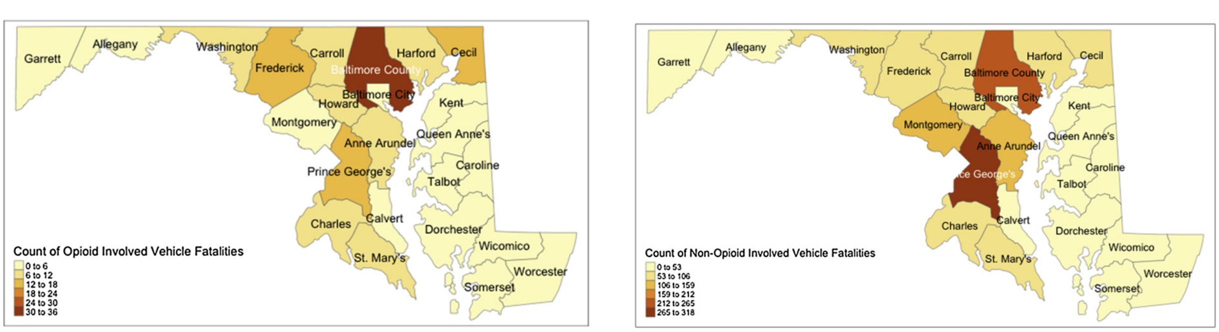

Fig. 3. Count of Opioid and Non-Opioid Involved Motor Vehicle Fatalities by County.

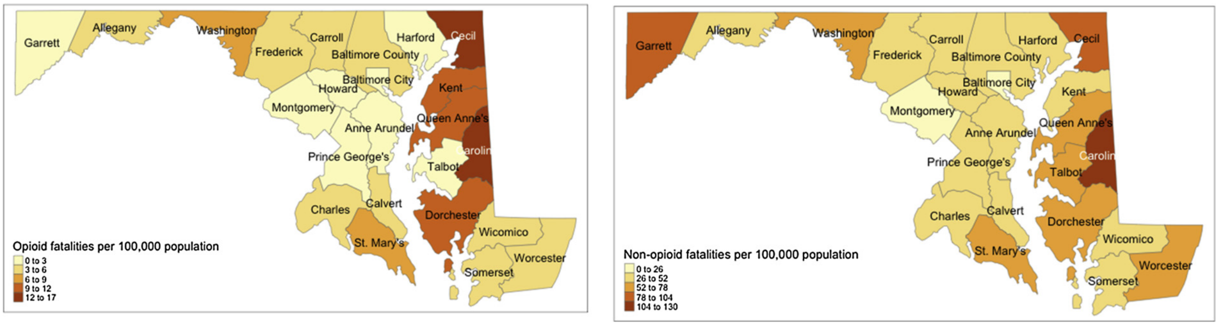

Fig. 4. Motor Vehicle Fatality Rates by County, per 100,000 people.

reasons. First, the data included in this analysis was more recent, so it could be that the majority of the increase in the prevalence of opioids occurred before 2006. Additionally, Maryland was not one of the states included in the prior research, which may reflect regional differences in the use of opioids. It is interesting to note that for all of the years of analysis in this work, Maryland was consistently higher than 7.2% prevalence of opioids in fatally injured drivers.

Based on the spatial analysis, we can conclude that the presence of opioids was higher in driver fatalities occurring in rural counties, and this reflect broader patterns of opioid overdose deaths across the state. Counties with higher opioid-involved driver fatalities corresponded to counties with a higher prevalence of opioid overdoses and therefore opioid use. Based on this finding, one could interpret the information in Fig. 5 indicates the relative likelihood of encountering drivers with opioids in their system. This work has identified areas where the prevalence of opioid-involved vehicular deaths is the highest. These counties can be important focal points for efforts to combat opioid abuse. The increased risk of crashing on rural roads could be a contributing factor for these findings. Therefore, part of the underlying cause between the relative county shares of VMT could be that rural roads have more hazardous conditions, such as having one lane roads, less lighting, and narrower roadways (Clark and Cushing, 2004).

This research found that the presence of opioids on Maryland roads is concentrated predominantly in the middle-aged Caucasian population. This research did not analyse prescription opioids, due to the inability to tell whether opioids were obtained legally through identification of the substance alone. Other research, however, identifies opioids administered therapeutically as a major contributing factor to the prevalence of opioid-related deaths (Madras, 2017). Opioid analgesics are now the most commonly prescribed class of medications in the United States, and researchers are beginning to draw a link between an increase in prescribing opioids and the increase in opioid deaths (King et al., 2014; Volkow and McLellan, 2016). This points to an important role of the health sector in altering pain management and prescribing practices in ways that can reduce the risk for opioid abuse and dependency, and the need for a combined and collaborative effort between healthcare providers, law enforcement, and legislators. Recent efforts in this regard include increased prescription monitoring programs, opioid prescribing caps, and laws directed at regulating pain clinics (McGinty et al., 2018).

Prior research has found that drugs, including opioids, may more than double drivers' risk of being involved in fatal motor vehicle crashes (Elvik, 2013; Li et al., 2013). Accounting for an average of 10 percent of Maryland's motor vehicle fatalities over the past decade, opioids are an important class of substances to monitor. It should be noted that a positive test indicates that the driver had the identified substance in their system at the time of death, but an important qualification is that this does not necessarily mean the driver was impaired by the drug at the time of the crash.

Limitations: There are a few notable limitations resulting from how opioid cases were identified from the medical examiner data. One major limitation is using positive toxicology results to indicate opioid cases, without use of any threshold. Although some studies use threshold levels to classify only cases with amounts of a substance above a certain level as positive cases (Stanford Chihuri and Li, 2017; Kuypers et al., 2012), many do not specify a threshold level (Poulsen et al., 2014; Rudisill et al., 2014; Monárrez-Espino et al., 2016). Moreover, we did not find any consensus in the literature on a level of opioids presence in toxicological results that could indicate impairment. To reduce the influence of cases that may have been administered opioids post-crash, we analysed a sub-sample of cases to those where the death occurred at the scene of the crash. We also replicated the approach of Stanford Chihuri and Li (2017) by analysing drivers that died within an hour of the crash. The results for opioid-involved deaths occurring with an hour following the crash were similar to the results for opioid-involved deaths occurring at the scene of the crash; therefore we chose the stricter definition of deaths occurring at the scene, as deaths within an hour could have included the administration of opioids as part of medical intervention. To the best of our knowledge this is the first study to compare all opioid-involved crashes to those occurring at the scene of the crash. As shown in Fig. 2, this restriction has significant implications on the results and interpretation of trends.

Another limitation is in regard to the comprehensiveness of the data source, which could have implications for the representativeness and

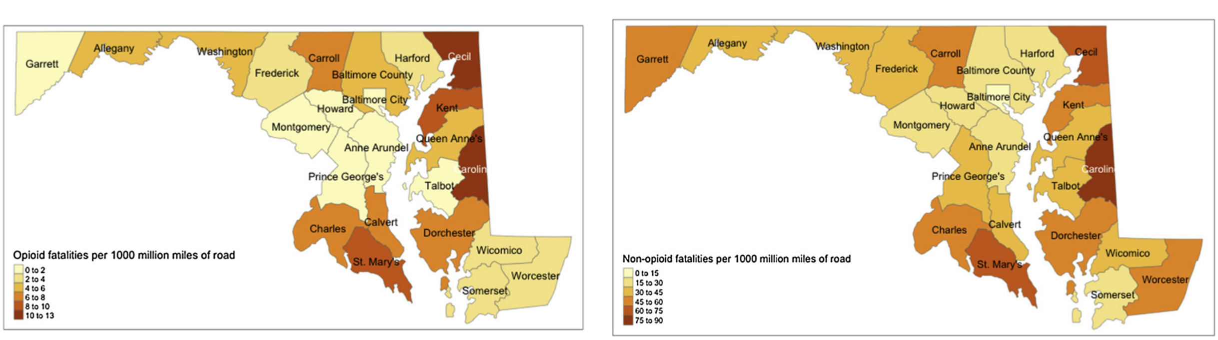

Fig. 5. Rate of Motor Vehicle Fatalities Relative to Vehicle Miles Travelled.

generalizability of the results. Prior research has found several limitations with medical examiner's data, namely that medical examiner reports generally underreport the actual number of injury deaths and may overrepresent certain demographics (Dijkhuis et al., 1994). There are also drugs that may not be tested for by the Medical Examiner's Office; for our dataset this included Cannabis. Data from the Medical Examiner do not distinguish commercial vehicles from other vehicles. Commercial drivers' crash risk is distinct from other drivers (Robb et al., 2008) and they are subject to drug testing and limits on the number of hours they can drive. Therefore the inclusion of commercial drivers in this sample may lead to an under-reporting of opioid-involved crash deaths in the general population. These are important considerations while analysing the data; even still, medical examiner reports contain a wealth of detailed information that is not available through other sources.

Future work: Given the difficulty in establishing a causal link between opioids and crashes, an important area for future research will be to determine and establish thresholds for opioid intoxication. Examining trends in the use of opioids in combination with alcohol and other drugs could inform the extent to which opioids should receive prioritized resources over other substances that impair driving. Trends in the time of day and seasonal variation could also lead to a better understanding of the mechanism involved in opioid-involved motor vehicle fatalities and how to develop policy solutions to tackle this significant public health issue. Another avenue of research would link Medical Examiner data to other dataset. For example, Medical Examiner data could be linked to other sources of motor vehicle crash data to determine if the drivers who tested positive for opiates were more likely to be culpable for the crash. Lastly, as more health databases become available for researchers, such as the Prescription Drug Monitoring Programs, further linkages could be made to determine the licit or illicit nature of opioid use.

5. Conclusion

The prevalence and characteristics of opioid-involved motor vehicle fatalities are an under-examined area of the literature. Data from the Medical Examiner in Maryland indicate that opioid-involved crash deaths are increasing and are not uniformly distributed within the population. White, middle-aged, older adults and those living in rural counties are over-represented in opioid-involved crash deaths. These data can be used for targeted prevention and enhanced enforcement efforts, as well as monitoring trends in opioid-involved crash deaths.

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