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The relationship between US heroin market dynamics and heroin-related overdose, 1992–2008

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Abstract

Background and Aims—Heroin-related overdose is linked to polydrug use, changes in physiological tolerance and social factors. Individual risk can also be influenced by the structural risk environment including the illicit drug market. We hypothesized that components of the US illicit drug market, specifically heroin source/type, price and purity, will have independent effects on the number of heroin-related overdose hospital admissions.

Methods—Yearly, from 1992 to 2008, Metropolitan Statistical Area (MSA) price and purity series were estimated from the US Drug Enforcement Administration data. Yearly heroin overdose hospitalizations were constructed from the Nationwide Inpatient Sample. Socio-demographic variables were constructed using several databases. Negative binomial models were used to estimate the effect of price, purity and source region of heroin on yearly hospital counts of heroin overdoses controlling for poverty, unemployment, crime, MSA socio-demographic characteristics and population size.

Results—Purity was not associated with heroin overdose, but each \$100 decrease in the price per pure gram of heroin resulted in a 2.9% [95% confidence interval (CI) = 4.8%, 1.0%] increase in the number of heroin overdose hospitalizations ($P = 0.003$). Each 10% increase in the market share of Colombian-sourced heroin was associated with a 4.1% (95% CI = 1.7%, 6.6%) increase in number of overdoses reported in hospitals ($P = 0.001$) independent of heroin quality.

Conclusions—Decreases in the price of pure heroin in the United States are associated with increased heroin-related overdose hospital admissions. Increases in market concentration of Colombian-source/type heroin is also associated with an increase in heroin-related overdose hospital admissions. Increases in US heroin-related overdose admissions appear to be related to structural changes in the US heroin market.

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Declaration of interests

The authors have no commercial interests to disclose.

Keywords

Heroin; heroin distribution; heroin overdose; heroin type; structural environmental risk

INTRODUCTION

Overdose is a common occurrence among individuals who use heroin and frequently results in hospital admission or death [1–5]. The proximal causes and individual factors associated with heroin-related overdose (HOD) are well known [1,3,6,7]. Heroin overdoses are frequently due to polydrug use, specifically when heroin is combined with central nervous system depressants such as alcohol and benzodiazepines that contribute to respiratory failure [8]. A lack of experience in heroin use and rapid changes in tolerance due to incarceration, relapse following drug treatment or infrequent heroin use have been linked to higher rates of overdose [6,9–11]. The pathway between these proximal causes and HOD is fairly straightforward. Moving upstream, social causes such as poverty, homelessness, sexual minority status or other forms of social exclusion have also been linked to increased risk of drug overdose [12–15]. Moreover, many have suggested that socio-behavioral risk-taking is influenced strongly by the structural risk environment [14].

The risk environment represents a number of structural components that moderate the relationship between individual factors and injection drug users' (IDUs') health. For example, higher levels of drug law enforcement have been linked to increased risk of overdose deaths [16]. The hypothesized agent of action is that increased criminal justice risk associated with drug use leads to specific behaviors, e.g. not calling for emergency help (i.e. calling 911 in the United States) following a witnessed overdose, which increase individual harm associated with drug use [17]. Other structural factors such as needle exchange, naloxone distribution, safe injection rooms and the availability of methadone treatment can reduce the risk of overdose or harm associated with overdose in areas where these services are available [18–20].

However, there are other components of the risk environment that have been hypothesized to affect heroin users' health but are less well understood. In particular, components of the drug market, specifically the source/type, availability, price and purity of heroin have been linked to health outcomes [21–24]. The hypothesized causal mechanism that links changes in price or purity to different health outcomes is that individual consumers of heroin behave in the same way as consumers of any good; there is elasticity of demand related to changes in price per unit of pure heroin [23,25]. The empirical evidence provides some support for this hypothesis. Decreases in heroin and cocaine prices in metropolitan areas have been linked to increased rates of drug-related emergency-room admissions in the United States [21,23]. In 2000, a heroin supply shock ('drought') in Australia offered an opportunity to examine how dramatic reductions in the supply of heroin led to a reduction in drug-related health problems. Conversely, rapid increases in purity in one region of Australia and the city of Baltimore have been linked to increased heroin overdose fatalities [22,26]. However, the literature is inconsistent, with some studies and commentators arguing that factors such as price and purity do not play a role in overdose due to the rapid human physiological

tolerance responses to increasing concentrations of opiates [26–28]. The evidence in sum seems to suggest that, while linked, heroin price and purity have only a modest effect on the risk of HOD [27].

We have found previously that the decrease in the price and increase in the purity of heroin in the United States was associated with the entrance and expansion of heroin sourced from Colombia [29]. Added to the traditional view of the risk environment, we propose that changes to the heroin market also represent changes in risk to heroin-using populations. Specifically, a new market participant, Colombian-sourced heroin, was introduced as a purer and less expensive product than previously sourced heroin, e.g. from southeast and southwest Asia, and successfully out-competed those sources for market dominance. (See Ciccarone for more detail.) Theoretically, this increasingly alluring market could then act on individual health in two ways. Heroin-dependent individuals could intensify their use/dependence, thus increasing the risk of overdose upon re-initiation following periods of abstinence, e.g. due to incarceration or brief treatment. In addition, changes in price or purity could attract new users, thereby increasing the population at risk for HOD.

The current study adds to the existing literature by examining several components of the risk environment—using US national-level data—that can affect community incidence of heroin overdose. Specifically, we examine the role that changes in the price, purity and source region of heroin in 18 Metropolitan Statistical Areas (MSAs) have on HOD admissions to 3409 hospitals in those MSAs. This is the first study, to our knowledge, that uses representative national hospital data combined with Drug Enforcement Administration (DEA) price, purity and heroin market data to investigate a link between structural heroin market factors and heroin overdoses. We hypothesize that decreases in the price per unit pure heroin or increases in purity are associated with higher counts of hospitalization for HOD. Furthermore, we investigate the role that the novel entry of Colombian-sourced heroin had on HOD.

METHODS

Sample MSAs

We used MSAs, consolidated MSAs (CMSAs) or primary MSAs (PMSAs) to define geographic entities as defined by the Office of Management and Budget. We will refer to these different units collectively as MSAs, but the actual geographic designation is identified in Table 1. These units function as integrated economic and social entities that span multiple counties but have a common urban core of more than 50 000 [30]. We used 27 MSAs (see Table 1) to construct the price and purity series for retail level heroin purchases and samples (under 1 g) but only estimated yearly price and purity estimates for MSAs that had more than 100 retail observations between 1993 and 2008 in the DEA System to Retrieve Information from Drug Evidence (STRIDE) data set. Portland was excluded due to only 27 retail samples between 1993 and 2008. Albuquerque, Atlanta, Dallas, Detroit, El Paso, Houston New Orleans and San Antonio are excluded from the regression analysis due to restrictions on identifying hospital locations, which prevent specification of the hospitals' MSA [31]. Table 1 lists all 27 MSAs, and those with heroin overdose frequency counts identify the 18 included in the regression analysis.

Counts of heroin overdose hospital admissions

The dependent variable for these analyses is a count of HOD admissions in a given hospital in a given year in one of 18 MSAs. HOD hospitalization data come from the Nationwide Inpatient Sample (NIS), an approximately 20% stratified national random sample of United States community hospitals [31]. For each year's sample of hospitals, the NIS randomly draws 20% of hospitals from its stratified sampling frame to construct the data set, so each individual hospital only appears a limited number of times (a mean of 3.7 times per hospital). Overall, there were 3409 hospitals sampled from the 18 MSAs, and Table 1 identifies the number of hospitals in each of the MSAs. Data from 1993 to 2008 NIS were used to estimate the number of HODs in hospitals in each of 18 MSAs. Cases of heroin overdose were coded using ICD-9 codes included in the billing records: primary diagnoses code of 965.01 or E code of E850.0.

Heroin price and purity series

The heroin price and purity series and the source of the heroin come from the DEA-administered STRIDE data set. The STRIDE data are collected through several procedures. Included in the purity series are all samples collected that include purity analysis. Included in the price series are purchases made as part of an investigation or through the Domestic Monitoring Program. Because the collection of STRIDE data is a convenience sample and not based on random selection we used estimated purity and price data in the models. To construct the estimated price and purity series we followed previous suggestions for data cleaning and modeling, with some adjustments [32]. Because we are interested in the effect of heroin price and purity on users we used only the retail market (less than or equal to a gram) samples for our price and purity series.

To construct the purity series we used random coefficient models from Arkes *et al.* that predict purity as a function of the amount collected and the year the sample was collected (equation 1).

$$\begin{aligned}
 Purity_{ijk} &= \alpha_{0k} + \alpha_1 time_{ij} + \alpha_2 AMT_{ijk} + \varepsilon_{ijk} \\
 \alpha_{0k} &= \gamma_0 + \mu_{0k} \\
 \alpha_1 &= \gamma_1 + \mu_{1k} \\
 \alpha_2 &= \gamma_2 + \mu_{2k} \\
 \varepsilon_{ijk} &\sim N(0, \sigma^2)
 \end{aligned}
 \tag{equation 1}$$

α_{0k} , α_1 and α_2 represent the intercept for MSA k , a vector of time coefficients and a vector of coefficients for the amount of heroin in MSA k at time j . $Time_{ij}$ is a vector of dummy variables for the year and AMT_{ijk} is the raw weight of the i th observation in MSA k at time j . The random intercepts and coefficients are independent and identically distributed. Predicted estimates below 0 or above 100% were modified to 0.5% and 99.5%, respectively.

These purity estimates were then used to model the price of heroin (equation 2).

$$\begin{aligned}\ln(\text{Real Price}_{ijk}) &= \alpha_{0k} + \alpha_1 \text{time}_j + \alpha_2 [\ln(\text{AMT}_{ijk}) + \ln(\text{predicted purity}_{ijk})] \\ \alpha_{0k} &= \gamma_0 + \mu_{0k} \\ \alpha_1 &= \gamma_1 + \mu_{1k} \\ \alpha_2 &= \gamma_2 + \mu_{2k}\end{aligned}$$

(equation 2)

The natural log of the inflation-adjusted price using 2008 dollars for observation i in year j and city k is a function of a vector of time effects, a vector of MSA effects and the sum of the natural log of the amount of heroin collected and the expected purity estimated in equation 1. This last term is the natural log of the expected pure grams of the sample. The random intercepts and coefficients are independent and identically distributed.

The resulting price and purity series are based on the expected purity hypothesis that most clearly models the user's expected experience in the drug market [32]. Specifically, the estimated price and purity data use the expected purity per gram rather than the actual purity, compensating for the presence of outliers due to 'bunk' samples with zero percentage heroin purity.

Part of the STRIDE data are collected for use in the Heroin Signature Program that collects heroin samples for the purpose of identifying source region [33]. We used this series to construct a variable identifying the percentage of heroin samples in each MSA for each year that originates from Colombia or Mexico. Heroin originating from these two source countries accounts, by some estimates, for 99% of US retail heroin [34].

Demographic MSA controls

Data for local MSA conditions come from several sources. Yearly MSA unemployment and poverty rates were collected from the March Current Population Survey (CPS) supplement. Data on yearly MSA percentage male by race and 5-year age categories and MSA population size were constructed from the Surveillance, Epidemiology and End Results (SEER) data set. Yearly crime estimates for MSAs was taken from the Uniform Crime Reports. We also estimated models with data documenting arrests for heroin and cocaine possession and sales, but due to missing data in this variable we used total crime in all presented models. The choice of the crime variable did not affect the models in any substantive way.

Statistical model for counts of heroin-related overdose hospital admissions

We used a random intercept negative binomial model with robust standard errors to predict the counts of yearly HODs in the sampled hospitals and adjust for the overdispersion of the variance of the count data relative to the mean (formula 3). We estimate a random intercept for each hospital, resulting in a two-level model. The random hospital intercept models the within-hospital covariance over time and provides an additional method for modeling the overdispersion of the HOD data. We also used robust standard errors to further correct for the effect of overdispersion and heteroskedasticity on the standard errors [35] (equation 3).

$$HOD_{ijk} = \exp(\alpha_0 + \alpha_1 P_{jk} + \alpha_2 Colombian_{jk} + \alpha_3 Crime_{jk} + \alpha_4 UE_{jk} + \alpha_5 Pov_{jk} + \alpha_6 Demo_{jk} + \alpha_7 MSA_k + \varepsilon_{ij})$$

$$\varepsilon_{ij} \equiv \zeta_i + \varepsilon_{ij}$$

(equation 3)

HODs in hospital i in year j are modeled as a function of the coefficients α_{1-5} , respectively, representing raw price, purity or price per pure gram (P), percentage Colombian-sourced heroin, total count of crime, unemployment and percentage in poverty in year j and MSA k . Coefficient α_6 is a vector of demographic controls with percentage male and black, Hispanic and white for year j in MSA k . Coefficient α_7 is a vector of MSA indicator variables, to estimate a fixed effect for within-MSA shared variance. We chose a fixed-effect approach to MSAs rather than a random effect because of the limited number of MSAs in the model ($n = 18$), and our belief that MSAs have unique characteristics rather than being drawn from a population of MSAs. Hospitals each have a random intercept (ζ_i) that are assumed to be normally distributed. We also calculated MSA means and yearly means for heroin overdoses and price, purity and price per pure gram that were used for graphs and are displayed in Table 1. All regression models were estimated in Stata version 13, using MENBREG with adaptive quadrature [36].

RESULTS

Table 1 shows the MSAs, the count of hospitals and DEA samples in that MSA and the means and standard deviations for the price and purity of heroin samples over time. The mean purity ranged from 16% in Seattle to 62% in Philadelphia. The mean price per pure gram of heroin ranged from \$362.02 in San Diego to \$2555.91 in New Orleans. There was substantial variation in the price and purity of samples over time and between MSAs. Consistent with the literature, we found that MSAs tend to be either primarily Colombian-sourced heroin-dominant (CHD) or Mexican-sourced heroin-dominant [29,37].

Figure 1 plots the bivariate relationship between the MSA means for heroin purity and price per gram of pure heroin and the MSA means for the number of HOD hospitalizations per 100 000 population between 1993 and 2008. Each graph displays two separate fitted lines, one for cities with more than 50% of heroin samples originating from Colombia, i.e. CHD, and for cities with fewer than 50% of heroin samples originating from Colombia (non-CHD). The non-CHD cities obtain most of their heroin from Mexico [29]. The correlation between purity and overdoses is 0.59, with higher levels of purity associated with higher levels of HOD. The effect is stronger in CHD MSAs ($r = 0.63$) than in non-CHD MSAs ($r = 0.34$). The second graph in Fig. 1 displays mean MSA price per gram of pure heroin and HOD, showing a strong inverse correlation with higher price for a gram of pure heroin associated with lower MSA HOD ($r = -0.44$). This relationship is stronger in CHD MSAs ($r = -0.69$) than in non-CHD MSAs ($r = -0.21$).

Figure 2 shows fitted lines and observed means for the yearly price of pure heroin in collected samples between 1993 and 2008 and yearly hospital counts of HOD-related admissions during the same time-period. The figure shows a moderate inverse relationship between the price of pure heroin and HOD ($r = -0.17$).

We estimated three random-effects negative binomial models alternating the main dependent variable: raw mean yearly MSA price of heroin, mean yearly MSA purity of heroin and the mean yearly price per gram pure of heroin. All models were adjusted for MSA demographics along with indicators for each MSA as described in formula 3. The raw price of heroin ($P = 0.51$) had no relationship to the count of hospital HOD. The coefficient for purity was consistent with our hypothesis, but did not have a statistically significant effect ($P = 0.28$) on hospital counts of overdoses.

Table 2 shows the results from the price per gram pure heroin model. Consistent with our hypothesis, yearly MSA mean heroin price per gram pure is related statistically significantly to yearly hospital mean HOD ($P = 0.003$). Specifically, each \$100 increase in the price per gram pure of heroin in an MSA results in a 2.9% decrease in the number of HOD reported in hospitals in that MSA. Average heroin price per pure gram was \$1368 in 1993 and by 2008 heroin price per gram pure was \$688, a decrease of \$680. This model predicts that the change in the price of pure heroin would increase HOD hospitalizations by 20.4%. Between 1993 and 2008 we observed an increase in the average number of hospital HOD from 0.77 to 1.31: an absolute increase of 0.7 HOD hospitalizations per hospital. This effect of heroin price per pure gram on HOD occurs independently of the percentage of heroin originating from Colombia and other covariates.

Consistent across the price, purity and price per gram pure models was the positive relationship between the percentage of DEA samples in a given MSA which are Colombian-sourced heroin and the number of HOD seen in hospitals after adjusting for MSA characteristics. In the model shown in Table 2 an absolute 10% increase in Colombian heroin samples was associated with an absolute 4.1% increase in number of overdoses reported in hospitals ($P = 0.001$). While there is no statistically significant interaction between percentage of Colombian-sourced CHD heroin and price per pure gram, higher levels of Colombian heroin are associated with steeper slopes for the relationship between price per pure gram and hospital HOD. This is consistent with the bivariate relationship shown in Fig. 1. In MSAs with 0% Colombian-sourced heroin a \$100 decrease in the price per pure gram is associated with a 3.7% increase in HOD, but in cities with 100% Colombian heroin a \$100 decrease in the price per pure gram is associated with a 5.7% increase in hospital HOD. These effects are independent of the price per gram of pure heroin. Crime, percentage in poverty and percentage unemployed were not associated with HOD in any of the models.

DISCUSSION

Consistent with our expectations, we found a relationship between price per unit pure heroin in an MSA and HOD admissions in hospitals located in that MSA. Heroin purity had an effect in the expected direction, but we were not able to rule out the possibility of no relation

or even a negative association between purity and HOD at the 95% confidence level. We found no evidence to support the hypothesis that actual street price of heroin, independent of purity, was associated with HOD. While the existing literature has found that increased purity is modestly associated with increases in heroin overdose, our findings suggest that it is the price per unit pure, rather than raw purity, that has the most distinct effect. We did not find any association of crime, poverty or unemployment with heroin overdoses. This evidence of a relationship between price per pure gram of heroin and unemployment on heroin overdoses is consistent with the literature on the elasticity of demand for heroin and other drugs. Simply stated, lower levels of income reduce the amount of heroin consumed at a given price and decreases in the price of heroin increase HOD at a given income.

Somewhat surprising is the robust and independent effect of the percentage of heroin marked as originating from Colombia on HOD. Previously we found that increases in Colombian-sourced heroin were associated with increases in the purity and reductions in the price of heroin [29]. Our starting belief was that any effect of Colombian-sourced heroin on HOD would be mediated by its effect on price and purity rather than as an independent effect. However, the findings presented here suggest that our marker for Colombian-sourced heroin has an effect independent of price and purity.

One problem for interpreting this finding is possible misclassification of heroin source. The DEA Heroin Signature Program uses the chemical properties of the heroin sample to determine country origin [33]. Recent estimates of Colombian production suggest a sharp drop-off in the amount of heroin that should be coming from Colombia, but US seizure data indicate relatively consistent Colombian production [34]. This disconnect suggests discrepancies in the estimation methods: either there are unaccounted supplies coming from Colombia or domestic seizure data (including the DEA Heroin Signature Program) has not accounted for the possibility that Mexican heroin producers are recently replicating Colombian production processes, thus producing a similar form of heroin. Mexican heroin production has increased substantially in recent years, theoretically supporting the latter interpretation [34]. Conversely, our team's ethnographic data (unpublished) lend support to the notion that novel forms of powdered heroin are entering traditional Mexican-sourced heroin retail outlets, but these are not strict mimics of Colombian-sourced heroin. We should thus be cautious in interpreting the overdose risk found in our analysis as being related to a strict geographic based explanation.

Speculating about alternative hypotheses, the independent effect of Colombian-sourced heroin may be due to particularities in heroin market structure, structural vulnerabilities of US inner cities and possibly even the chemical characteristics of the form of heroin that the DEA laboratories classified as Colombian-sourced. Regarding market structure, Colombian heroin wholesalers may have access to a better and more developed distribution network, linked to the Colombian-sourced cocaine trade. This access may increase the size of the market, or perhaps facilitate access to heroin initiates or inexperienced users who are at increased risk for HOD [10,11,37,38]. For example, US hospital admissions for opioid- and heroin-related overdoses are rising, intertwined with the greatest increase in heroin overdoses seen among those aged 20–34 years [19]; heroin initiates, often young or inexperienced, are transitioning after becoming dependent on opioids [38,39].

The buying and selling of heroin in eastern US cities where Colombian-sourced heroin predominates may exploit certain structural vulnerabilities of those cities, e.g. ethnic hypersegregation. We have previously found a relationship between the degree of Hispanic hypersegregation and heroin price and purity in Colombian-sourced heroin-predominant US cities [40]. One additional factor is worth considering: heroin from Colombia is physically and chemically different from the heroin from South Asia which it replaced, and more so from its current US competitor Mexican-sourced ‘black-tar’ heroin (BTH). It is a powdered heroin, more water-soluble and less chemically complex than BTH; it is prepared and used differently and also has more possibilities for the introduction of powdered adulterants such as fentanyl [24,41,42]. These may result in differential uptake into the central nervous system and exploitation of physiological vulnerabilities. Internet heroin user blogs discuss the faster rush of East Coast powder heroin compared with BTH [43]. Indeed, it is speculatively possible that Colombian-sourced heroin, or its mimics, is simply more dangerous to use than BTH. Future investigations should examine the role that new forms/supplies of heroin have on community and individual vulnerabilities and risk.

There are several limitations to this study that suggest caution when interpreting these results. Data on the price and purity series produced from the STRIDE database have known challenges, and there is debate about the value of these data and their use in analysis [44]. We have attempted to mitigate these disadvantages with our modeling approach, but these approaches are built on untested assumptions. Furthermore, evidence of problems with the DEA data on heroin sources suggests caution in overinterpreting those data. Unfortunately, there is no alternative to the STRIDE database when analyzing drug prices in the United States. Our hospital heroin overdose data also have known problems. First, it excludes all HODs which do not result in in-patient admissions [7]. However, by focusing on in-patient admissions we create a more homogenous set of serious HOD that have been vetted by emergency room physicians. Secondly, using billing data and ICD-9 codes for heroin research lacks specificity [45]. These limitations and the general limitation of ecological research means that the specific estimates presented here need to be viewed with caution and used to guide future research.

While limited, this nation-wide 17-year analysis found strong evidence that the introduction of a new heroin supply from Colombia had an independent effect on the rate of HOD. This effect was in addition to the effect that changes in the price per gram pure had on HOD. Given the recent increase in the number of HOD, the role that market forces have on the risk environment for drug users needs more focused research attention [19].

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Figure 1.
Heroin purity and price per gram pure with heroin overdoses

Figure 2.
Yearly mean price per gram pure heroin and hospital heroin overdoses

Table 1

Metropolitan Statistical Area (MSA) characteristics.

City name	Geographic unit	DEA obs	Hospitals	Purity	Purity SD	Price per gram pure	PPGP SD	HOD	HOD SD	% Colombian	% Colombian SD
Whole sample		19109	3409	37.45	17.15	904.83	745.01	0.98	3.67	44.55%	40.37%
Atlanta	CMSA/MSA	608	–	42.60	10.85	1471.94	481.64	–	–	51.13%	35.18%
Baltimore	PMSA	398	178	46.67	11.72	501.59	176.63	8.30	2.93	69.24%	39.82%
Boston	PMSA	820	233	50.32	16.49	955.01	365.26	3.83	1.66	77.36%	38.13%
Phoenix	CMSA/MSA	601	104	40.60	10.20	718.99	614.74	2.64	1.52	0.00%	0.00%
San Francisco	CMSA/MSA	464	256	18.37	8.40	937.84	497.76	0.97	0.55	0.00%	0.00%
Los Angeles	CMSA/MSA	358	672	29.28	5.98	620.34	217.96	1.17	0.20	0.29%	1.27%
San Diego	CMSA/MSA	841	80	48.80	7.13	362.02	179.87	2.37	1.75	0.18%	0.79%
Bridgeport, CT	PMSA	237	55	58.15	11.61	658.29	164.24	3.31	1.49	12.50%	34.16%
Philadelphia	CMSA/MSA	1068	216	62.53	10.30	571.36	199.86	4.89	3.14	80.33%	37.79%
Chicago	CMSA/MSA	665	468	25.25	7.37	859.36	455.31	4.82	5.16	48.33%	36.43%
New Orleans	CMSA/MSA	635	–	29.33	6.93	2555.91	1746.30	–	–	76.67%	34.79%
New York	PMSA	2037	284	57.54	8.47	546.39	135.68	4.16	0.94	76.59%	36.50%
Newark	PMSA	904	65	60.16	6.73	617.28	330.86	5.11	3.64	78.90%	37.01%
Orlando	CMSA/MSA	448	60	46.30	12.57	1030.92	284.85	3.94	2.92	81.39%	38.88%
Miami	CMSA/MSA	450	140	25.77	8.45	1182.81	975.71	1.13	0.71	79.46%	36.54%
Milwaukee	CMSA/MSA	183	163	40.31	6.89	923.72	304.72	0.92	0.66	6.67%	25.82%
Washington DC	PMSA	5383	101	22.78	3.49	942.96	387.09	1.64	0.74	54.49%	29.89%
Seattle	CMSA/MSA	415	98	16.26	5.45	1353.52	1125.33	1.24	0.99	0.00%	0.00%
Houston	CMSA/MSA	242	–	26.72	7.73	1737.14	819.09	–	–	10.65%	24.80%
Dallas	CMSA/MSA	217	–	18.18	6.04	1172.73	506.68	–	–	0.00%	0.00%
El Paso	CMSA/MSA	110	–	45.33	3.47	494.90	249.62	–	–	0.00%	0.00%
San Antonio	CMSA/MSA	67	–	16.23	6.67	1455.40	652.45	–	–	3.97%	10.32%
Denver	CMSA/MSA	470	84	31.71	12.15	1252.93	988.69	2.30	1.94	0.28%	1.18%
Detroit	CMSA/MSA	850	–	40.13	7.35	904.67	297.41	–	–	56.51%	33.83%
Portland	CMSA/MSA	27	–	49.43	6.63	350.62	85.49	2.89	1.36	0.00%	0.00%
St Louis	CMSA/MSA	475	152	18.27	5.16	2444.63	1379.81	1.86	1.73	14.11%	25.81%
Albuquerque	CMSA/MSA	136	–	44.77	6.70	629.70	357.24	–	–	0.00%	0.00%

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CMSA = Consolidated Metropolitan Statistical Areas; PMSA = Primary Metropolitan Statistical Areas; DEA = Drug Enforcement Administration; PPGP = price per gram pure; HOD = heroin-related overdose; SD = standard deviation.

Table 2

Negative binomial price gram pure heroin random hospital intercept model.

Yearly hospital HOD cases	IRR	95% CI
Price pure 100 grams pure	0.971 **	(0.952, 0.990)
% CHD (10%)	1.041 ***	(1.017, 1.066)
Crime per 10 000	0.999	(0.992, 1.006)
Unemployment	0.972	(0.939, 1.005)
% in poverty	0.983	(0.965, 1.001)
% white males	0.973	(0.727, 1.303)
% black males	1.557	(0.997, 2.433)
% Hispanic males	0.931	(0.771, 1.125)
% 20–24 years old	0.954	(0.727, 1.251)
% 25–29 years old	0.810	(0.617, 1.062)
% 30–34 years old	1.429 **	(1.135, 1.799)
% 35–39 years old	1.007	(0.711, 1.426)
% 40–44 years old	0.653 *	(0.453, 0.941)
% 45–49 years old	1.372	(0.922, 2.040)
% 50–54 years old	1.246	(0.951, 1.633)
MSA population (logged)	0.901	(0.382, 2.125)
MSAs		
Baltimore	—	—
Boston	13.593 *	(1.912, 139.931)
Phoenix-Mesa	3.228 **	(2.591, 393.082)
San Francisco	83.750	(0.547, 60.245)
Los Angeles	68.957 **	(3.342, 198.244)
San Diego	7.316 **	(2.214, 283.494)
Bridgeport, CT	1.605	(0.974, 84.220)
Philadelphia	3.053	(0.842, 5.594)
Chicago	7.391 **	(1.703, 14.312)
New York	38.494	(0.477, 14.795)
Newark	1.024	(0.553, 4.506)
Orlando	0.552	(0.593, 50.465)
Miami	0.161	(0.156, 8.686)
Milwaukee	0.245	(0.233, 11.940)
Washington DC	1.812 *	(0.100, 0.976)
Seattle	8.313	(0.639, 77.942)
Denver	1.419	(0.992, 180.755)
St Louis	0.392	(0.389, 4.501)
<i>Random intercept</i>	<i>Variance</i>	

Yearly hospital HOD cases	IRR	95% CI
Hospital intercept variance	1.305	(1.118, 1.524)

 $P < 0.001$;

**
 $P < 0.01$;

*
 $P < 0.05$.

MSA = Metropolitan Statistical Area; IRR = inter-rater reliability; CI = confidence interval; CHD = Colombian-sourced heroin dominant; HOD = heroin-related overdose.