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Associations between Neighborhood-Level Factors and Opioid-Related Mortality: A Multilevel Analysis using Death Certificate Data

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Abstract

Aim.—To identify associations between opioid-related mortality and neighborhood-level risk factors.

Design.—Cross-sectional study.

Setting.—Massachusetts, USA.

Participants.—Using 2011–2014 Massachusetts death certificate data, we identified opioid-related (n=3,089) and non-opioid-related premature deaths (n=8,729).

Measurements.—The independent variables consisted of four sets of neighborhood-level factors: (1) psychosocial, (2) economic, (3) built environment, and (4) health related. At the individual level we included the following compositional factors: age at death, sex, race/ethnicity, marital status, education, veteran status, and nativity. The primary outcome of interest was opioid-related mortality.

Findings.—Multilevel models identified number of social associations per 10,000 (OR=0.84, p=0.002, 95% CI=0.75–0.94) and number of hospital beds per 10,000 (OR=0.78, p<0.001,

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95%CI=0.68–0.88) to be inversely associated with opioid-related mortality, whereas percent living in poverty (OR=1.01, p=0.008, 95% CI=1.00–1.01), food insecurity rate (OR=1.21, p=0.002, 95%CI=1.07–1.37), number of federally qualified health centers (OR= 1.02, p=0.028, 95%CI=1.02–1.08), and per capita morphine milligram equivalents of hydromorphone (OR=1.05, p=0.003, 95%CI=1.01–1.08) were positively associated with opioid-related mortality.

Conclusions.—Opioid-related deaths between 2011–2014 in the state of Massachusetts appear to be positively associated with percent living in poverty, food insecurity rate, number of federally qualified health centers, and per capita morphine milligram equivalents of hydromorphone, but inversely associated with number of social associations per 10,000 and number of hospital beds per 10,000.

Keywords

opioids; mortality; neighborhood; death certificate; psychosocial; economic; built environment; health services; multilevel

Introduction

The opioid crisis has emerged as a serious global public health problem. In 2016, there were approximately 34 million opioid users worldwide.[1] Opioids, both prescription painkillers and illicit drugs, have analgesic effects and rewarding properties[2] that enable dependence and addiction.[3] According to the World Drug Report, among individuals with a drug use disorder, opioids were associated with 76% of overdose deaths.[1] In the United States, opioid misuse, abuse, and overdose have dramatically increased over the past 20 years. In 2017, more than 47,600 U.S. residents died from an opioid overdose, the highest number of opioid-related deaths ever recorded in the U.S.[4] The state of Massachusetts has followed a similar trajectory, with the number of opioid-related deaths more than doubling between 2013–2017.[5] Prior studies have tracked the prevalence of opioid use and deaths worldwide, as well as evaluated the individual-level characteristics associated with opioid use and mortality.[1, 6–8] Other studies have assessed the promise of supply-side health policy interventions, such as increasing border control to eliminate drug trafficking and reducing the availability of opioids.[6, 9–11] Evidence suggests that neither individual-level or supply-side interventions will be entirely effective, and focusing on individual-level interventions may result in more drug-related arrests without an accompanying decrease in heroin-related deaths.[12] As the geography and demographics of the opioid epidemic expand,[13, 14] it is critical to examine how community contextual characteristics are associated with opioid-related mortality to help inform the development of population-level interventions and harm reduction policies.

We categorize neighborhood predictors of opioid-related mortality into four sets of factors: 1) psychosocial; 2) economic; 3) built environment; and 4) health-related.[15] ***Psychosocial factors*** can be defined as the influence of social relationships and perceived social control on health outcomes.[15] Evidence suggests that areas with high levels of social disorder, result in lower levels of social efficacy (i.e., community supervision, involvement, and trust)[16, 17] and informal social control (i.e., internalization of social norms and values).[18–21] For example, lack of supervision and low community involvement are associated with high crime rates

and feelings of estrangement,[17] and may contribute towards a higher incidence of opioid use in a neighborhood, and a decreased probability of intervention by neighbors in the event of an overdose.

Economic factors refer to individual- and group- level economic resources that influence health.[15] For example, residents living within high poverty neighborhoods, as opposed to lower poverty neighborhoods, may be more vulnerable to the entry of illegally distributed opioids, more likely to opt for illicit opioids due to the cost of prescription medications and/or a lack of medical insurance, have less time to dedicate to rehabilitation, and have more desire for pain medication due to the physical and mental stress of their job.[23]

The ***built environment*** refers to the human-made space that surround where we live,[15] influencing health through housing quality, availability of green space, public transit, and access to food sources. Research suggests that the built environment can influence people's routine behavior, health, and social patterns.[24–27] The built environment may influence the willingness of neighbors to intervene in an emergency, whether and where people choose to use opioids, and the risk for deaths resulting from mixing opioids with other substances.[28, 29]

Finally, ***health-related factors*** refer to risky behaviors (e.g. heavy drinking) as well as the use, availability, and access to health services (e.g. number of hospital beds and supply of prescription opioids). Evidence suggests that certain risky behaviors can be normalized when highly prevalent.[30] For example, person that misuse opioids and live in neighborhoods with a high percent of heavy drinkers, may be at higher risk of combining alcohol and opioids, which can lead to overdose and subsequent emergency department use and/or hospitalization.[31, 32] An individual's ability to access pharmaceuticals and other health services may influence their need for pain medication, decisions on how to acquire opioids, ability to find office-based opioid treatment with medication assisted treatment (e.g., buprenorphine), and access to emergency health services in the event of an overdose.[23, 34]

In this study, our primary aim is to 1) identify associations between opioid-related mortality and neighborhood-level risk factors and 2) graphically illustrate the distribution of opioid-related and non-natural premature deaths at the neighborhood-level. Using state death certificate data linked to area-level data and multilevel models, we compare the influence of individual-level variables to neighborhood-level factors and identify associations that may be useful to public health practitioners, policymakers, and clinicians seeking to address opioid-related mortality.

Methods

Data

We used 2011–2014 all-age death certificate data (n=188,561) obtained from the Office of Data Management and Outcomes Assessment, Massachusetts Department of Public Health. Data include decedents' address at time of death and individual-level demographics (e.g., age at death, race, nativity, marital status, and cause of death). Data were geocoded using the decedents' primary residence at time of death (188,473 deaths successfully geocoded).

Deaths from natural causes (n=176,567) and with missing addresses (n=88) were excluded. Neighborhood-level data were merged using Federal Information Processing Series (FIPS) codes to the Area Health Resource File (AHRF), datasets identified through PolicyMap[36], Robert Wood Johnson Foundation (RWJF) County Health Rankings, U.S. Department of Justice (USDOJ) Crime Statistics Reports and the Automated Reports and Consolidated Ordering System (ARCOS), and U.S. Census data at the county and block group levels. Block groups, which consist of approximately 1,500 inhabitants, are the smallest geographic unit for which the U.S. Census provides descriptive statistics. We used block group-level data when possible to better localize the social, economic and health structures and behaviors that occur within communities.

Dependent Variable—The primary outcome was a dichotomous variable (1=opioid-related death; 0= non-natural premature death unrelated to opioid use). A death was classified as opioid-related if the underlying cause was from a drug overdose and had a primary, secondary, or tertiary cause of death of opioid use disorder (OUD)[37] (n=3,089). We used the first three causes of death to have a robust sample and increase estimate precision. Additionally, there is evidence of variability in the position (e.g. primary, secondary, or tertiary diagnosis) that coroners and medical examiners record opioid-related deaths.[38] Our approach helps minimize the under-identification of opioid-related death. Non-natural premature deaths were those categorized as accidents, homicides, suicides, undetermined, pending an investigation, or unclassifiable (n=8,729).

Independent Variables—Using PubMed/Medline, we identified area-level factors found to impact mental health and physical health,[39–42] substance use,[43–45] overdose,[29] and mortality.[29, 46] Based on clinical expertise and strong conceptual links to opioid-overdose death, we refined and curated a list of area-level variables that were organized according to our four overarching categories. The social networks and interactions that take place within neighborhoods (block group) are likely to have a more immediate and direct effect than those at larger geographic units of observation, but we retain certain higher-level variables when census block group data is unavailable because of their conceptual importance.

Block group-level ***psychosocial*** **factors** included: 1) Percent of White residents (measured by the U.S. Census); 2) Theil Index, a measure (range 0 to 1) of residential segregation, where 0 indicates a block group has an equal distribution of racial/ethnic households (i.e. maximum integration) and a score of 1 suggests a block group is completely homogenous (i.e. maximum segregation);[47] 3) Percent of single female-headed households (measured by the U.S. Census); and 4) Percent of owner occupied homes (measured by the U.S. Census). County-level psychosocial factors are: 1) Number of robberies per 100,000 (measured by the USDOJ Crime Statistics Report); and 2) Number of social associations per 10,000, such as civic, religious, political, or sports organizations (measured by the RWJF County Health Rankings).

Block group-level ***economic*** **factors** are: 1) Percent of families living in poverty (measured by the U.S. Census), an income measure found to be more robust than median household income;[48] and 2) Percent of cost-burdened renters, a housing-related measure of financial hardship.[49] County-level economic factors are: 1) Rate of food insecurity; 2) Percent of

residents on SNAP (food stamps) benefits; and 3) the 2011–2015 unemployment rate (measured by the U.S. Census).

Built environment **factors** at the block group-level are: 1) Percent of residents taking public transit to work; 2) Percent moved into the area between 2000 and 2009 (measured by the U.S. Census), captures the in-migration that may signal changing neighborhood dynamics that may influence opioid-related mortality;[23] 3) Percent of vacant rental units (measured by the U.S. Census); and 4) Limited access to supermarkets, where higher values indicate greater inadequacies in access to healthy food options.[50]

Health-related factors at the county-level downloaded from the AHRF are: 1) Number of Federally Qualified Health Centers (FQHCs); 2) Number of hospital beds per 10,000; 3) Number of emergency room visits per 10,000; 4) Number of HIV cases per 100,000, reflects a risky behavior that is associated with intravenous drug use (e.g. heroin); and 5) Percent of heavy drinkers. From the USDOJ-ARCOS system, we obtained the amount of opioids (Oxycodone, Hydromorphone, Morphine, and Fentanyl) distributed to retailers by manufacturers, converted to county-level per capita grams of morphine milligram equivalents (MME).[51] At the block group-level, we included percent of residents working in construction, (measured by the U.S. Census). Considered a risky profession as this occupation is likelier than others to misuse prescription opioids, experience opioid-related overdose, and die from opioid misuse - accounting for 25% of total opioid-related deaths in Massachusetts, 2011–2015.[33]

At the individual level, we include: age at death, year of death, sex, race/ethnicity, marital status, education, veteran status, and nativity. Adjusting for these individual-level factors allows us to identify neighborhood differences after accounting for the demographic profiles of those communities that have been shown to be related to opioid-related deaths in Massachusetts, e.g., opioid use disorder rates are higher among Whites than racial/ethnic minorities,[40] higher among veterans,[52] and nearly equal between men and women.[44]

Statistical Analysis

To characterize the sample, we compared individual- and neighborhood-level characteristics between decedents with an opioid-related cause of death and decedents with non-natural premature causes unrelated to opioid use. We used t-tests and chi-square tests to compare the groups on continuous and categorical variables, respectively.

The data have a multilevel structure with individuals at level 1, nested within 2,517 census block groups in level 2, nested in 14 counties at level 3. Multilevel models enable analysis of both area-level and individual-level correlates, while accounting for the non-independence of individuals living in the same geographic area.[53] To construct multilevel models, we first explored the most appropriate geographic level(s) to include in our models by examining mean outcomes by level (county, census tract, census block group, census block) for individuals with opioid-related death and non-natural premature causes of death and by estimating null multilevel models (with no covariates). We model at the census block group and county level for conceptual reasons – individuals living within census block groups were

expected to have similar substance use outcomes because of the locality of social networks, resiliency, and individuals living within counties are expected to have similar behavioral health treatment options because of important county-level provider characteristics.[54, 55] Maps of opioid-related mortality and non-natural premature mortality were provided by census block groups for the state of Massachusetts and the Boston metropolitan area to provide a visual representation of the outcome.

For our main analysis where we identify associations between neighborhood-level risk factors and opioid-related mortality, we first estimated a null random intercepts model without covariates to assess unadjusted variation in the outcome variable at the individual, block group- and county-levels. Then, we specified a model with all individual-level demographics and all area-level risk factors. Linearity of continuous variables were checked graphically by plotting them against the log-odds of the outcome. Departures from linearity were further checked by testing the inclusion of polynomial terms or restricted cubic splines.[56] To assess the robustness of our findings, we conducted several sensitivity analysis. First, we reran regression models limiting cause of death to the primary diagnosis (Appendix Table 1), checking the potential impact of under-identifying opioid-related cases. Second, we reran regression models excluding homicides and suicides from non-natural premature deaths (Appendix Table 2), which are causes of death related to risky neighborhood environments and may influence our results. Third, we ran regression models sequentially adding area-level risk factor categories (Appendix Table 3).

Because we were interested in the influence of census block group- and county-level variables, we let intercepts vary by census block group and county in each model but held fixed the effects of all covariates. This random intercepts modeling strategy accounts for variation in unmeasured census block group- and county-level effects, but differs from random effects models in that it assumes that the effect, or return, of measured factors is similar across census block groups and counties. All models were estimated using multilevel mixed effects logistic regression models in Stata 14.[57] Our analysis was not pre-registered and results should be considered exploratory. This project was approved by the Institutional Review Board.

Results

Table 1 provides the descriptive characteristics of our sample population. Persons with opioid-related deaths compared to non-natural premature deaths, were likelier to be between 25 and 54 years of age, male, non-Hispanic White, non-married, high school graduates, non-veterans, and born in the US. Significant differences existed between groups on area-level factors. Relative to persons with non-natural premature deaths, persons with opioid-related deaths resided in block groups with a greater percentage of single female-headed households, residents living in poverty, and cost-burdened renters. Persons with opioid-related deaths, compared to persons with non-natural premature deaths, also lived in block groups with a lower percentage of owner-occupied homes.

Results from the regression analysis (Table 2) showed the ***psychosocial factor,*** number of social associations per 10,000 county residents, was negatively associated with opioid-

related mortality. The ***economic factors,*** percent living in poverty at the block group-level and food insecurity rate at the county-level were positively associated with opioid-related mortality. Regarding county-level ***health-related factors***, number of hospital beds was a negatively associated with opioid-related mortality, while number of FQHC's and per capita MME of hydromorphone were positively associated with opioid-related mortality. Results did not show significant associations between opioid-related mortality and ***built environment factors***.

At the individual level, relative to persons aged 35–44 at time of death, those aged between 25–34 were likelier to have had an opioid-related death, while remaining age groups (0–14, 15–24, 45–54, and 65+) were less likely to have an opioid-related death (Table 2). Being female (compared to male) was also positively associated with opioid-related death. Individual-level factors that were negatively associated with opioid-related death included self-identifying as a racial/ethnic group other than White, being married (compared to unmarried), having more than a high school education (compared to less than a high school education), and being foreign-born (compared to US-born).

In our first sensitivity analysis, where cause of death was limited to the primary diagnosis (Appendix Table 1), similar to our main findings, social associations per 10,000 and number of hospital beds per 10,000 were negatively associated with opioid-related mortality, whereas percent living in poverty, food insecurity, and per capita MME of hydromorphone were positively associated with opioid-related mortality. Number of FQHCs was no longer significantly associated with the outcome. In our second sensitivity analysis, where homicides and suicides were excluded from non-natural premature deaths (Appendix Table 2), all associations were similar in direction and significance as our main findings. In our final sensitivity analysis, where categories of area-level factors we sequentially added to regression models (Appendix Table 3), several associations that were not prevalent in the main model were observed.

Figure 1 presents two heat maps of Massachusetts with each census block group shaded based on rates of opioid-related mortality and non-natural premature mortality. A number of adjoining census block groups had 1–2 opioid-related deaths, with notable groupings in the north-west and central part of the state (Figure 1a). Across the state were census block groups with 3–4 and 5+ opioid-related deaths. When looking at non-natural premature deaths (Figure 1b), there are few census block groups with 0 deaths and a larger number with 1+ non-natural premature death, compared to opioid-related deaths. To improve resolution in dense population areas, Figure 2 presents two heat maps of the above-named outcomes for the Boston metropolitan area by census block group. There is overlap between Figure 2a and 2b in the census block groups with 0 deaths. As in Figure 1, there are a number of census block groups with 1+ non-natural premature death, relative to opioid-related deaths.

Discussion

This study advances the current body of literature in several ways. First, the study focuses on Massachusetts, one of the top ten US states with the highest rate of opioid-related mortality.

[35] Second, by using state death certificate data, as opposed to clinical records, opioid-related mortality is captured both within and outside of the healthcare system. Third, we have done a conceptually-based scan of neighborhood-level variables, identifying several variables rarely used in the neighborhood and health literature (e.g. percentage of jobs in construction), in addition to more commonly-used neighborhood-level variables (e.g., percent single female-headed household), thought to be associated with opioid-related deaths. In our study, we identified that specific area-level psychosocial, economic, and health-related factors were significantly associated with opioid-related mortality. In particular, we identified that a greater number of social associations and number of hospital beds in the area were negatively associated, whereas poverty, food insecurity, number of FQHC's, and availability of hydromorphone were positively associated with opioid-related mortality.

The number of residents participating in social associations can be viewed as a measure of neighborhood engagement and cohesion. Increased familiarity between neighbors via formal group settings may enhance collective guardianship of a neighborhood, feelings of inclusion and belonging, and builds trust.[16–21] Social organization participation may suggest greater levels of social cohesion/social capital, which is a positive predictor of overall health, and appears in this study to be inversely associated with opioid-related mortality. Analogous results were found by Lundborg in his assessment of social capital and substance use among Swedish adolescents, where higher levels of social participation (i.e. involvement in political groups or athletic clubs) were inversely related with illicit drug use.[58]

The inverse relationship between number of hospital beds per county and opioid-related mortality suggest hospitals may play an important role in the opioid epidemic. Individuals with OUD may obtain substance use treatment, detoxification, or short-term inpatient services within a hospital setting. Bed availability means people can obtain needed inpatient medical attention and an opportunity for clinical staff to engage people in evidence-based treatment such as medication assisted therapy. However, insufficient supply of hospital beds and traditional barriers to care, such as health insurance status and ability to pay, may impede access to these timely and needed services, which can lead to the increase risk of homelessness, incarceration, and overdose. Our findings coincide with the state increasing the number of detox beds, limiting opioid prescriptions, and educating medical professionals on appropriate pain management and addiction treatment.[59] Continued efforts to expand the number of hospital beds may help to explain the 8.3% decrease in opioid-related overdose deaths in Massachusetts between 2016 and 2017.[60]

Poverty and food insecurity were found to be positively associated with opioid-related death. Our results are concordant with those of prior studies in the U.S. as well as India and Luxembourg which found significant associations between area-level socioeconomic disadvantage and opioid misuse and opioid-related overdose.[6–8, 61, 62,63] The ties between economic insecurity, pain management, and opioid misuse have been cited as an explanation for recent increases in mortality among middle-aged Whites. We add to this explanation by identifying that individuals living in neighborhoods with a high level of economic insecurity may be at risk for opioid-related mortality. Likewise, food insecurity has been shown to interfere with access to harm reduction programs and other health and social support

programs, and communities where food insecurity is widespread may make it more difficult to maintain abstinence among those with OUD[64].

The positive association between number of FQHCs per county and opioid-related mortality was an unexpected result and may represent unmeasured levels of need for treatment services in a neighborhood given that FQHCs are frequently placed in geographic areas of highest medical need. Alternatively, having a larger supply of providers in a neighborhood may increase access to opioid-based painkillers in the early part of this decade when pain medications were less regulated. Since the time of the data under analysis, state level prescription monitoring efforts have been increased that may have reduced the association between FQHCs and opioid-related deaths. Evaluating this association of these efforts with the decrease in opioid-related overdose deaths in Massachusetts is needed.[60]

The finding that hydromorphone is positively associated, with opioid-related mortality is consistent with prior work that found an increased supply of opioids are positively associated with overdose and mortality.[65] Hydromorphone is a potent schedule II opioid analgesic with similar abuse and dependence liabilities as oxycodone.[66] Between 2004 and 2011 there was a 140% increase in hydromorphone prescriptions,[67] which ran parallel to the upsurge in hydromorphone misuse diagnosed within emergency departments.[68] Our findings of a significant association with hydromorphone but not oxycodone is consistent with data from some states showing that between 2001 and 2012 hydromorphone-related deaths increased, while oxycodone-related overdose deaths declined.[69, 70] This suggests that illicit users may have shifted their use of prescription medications as oxycodone became more heavily regulated.[71, 72] The positive association between hydromorphone and opioid-related mortality suggests that the vigilance of prescription monitoring needs to be maintained to suppress the supply of opioids in the community. However, caution should be exercised as increased surveillance may lead persons that misuse prescription opioids to shift to illicit opioids, such as fentanyl-laced heroin, further increasing the risk of fatal overdose. As a means to combat both legal and illicit opioid misuse, Massachusetts has made naloxone, an opioid antagonist used to counter the effects of opioid overdose, widely available without a prescription.[73] Future research should assess the impact of expanding naloxone availability on opioid-related overdose and mortality.

A number of limitations of this study are worth mentioning. First, we did not include deceased individuals in the analysis where no address was available, possibly excluding homeless populations that might have significantly different neighborhood-level determinants of their death. Second, the study uses cross-sectional data and the identified associations should not be considered causal as we cannot determine temporality of outcome and exposures. Future studies capitalizing on longitudinal data, and assessing the dynamic relationships of individuals to their communities as they change residence, would greatly enhance our knowledge of the role of neighborhood and opioid-related mortality. Finally, not all variables were available at the census block group-level. While county variables provide a signal of the contextual situation of the deceased individuals, there is likely significant heterogeneity on these characteristics within counties that we were unable to identify.

Despite these limitations, we identified associations between several neighborhood-level factors and opioid-related mortality. As the opioid epidemic expands to include other geographic regions and populations both within and outside of the U.S., enhanced partnerships are needed between researchers and public health officials to monitor the crises. Our findings can help inform the development of future research agendas that seek better understanding of the causal link between neighborhood-level risk factors and opioid-related death to inform policy and development of population-level opioid interventions.

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Appendix

Appendix Table 1.

Mixed model regression results identifying associations between individual, census block group, and county-level characteristics with opioid-related mortality. [a, b]

Census Block Group and County Characteristics	OR	95% CI	
Psychosocial Factors			
Percent Single Female-Headed Household	1.00	0.99	1.01
Percent Owner Occupied	1.00	1.00	1.00
Percent White	1.00	1.00	1.01
Theil Index	0.49	0.19	1.28
Number of Robberies per 100,000 ‡	1.00	0.99	1.01
Number of Social Associations per 10,000 ‡	0.86	0.76	0.97
Economic Factors			
Percent Living in Poverty	1.01	1.00	1.01
Percent of Cost Burdened Renters	1.00	1.00	1.00
Unemployment Rate ‡	1.00	0.98	1.01
Percent SNAP ‡	1.00	0.92	1.07
Food Insecurity Rate ‡	1.19	1.04	1.36
Built Environment Factors			
Percent Moved between 2000 to 2009	1.00	0.99	1.00
Percent of Workers Taking Public Transit	1.00	1.00	1.01
Percent Vacant Housing Units	1.00	1.00	1.00
Limited Access to Supermarkets	1.00	1.00	1.00
Health Related Factors			
Percent Working in Construction Occupations	1.00	0.99	1.01
Percent of Heavy Drinkers ‡	1.03	0.91	1.18
Number of FQHC's ‡	1.02	1.00	1.05
Number Hospital Beds per 10,000 ‡	0.78	0.68	0.90
Number of ER Visits per 10,000 ‡	1.00	1.00	1.00
Number HIV cases per 100,000 ‡	1.00	1.00	1.00

Census Block Group and County Characteristics	OR	95% CI	
Per Capita MME Oxycodone ‡	1.00	1.00	1.00
Per Capita MME Hydromorphone ‡	1.05	1.01	1.09
Per Capita MME Morphine ‡	0.99	0.98	1.00
Per Capita MME Fentanyl ‡	1.00	0.99	1.00
Individual-Level Factors			
Age (35–44 Referent)			
0–14	0.01	0.00	0.05
18–24	0.50	0.40	0.62
25–34	1.11	0.94	1.31
45–54	0.65	0.56	0.77
55–64	0.40	0.33	0.48
65+	0.02	0.01	0.02
Female (Male Referent)	1.20	1.06	1.36
Race (Non-Latino White Referent)			
Asian	0.11	0.04	0.29
Non-Latino Black	0.23	0.17	0.31
Latino	0.58	0.44	0.77
Other Race/Ethnicity	0.30	0.18	0.51
Married (Unmarried Referent)	0.69	0.60	0.80
Education (<High School Referent)			
High School Graduate	1.01	0.85	1.20
More than High School, Less than College Graduate	0.78	0.63	0.96
College Graduate or More	0.46	0.36	0.58
Veteran	1.05	0.80	1.39
Foreign-born	0.65	0.52	0.81
Year of Death (2011 as referent)			
2012	1.29	1.07	1.57
2013	1.49	1.20	1.86
2014	1.99	1.59	2.49

*** p<0.001;

** p<0.01;

* p<0.05

OR: Odds ratio, CI: Confidence interval

a. Opioid-related mortality: Primary cause of death had an ICD-10 code related to opioid use disorder (ICD-10 T40.0, T40.1, T40.2, T40.3, T40.4, or T40.6)

b. Variables included simultaneously adjusting for each other

‡ County-level

Appendix

Appendix Table 2.

Mixed model regression results identifying associations between individual, census block group, and county-level characteristics with opioid-related mortality. [a, b, c]

Census Block Group and County Characteristics	OR	95% CI	
Psychosocial Factors			
Percent Single Female-Headed Household	1.00	0.99	1.01
Percent Owner Occupied	1.00	1.00	1.00
Percent White	1.00	1.00	1.01
Theil Index	0.48	0.18	1.23
Number of Robberies per 100,000 ‡	1.00	0.99	1.02
Number of Social Associations per 10,000 ‡	0.86	0.76	0.96
Economic Factors			
Percent Living in Poverty	1.01	1.00	1.01
Percent of Cost Burdened Renters	1.00	1.00	1.00
Unemployment Rate ‡	0.99	0.97	1.01
Percent SNAP ‡	0.99	0.92	1.06
Food Insecurity Rate ‡	1.24	1.09	1.42
Built Environment Factors			
Percent Moved between 2000 to 2009	1.00	0.99	1.00
Percent of Workers Taking Public Transit	1.00	1.00	1.01
Percent Vacant Housing Units	1.00	1.00	1.00
Limited Access to Supermarkets	1.00	1.00	1.00
Health Related Factors			
Percent Working in Construction Occupations	1.01	1.00	1.01
Percent of Heavy Drinkers ‡	1.01	0.89	1.15
Number of FQHC's ‡	1.02	0.99	1.04
Number Hospital Beds per 10,000 ‡	0.75	0.65	0.86
Number of ER Visits per 10,000 ‡	1.00	1.00	1.00
Number HIV cases per 100,000 ‡	1.00	1.00	1.00
Per Capita MME Oxycodone ‡	1.00	1.00	1.00
Per Capita MME Hydromorphone ‡	1.05	1.01	1.09
Per Capita MME Morphine ‡	0.99	0.98	1.00
Per Capita MME Fentanyl ‡	1.00	0.99	1.00
Individual-Level Factors			
Age (35–44 Referent)			
0–14	0.01	0.00	0.03
15–17	0.01	0.00	0.11
18–24	0.50	0.40	0.63
25–34	1.15	0.97	1.37
45–54	0.62	0.53	0.73
55–64	0.34	0.28	0.41
65+	0.01	0.01	0.02

Census Block Group and County Characteristics	OR	95% CI	
Female (Male Referent)	1.04	0.92	1.18
Race (Non-Latino White Referent)			
Asian	0.21	0.11	0.42
Non-Latino Black	0.33	0.25	0.44
Latino	0.83	0.63	1.09
Other Race/Ethnicity	0.36	0.21	0.63
Married (Unmarried Referent)	0.79	0.69	0.91
Education (<High School Referent)			
High School Graduate	1.11	0.94	1.32
More than High School, Less than College Graduate	0.84	0.69	1.03
College Graduate or More	0.60	0.48	0.76
Veteran			
Foreign-born	0.94	0.72	1.24
Year of Death (2011 as referent)	0.60	0.48	0.74
2012	1.34	1.11	1.61
2013	1.43	1.16	1.77
2014	1.93	1.55	2.41

*** p<0.001;

** p<0.01;

* p<0.05

OR: Odds ratio, CI: Confidence interval

a. Opioid-related mortality: Primary, secondary, or tertiary cause of death had an ICD-10 code related to opioid use disorder (ICD-10 T40.0, T40.1, T40.2, T40.3, T40.4, or T40.6)

b. Homicides and suicides excluded from premature non-natural deaths

c. Variables included simultaneously adjusting for each other

ǂ County-level

Appendix

Appendix Table 3.

Mixed model step regression results identifying associations between individual, census block group, and county-level characteristics with opioid-related mortality. [a]

	Model 1		Model 2	
Census Block Group and County Characteristics	**OR**	**95% CI**	**OR**	**95% CI**
Psychosocial Factors				
Percent Single Female-Headed Household			1.00	1.00 1.01
Percent Owner Occupied			1.00	0.99 1.00
Percent White			1.00	1.00 1.01
Theil Index			0.53	0.23 1.19
Number of Robberies per 100,000 ǂ			1.00	1.00 1.00
Number of Social Associations per 10,000 ǂ			0.95	0.89 1.01
Economic Factors				

	Model 1			Model 2		
Census Block Group and County Characteristics	**OR**	**95% CI**		**OR**	**95% CI**	
Percent Living in Poverty						
Percent of Cost Burdened Renters						
Unemployment Rate ‡						
Percent SNAP ‡						
Food Insecurity Rate ‡						
Built Environment Factors						
Percent Moved between 2000 to 2009						
Percent of Workers Taking Public Transit						
Percent Vacant Housing Units						
Limited Access to Supermarkets						
Health Related Factors						
Percent Working in Construction Occupations						
Percent of Heavy Drinkers ‡						
Number of FQHC's ‡						
Number Hospital Beds per 10,000 ‡						
Number of ER Visits per 10,000 ‡						
Number HIV cases per 100,000 ‡						
Per Capita MME Oxycodone ‡						
Per Capita MME Hydromorphone ‡						
Per Capita MME Morphine ‡						
Per Capita MME Fentanyl ‡						
Individual-Level Factors						
Age (35–44 Referent)						
0–14	0.01	0.00	0.03	0.01	0.00	0.03
15–17	0.01	0.00	0.06	0.01	0.00	0.07
18–24	0.43	0.35	0.52	0.45	0.37	0.54
25–34	1.04	0.90	1.20	1.05	0.91	1.22
45–54	0.68	0.60	0.78	0.69	0.60	0.79
55–64	0.39	0.34	0.46	0.40	0.34	0.47
65+	0.02	0.01	0.02	0.02	0.01	0.03
Female (Male Referent)	1.26	1.13	1.40	1.25	1.12	1.39
Race (Non-Latino White Referent)						
Asian	0.24	0.13	0.44	0.22	0.12	0.41
Non-Latino Black	0.27	0.21	0.34	0.25	0.20	0.32
Latino	0.70	0.56	0.88	0.64	0.50	0.80
Other Race/Ethnicity	0.25	0.15	0.41	0.24	0.14	0.39
Married (Unmarried Referent)	0.68	0.60	0.76	0.69	0.61	0.78
Education (<High School Referent)						
High School Graduate	0.98	0.84	1.13	1.00	0.87	1.16
More than High School, Less than College Graduate	0.72	0.60	0.86	0.75	0.62	0.89
College Graduate or More	0.41	0.33	0.49	0.44	0.36	0.53

Census Block Group and County Characteristics	Model 1 OR	95% CI		Model 2 OR	95% CI	
Veteran	0.96	0.75	1.23	0.97	0.75	1.24
Foreign-born	0.66	0.55	0.80	0.65	0.54	0.78
Year of Death (2011 as referent)						
2012	1.34	1.17	1.54	1.35	1.18	1.55
2013	1.61	1.41	1.84	1.60	1.40	1.82
2014	2.11	1.83	2.43	2.12	1.84	2.44

Census Block Group and County Characteristics	Model 3 OR	95% CI		Model 4 OR	95% CI		Model 5 OR	95% CI	
Psychosocial Factors									
Percent Single Female-Headed Household	1.00	1.00	1.01	1.00	1.00	1.01	1.00	1.00	1.01
Percent Owner Occupied	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Percent White	1.00	1.00	1.01	1.00	1.00	1.01	1.00	1.00	1.01
Theil Index	0.54	0.23	1.24	0.55	0.24	1.27	0.52	0.22	1.21
Number of Robberies per 100,000 ‡	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.01
Number of Social Associations per 10,000 ‡	0.93	0.87	0.98	0.92	0.87	0.98	0.84	0.75	0.94
Economic Factors									
Percent Living in Poverty	1.01	1.00	1.01	1.01	1.00	1.01	1.01	1.00	1.01
Percent of Cost Burdened Renters	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unemployment Rate ‡	1.00	0.98	1.01	1.00	0.98	1.01	1.00	0.98	1.01
Percent SNAP ‡	0.97	0.94	0.99	0.97	0.94	1.00	0.99	0.92	1.05
Food Insecurity Rate ‡	1.06	0.98	1.14	1.06	0.98	1.14	1.21	1.07	1.37
Built Environment Factors									
Percent Moved between 2000 to 2009				1.00	0.99	1.00	1.00	0.99	1.00
Percent of Workers Taking Public Transit				1.00	1.00	1.01	1.00	1.00	1.01
Percent Vacant Housing Units				1.00	1.00	1.00	1.00	1.00	1.00
Limited Access to Supermarkets				1.00	1.00	1.00	1.00	1.00	1.00
Health Related Factors									
Percent Working in Construction Occupations							1.00	0.99	1.01
Percent of Heavy Drinkers ‡							1.01	0.90	1.13
Number of FQHC's ‡							1.02	1.02	1.08
Number Hospital Beds per 10,000 ‡							0.78	0.69	0.89
Number of ER Visits per 10,000 ‡							1.00	1.00	1.00
Number HIV cases per 100,000 ‡							1.00	1.00	1.00
Per Capita MME Oxycodone ‡							1.00	1.00	1.00
Per Capita MME Hydromorphone ‡							1.05	1.01	1.09
Per Capita MME Morphine ‡							0.99	0.99	1.00
Per Capita MME Fentanyl ‡							1.00	0.99	1.00
Individual-Level Factors									
Age (35–44 Referent)									
0–14	0.01	0.00	0.04	0.01	0.00	0.04	0.01	0.00	0.04

Census Block Group and County Characteristics	Model 3			Model 4			Model 5		
	OR	95% CI		OR	95% CI		OR	95% CI	
15–17	0.01	0.00	0.07	0.01	0.00	0.07	0.01	0.00	0.07
18–24	0.44	0.36	0.53	0.44	0.36	0.53	0.43	0.35	0.53
25–34	1.06	0.91	1.22	1.06	0.91	1.22	1.04	0.90	1.21
45–54	0.69	0.60	0.79	0.69	0.60	0.79	0.68	0.59	0.79
55–64	0.41	0.35	0.48	0.41	0.35	0.48	0.41	0.35	0.48
65+	0.02	0.01	0.03	0.02	0.01	0.03	0.02	0.01	0.03
Female (Male Referent)	1.25	1.12	1.40	1.25	1.12	1.39	1.24	1.12	1.39
Race (Non-Latino White Referent)									
Asian	0.22	0.12	0.42	0.22	0.12	0.42	0.22	0.12	0.42
Non-Latino Black	0.25	0.20	0.33	0.25	0.20	0.33	0.26	0.20	0.33
Latino	0.65	0.51	0.82	0.65	0.51	0.82	0.65	0.51	0.82
Other Race/Ethnicity	0.24	0.14	0.39	0.24	0.14	0.39	0.24	0.14	0.39
Married (Unmarried Referent)	0.70	0.62	0.79	0.70	0.62	0.79	0.70	0.62	0.79
Education (<High School Referent)									
High School Graduate	1.00	0.86	1.16	1.00	0.86	1.16	1.01	0.87	1.18
More than High School, Less than College Graduate	0.76	0.64	0.91	0.76	0.64	0.92	0.77	0.64	0.92
College Graduate or More	0.45	0.36	0.55	0.45	0.36	0.55	0.45	0.37	0.55
Veteran	0.96	0.75	1.24	0.96	0.75	1.24	0.94	0.73	1.21
Foreign-born	0.64	0.53	0.78	0.64	0.53	0.78	0.64	0.53	0.78
Year of Death (2011 as referent)									
2012	1.36	1.19	1.57	1.36	1.19	1.57	1.22	1.03	1.44
2013	1.59	1.39	1.82	1.59	1.39	1.82	1.38	1.14	1.67
2014	2.13	1.85	2.46	2.13	1.85	2.46	1.90	1.56	2.32

OR: Odds ratio, CI: Confidence interval

[a] Opioid-related mortality: Primary, secondary, or tertiary cause of death had an ICD-10 code related to opioid use disorder (ICD-10 T40.0, T40.1, T40.2, T40.3, T40.4, or T40.6)

[ǂ] County-level

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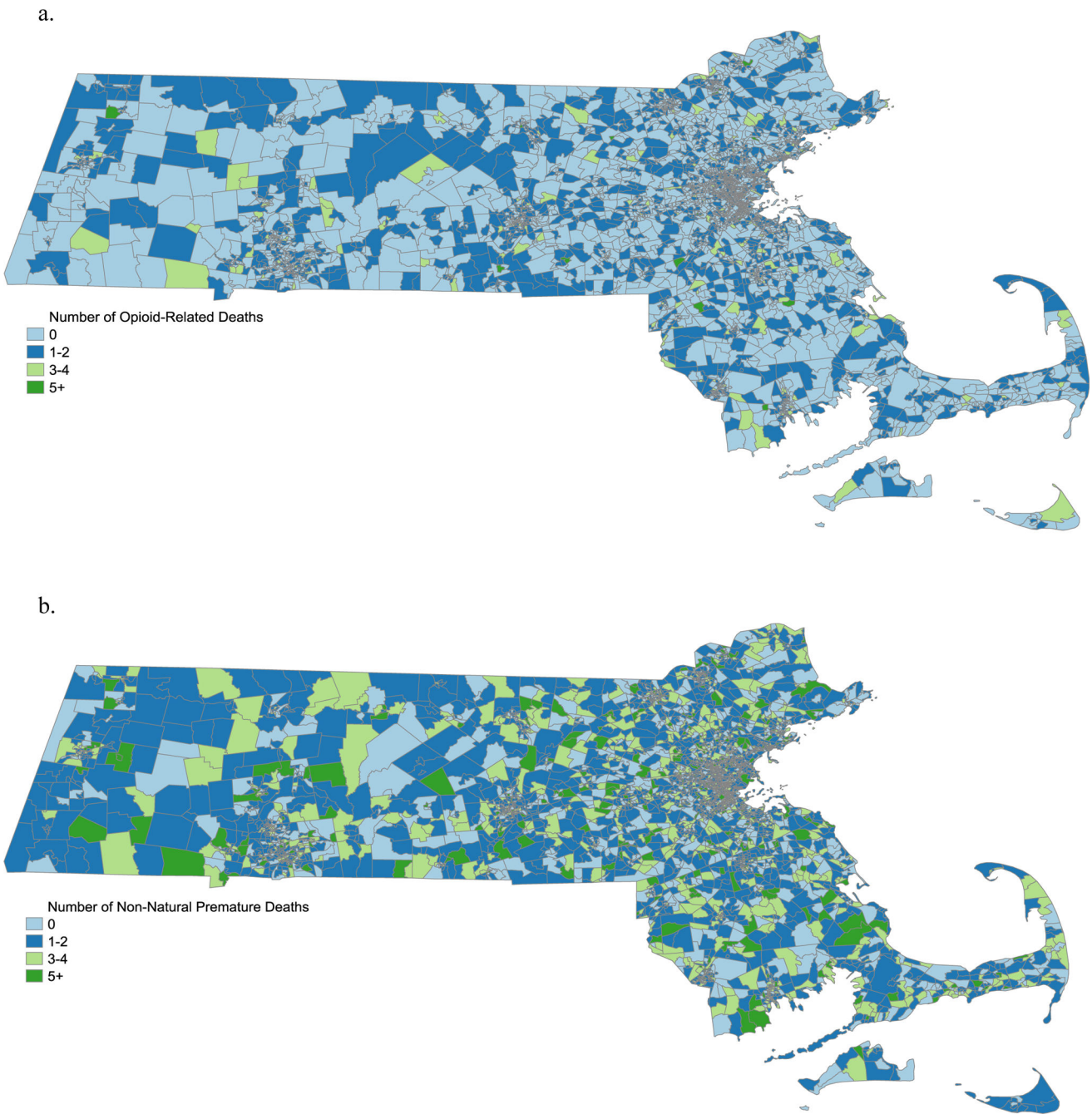

Figure 1.
Heat Map of Massachusetts: Opioid-Related and Non-Natural Death, Census Block Group-Level

Figure 2.

Heat Map of Boston Metropolitan Area: Opioid-Related and Non-Natural Death, Census Block Group-Level

Table 1.

Description of deceased from Massachusetts Death Registry 2011–2014 at the individual, census block group, and county levels

	Opioid-related Mortality [a]	Non-natural Mortality [b]	
Sample Population	**3,089**	**8,729**	
Psychosocial Factors			
Percent Single Female-Headed Household	15.24	13.72	**
Percent Owner Occupied	55.39	59.96	**
Percent White	77.09	77.95	
Theil Index	0.16	0.17	**
Number of Robberies per 100,000 ‡	79.81	79.48	
Number of Social Associations per 10,000 ‡	9.34	9.43	**
Economic Factors			
Percent Living in Poverty	12.12	9.92	**
Percent of Cost Burdened Renters	47.63	46.44	*
Unemployment Rate ‡	8.97	8.35	**
Percent SNAP ‡	12.27	12.21	
Food Insecurity Rate ‡	10.12	10.04	
Built Environment Factors			
Percent Moved between 2000 to 2009	35.04	34.79	
Percent of Workers Taking Public Transit	9.49	9.47	
Percent Vacant Housing Units	17.49	16.26	
Limited Access to Supermarkets	18.26	17.57	
Health-Related Factors			
Percent Working in Construction Occupations	7.61	6.98	*
Percent of Heavy Drinkers ‡	7.40	7.40	
Number of FQHC's ‡	9.51	9.56	
Number Hospital Beds per 10,000 ‡	3.12	3.13	
Number of ER Visits per 10,000 ‡	500.60	490.23	*
Number HIV cases per 100,000 ‡	329.90	333.35	
Per Capita MME Oxycodone ‡	331.56	331.68	
Per Capita MME Hydromorphone ‡	23.24	23.41	
Per Capita MME Morphine ‡	60.19	59.68	
Per Capita MME Fentanyl ‡	164.65	164.89	
Individual-Level Factors			
Age			**
0–14	0.06	2.73	

	Opioid-related Mortality [a]	Non-natural Mortality [b]	
Sample Population	**3,089**	**8,729**	
15–17	0.03	1.34	
18–24	7.35	7.46	
25–34	27.36	11.03	
35–44	23.79	10.09	
45–54	27.23	15.93	
55–64	12.33	13.59	
65+	1.85	37.83	
Female	30.37	36.11	**
Race			**
White	90.02	83.53	
Asian	0.42	1.97	
Non-Latino Black	3.27	7.37	
Latino	5.60	5.24	
Other Race/Ethnicity	0.68	1.88	
Married	17.93	28.29	**
Education			**
Less than High School	13.89	15.91	
High School Graduate	60.27	48.42	
More than High School, Less than College Graduate	16.85	16.18	
College Graduate or More	9.00	19.49	
Veteran	3.56	12.22	**
Foreign-born	7.81	13.93	**
Year of Death			***
2011	20.33	28.87	
2012	23.76	25.74	
2013	30.14	27.40	
2014	25.77	18.00	

[a] Opioid-related mortality: Primary, secondary, or tertiary cause of death had a ICD-10 code related to opioid use disorder (ICD-10 T40.0, T40.1, T40.2, T40.3, T40.4, or T40.6)

[b] Non-natural mortality: Deaths categorized as accidents, homicides, suicides, could not be determined, pending an investigation, or not classifiable

‡ County-level

* $p<0.05$;

** $p<0.001$

Table 2.

Mixed model regression results identifying associations between individual, census block group, and county-level characteristics with opioid-related mortality (n = 11,818). [a, b]

Census Block Group and County Characteristics	OR		95% CI
Psychosocial Factors			
Percent Single Female-Headed Household	1.00		0.99 – 1.01
Percent Owner Occupied	1.00		0.99 – 1.00
Percent White	1.00		0.99 – 1.01
Theil Index	0.52		0.22 – 1.21
Number of Robberies per 100,000 ‡	1.00		0.98 – 1.01
Number of Social Associations per 10,000 ‡	0.84	**	0.75 – 0.94
Economic Factors			
Percent Living in Poverty	1.01	**	1.00 – 1.01
Percent of Cost Burdened Renters	1.00		0.99 – 1.00
Unemployment Rate ‡	1.00		0.98 – 1.01
Percent SNAP ‡	0.99		0.92 – 1.05
Food Insecurity Rate ‡	1.21	**	1.07 – 1.37
Built Environment Factors			
Percent Moved between 2000 to 2009	1.00		0.99 – 1.00
Percent of Workers Taking Public Transit	1.00		0.99 – 1.00
Percent Vacant Housing Units	1.00		0.99 – 1.00
Limited Access to Supermarkets	1.00		0.99 – 1.00
Health-Related Factors			
Percent Working in Construction Occupations	1.00		0.99 – 1.01
Percent of Heavy Drinkers ‡	1.01		0.89 – 1.12
Number of FQHC's ‡	1.02	*	1.02 – 1.08
Number Hospital Beds per 10,000 ‡	0.78	***	0.68 – 0.88
Number of ER Visits per 10,000 ‡	1.00		0.99 – 1.00
Number HIV cases per 100,000 ‡	1.00		0.99 – 1.00
Per Capita MME Oxycodone ‡	1.00		0.99 – 1.00
Per Capita MME Hydromorphone ‡	1.05	**	1.01 – 1.08
Per Capita MME Morphine ‡	0.99		0.98 – 1.00
Per Capita MME Fentanyl ‡	1.00		0.99 – 1.00
Individual-Level Factors			
Age (35–44 Referent)			
0–14	0.01	***	0.00 – 0.04
15–17	0.01	***	0.00 – 0.07

Census Block Group and County Characteristics	OR		95% CI
18–24	0.43	***	0.35 – 0.52
25–34	1.04		0.89 – 1.20
45–54	0.68	***	0.59 – 0.78
55–64	0.41	***	0.34 – 0.48
65+	0.02	***	0.01 – 0.02
Female (Male Referent)	1.24	***	1.11 – 1.38
Race (Non-Latino White Referent)			
Asian	0.22	***	0.11 – 0.41
Non-Latino Black	0.26	***	0.19 – 0.32
Latino	0.65	***	0.50 – 0.82
Other Race/Ethnicity	0.24	***	0.14 – 0.39
Married (Unmarried Referent)	0.70	***	0.62 – 0.79
Education (<High School Referent)			
High School Graduate	1.01		0.87 – 1.17
More than High School, Less than College Graduate	0.77	**	0.63 – 0.91
College Graduate or More	0.45	***	0.36 – 0.55
Veteran	0.94		0.72 – 1.20
Foreign-born	0.64	***	0.53 – 0.77
Year of Death (2011 as referent)			
2012	1.22	*	1.02 – 1.43
2013	1.38	**	1.13 – 1.67
2014	1.90	***	1.55 – 2.32

*** p<0.001;

** p<0.01;

* p<0.05

OR: Odds ratio, CI: Confidence interval

a. Opioid-related mortality: Primary, secondary, or tertiary cause of death had an ICD-10 code related to opioid use disorder (ICD-10 T40.0, T40.1, T40.2, T40.3, T40.4, or T40.6)

b. Variables included simultaneously adjusting for each other

‡ County-level