Neighborhood Inequalities in Hepatitis C Mortality: Spatial and Temporal Patterns and Associated Factors

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Abstract Deaths attributable to hepatitis C (HCV) infection are increasing in the USA even as highly effective treatments become available. Neighborhood-level inequalities create barriers to care and treatment for many vulnerable populations. We seek to characterize citywide trends in HCV mortality rates over time and identify and describe neighborhoods in New York City (NYC) with disproportionately high rates and associated factors. We used a multiple cause of death (MCOD) definition for HCV mortality. Cases identified between January 1, 2006,

Thumbnail Sketch: Hepatitis C (HCV) mortality rates are increasing in the USA, exceeding those of HIV in many communities. HCV disproportionately affects persons living in poverty, and community-based interventions may be particularly useful to target high-risk populations. This is the first study examining inequalities in HCV mortality by census tract in New York City (NYC). The study found increasing rates of HCV mortality in NYC and over two thirds of decedents to be less than 65 years of age. HCV mortality rates were associated with multiple indicators of socioeconomic inequality and varied by neighborhood.

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and December 31, 2014, were geocoded to NYC census tracts (CT). We calculated age-adjusted HCV mortality rates and identified spatial clustering using a local Moran's I test. Temporal trends were analyzed using joinpoint regression. A multistep global and local Poisson modeling approach was used to test for neighborhood associations with sociodemographic indicators. During the study period, 3697 HCV-related deaths occurred in NYC, with an average annual percent increase of 2.6% ($p = 0.02$). The HCV mortality rates ranged from 0 to 373.6 per 100,000 by CT, and cluster analysis identified significant clustering of HCV mortality ($I = 0.23$). Regression identified positive associations between HCV mortality and the proportion of non-Hispanic black or Hispanic residents, neighborhood poverty, education, and non-English-speaking households. Local regression estimates identified spatially varying patterns in these associations. The rates of HCV mortality in NYC are increasing and vary by neighborhood. HCV mortality is associated with many indicators of geographic inequality. Results identified neighborhoods in greatest need for place-based interventions to address social determinants that may perpetuate inequalities in HCV mortality.

Keywords Hepatitis · Mortality · Spatial analysis · Communicable diseases · Disease modeling

Background

Deaths attributable to hepatitis C (HCV) infection are increasing in the United States of America even as

highly effective treatments become available [1]. As of 2007, HCV mortality rates in the USA have exceeded those of HIV in a trend expected to continue if HCV-related deaths are not prevented [2]. HCV attacks the liver, leading to cirrhosis, hepatocellular carcinoma (liver cancer), liver failure, and ultimately death. Decedents with HCV may die as many as two decades earlier than their noninfected counterparts [3]. Because screening and treatment for HCV is often not sought until symptoms of advanced liver disease appear, HCV can remain undetected for decades, having substantial public health and cost implications [4]. Late-stage diagnosis or delayed HCV treatment increases the likelihood of mortality [5], and creates missed opportunities for intervention. It is estimated that as many as half of persons living with HCV are unaware of their status [6] making the identification of high-risk populations crucial to halting this trend.

Nationally, HCV disproportionately affects low-income persons and racial minorities [7, 8] who may also experience poor access to healthcare services [9]. Racial, ethnic, and socioeconomic characteristics have been shown to impact HCV screening and access to care and treatment [10]. Since 1992, when HCV screening became mandatory in the blood supply used for transfusions, the primary risk factor for HCV in the USA has been injection drug use (IDU). HCV prevalence is highest among the “baby boomer” birth cohort: persons born between 1945 and 1965 [8]. HCV-positive persons are more likely to be uninsured or publicly insured [9]. Due to the stigma associated with HCV and its risk factors, place-based and community-tailored interventions are particularly important to reach high-risk populations.

Geographic inequalities in health, where health outcomes differ by location, are often attributable to variation in the underlying populations’ social and environmental conditions [11, 12]. In fact, neighborhood of residence is so strongly linked to health outcomes that it may be considered a health determinant [13]. These place-based inequalities are exacerbated by poor access to health and social services in neighborhoods and communities where residents have physical or linguistic barriers to high-quality care. Spatial analyses [14, 15] and geographic information systems (GIS) have powerful capabilities to describe disease patterns and identify high-need populations but are often underutilized in public health research and planning. These methods can be integral to the accurate placement of

community-based interventions, which support better outcomes than one-size-fits-all approaches [16, 17].

New York City (NYC) has some of the highest reported rates of HCV (2.4%, range 1.5–4.9%) and of populations with HCV risk factors in the USA [18]. Within NYC, HCV is strongly associated with increasing area-based poverty [19]. To date, however, there has not been a small-area analysis of HCV mortality in NYC. Our study aims to identify neighborhood-level inequalities in HCV mortality using a multiple cause of death (MCOd) definition (deaths directly or indirectly associated with HCV infection). The study (i) describes spatial and temporal patterns in the age-adjusted HCV mortality rates at the census tract (CT) level and (ii) tests for associations between HCV mortality and neighborhood demographic and socioeconomic characteristics using a global and local Poisson modeling approach. The results can be used to target neighborhoods with geographic inequalities in HCV mortality and will accurately inform the placement of public health interventions.

Methods

Data set

The study is an ecological analysis, set within NYC, which in 2014 had a population of approximately 8.5 million, with 1.7 million (20.3%) living below the federal poverty line [20]. Census tract was the geographical unit selected in this study in order to conduct small-area analysis, while simultaneously protecting patient confidentiality and maintaining stability in rate calculations. The 2167 NYC census tracts (CTs) were used [21] to maximize spatial variability as census tracts are more homogenous than ZIP codes or larger geographic units in terms of demographic, economic, or cultural characteristics [22]. Nonresidential CTs, including parks or airports, and CTs with population estimates less than three standard deviations from the mean, were excluded from the analysis.

Mortality Data

HCV mortality data were obtained from the NYC Health Department’s Bureau of Vital Statistics and included HCV-related deaths reported between January 1, 2006, and December 31, 2014. HCV mortality was

defined using an MCODE definition with *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision* (ICD-10) [23] codes [24, 25]. We included any cases with an underlying cause of death of chronic hepatitis C (B18.2, B171.1) or cases with chronic HCV listed as a contributing cause with an underlying cause of liver cancer (C22), drug-related (F11–F19, X40–X44, X60–X64, Y10–Y14, X85), liver cirrhosis (K70, K73–K74), or viral hepatitis (B15–B19) [3, 24, 25]. For each record, data on decedent's address, birth year, and date of death were collected. Cases were assigned to a CT based on address of residence at time of death using a spatial join [26]. The cases were used to calculate age-specific mortality rates by CT, using the 2010 census data. The 2000 standard population was used as the population for direct standardization of the age-adjusted rates for seven age categories (<34, 35–44, 45–54, 55–64, 65–74, 75–84, and ≥85 years) [27].

Explanatory Variables

Explanatory variables were identified through a review of the literature on HCV-specific sociodemographic risk factors and population-level determinants of poor access to care. Data for the explanatory variables were obtained from the 2010 Census (age and race/ethnicity) and from the 2009–2013 American Community Survey (ACS) [28] or closest available data: educational attainment, primary language spoken at home, overcrowding, uninsured status, poverty, and region of birth (US or foreign). All explanatory variables were continuous and calculated as a proportion of the 2010 Census population for each CT. Age was categorized into four continuous variables: proportion of residents <30 years, 30 to 44 years, 45 to 64 years, and 65 years and over. Race/ethnicity was measured with five variables, representing the proportion of Hispanic; white, non-Hispanic; black, non-Hispanic; Asian, non-Hispanic; and other, non-Hispanic persons in each CT. Educational attainment was grouped into four variables: proportion of persons with a high school diploma or lower, some college, bachelor's degree, and graduate degree. Overcrowding consisted of the proportion residing with 1.51 or more occupants per room. Poverty was defined as the proportion of persons living 100% below the federal poverty level (FPL) in each CT. Language spoken at home was analyzed as the proportion of non-English-speaking

residents in each CT. Foreign born was defined as the proportion of NYC residents born outside of the USA.

Temporal Trend Analysis

Joinpoint regression analysis was used to calculate the average annual percent change (AAPC) and 95% confidence interval in the age-adjusted HCV mortality rate over the 9-year study period. This method uses a Monte Carlo permutation test to find the minimum number of joinpoints (with zero joinpoints representing a straight line) that identify whether a change in trend is statistically significant [29]. We used the Joinpoint Regression Program, Version 4.3.1.0, with an autocorrelated errors model and assuming constant variance of model errors [16].

Rate and Hotspot Mapping

The distribution of annual average, age-adjusted HCV mortality rates per 100,000 was mapped by NYC CT. To identify clustering (or “hotspots”) in crude HCV mortality rates, a local indicators of spatial autocorrelation (LISA) Moran's *I* test with an empirical Bayes smoother was applied to the mortality case count using the 2010 Census population per CT as the offset term. The LISA clusters identify hotspots in HCV mortality (where CTs with high rates are surrounded by CTs with high rates), coldspots (CTs with low rates are surrounded by CTs with low rates), and spatial outliers (CTs with high rates are surrounded by CTs with low rates, and vice versa). In addition, a global Moran's *I* statistic was produced to measure spatial autocorrelation across the study site. The Moran's *I* statistic ranges from −1 to 1, with 0 indicating the presence of no spatial autocorrelation, 1 indicating absolute spatial autocorrelation, and −1 indicating perfect spatial dispersion of the rates. All explanatory variables were tested separately for the presence of spatial autocorrelation.

Global and Local Regression Analysis

A sequential, multistep global and local regression modeling approach was used to examine the association between HCV mortality and neighborhood explanatory variables. This approach has been shown to be appropriate for small-scale geographic data [30]. The dependent variable in all regression models was the HCV mortality count in each CT. The offset variable was the population count in the CT. In the first step, HCV

mortality was regressed against all explanatory factors in a Poisson model with a stepwise backward elimination approach used to determine the best fit model. The global Poisson model estimates the strength and direction of the relationship between the outcome and explanatory variables averaged across the entire study area. The β coefficients for the model were exponentiated to calculate risk ratios (RRs) per 10-percentage-point increase in each independent variable. While the global Poisson model tests for associations across NYC, the singular use of this regression model may mask important spatial variation in the strength of relationships at the CT level.

Following the identification of the model of best fit globally, a geographically weighted Poisson regression (GWPR) model was built, where the strength and direction of associations were allowed to vary across the study site. The GWPR model calculates CT-specific model parameters, including local β coefficients and pseudo- t and R^2 values, extending the capabilities of traditional regression modeling techniques [31, 32]. The local model parameters identify CTs where the strength of the relationship is strongest and CTs where the model has the best predictive accuracy. Explanatory variables found to be significant in the global model were used to build an analogous GWPR model. To control for multicollinearity [33], a semiparametric GWPR model was built, allowing all sociodemographic characteristics to vary locally, while treating the control variables (age categories, sex) as global explanatory variables [33]. The model bandwidth was selected with the “golden search” function in GWR4, which uses a corrected Akaike information criterion (AIC) to optimize bandwidth [34]. The local regression coefficients were mapped for the significant explanatory variables.

The goodness of fit between the global and local regression models was compared with AIC and pseudo- R^2 values. All regression analyses were conducted at the $\alpha < 0.05$ significance level. Poisson regression modeling was conducted in SAS 9.2, spatial autocorrelation tests were conducted in GeoDa, and GWPR analyses were conducted using GeoDa's GWR4 software. Choropleth maps were produced in ArcGIS 10.2.1 using quintiles.

Results

Between January 1, 2006, and December 31, 2014, 3697 HCV-related deaths occurred in NYC. The

underlying cause of death for 2565 (69.4%) of these cases was recorded as chronic viral hepatitis C (ICD-10: B182). Figure 1 shows that liver cancer (ICD-10: C220, C229) was the second most common underlying cause of death in this population ($n = 644$, 17.4%). The median age of death was 60, ranging from 24 to 101 years; 2554 (69%) cases died before age 65. Over two thirds of the deaths ($n = 2529$, 68.4%) occurred in persons born between 1945 and 1965. The temporal trend analysis found a statistically significant increase in HCV mortality rates during the 9-year period (AAPC = 2.6%, 95% CI 1.8–3.4%).

Almost all, or 3659 (99%), of the cases were matched to a CT. Figure 2a presents the age-adjusted, annual average HCV mortality rates ranging from 0 to 373.6 per 100,000 by CT. The global Moran's I for HCV mortality was 0.23, indicating the presence of moderate but significant spatial autocorrelation in many neighborhoods (Fig. 2b). Approximately 10% (211) of CTs were identified as hotspots. Hotspots were primarily located in the South and Central Bronx, upper Manhattan, lower Manhattan, and central Brooklyn. Eighty-two (4%) CTs were identified as high-rate outliers found in north/central Queens and southern Brooklyn. The explanatory variables also showed distinct spatial patterns for selected factors when mapped (Fig. 3), and all explanatory variables showed evidence of spatial autocorrelation.

Table 1 illustrates the sociodemographic factors found to be associated with HCV mortality at the CT level. The strongest positive associations were observed between HCV mortality and proportion Hispanic (RR = 1.12, $p < 0.01$), poverty (RR = 1.14, $p < 0.01$), less than or equal to a high school diploma (RR = 1.15, $p < 0.01$), and population aged 44 to 64 (RR = 1.49, $p < 0.01$). The proportion of foreign-born residents was associated with a decreased risk of HCV mortality (RR = 0.8, $p < 0.01$). No significant associations with proportion uninsured, overcrowding, educational attainment (some college), and Asian race were found through backward stepwise elimination. The pseudo- R^2 value for the global Poisson model was 0.25, and the AIC was 2928.67.

The GWPR model identified spatially varying relationships between HCV mortality and the significant explanatory variables as indicated by the local beta coefficients seen in Fig. 4. GWPR model coefficient distributions varied across the sociodemographic characteristics. Non-Hispanic black and Hispanic associations had the largest maximum local coefficients, with

Fig. 1 Annual hepatitis C mortality count by underlying vs. contributing cause of death, New York City, 2006–2014

the strongest associations found to be clustered in neighborhoods including neighborhoods in the South Bronx, lower Manhattan, and Central Brooklyn. The pseudo- R^2 value for the GWPR model was 0.58, a 132% increase over the pseudo- R^2 value in the global Poisson model. The AIC for the GWPR model was 2906.14.

Discussion

The present study found increasing rates of HCV-related mortality in NYC over time, with disproportionately high rates in neighborhoods with indicators of geographic disparity. More than two thirds of the decedents were aged less than 65 years at time of death, supporting previous findings

that HCV-infected persons are at increased risk of premature death [3]. The significant increase in HCV mortality during the 9-year period is consistent with national and international trends [1]. Approximately 10% of NYC CTs were identified as HCV mortality hotspots and may serve as primary target areas for interventions, including neighborhoods in the Bronx, Upper Manhattan, and Central Brooklyn. Census tract outliers may serve as secondary target neighborhoods where further investigation is warranted. The improved model fit in the GWPR model supports the use of spatial methods in this study as well as in future research, where using only a global model may have led to misclassification of disease patterns and associations [34].

The associations between HCV mortality and many of the indicators of geographic disparity support

Fig. 2 **a** Average annual, age-adjusted hepatitis C mortality rates in New York City by census tract, 2006–2014. **b** Local indicators of spatial autocorrelation for hepatitis C mortality rates, by cluster type, New York City, 2006–2014

Fig. 3 Spatial distribution of census tract-level factors associated with HCV mortality, New York City, 2006–2014

previous research that found HCV-infected persons are more likely to live in communities segregated by race/ethnicity or income [19, 35]. Here, the strongest associations with HCV mortality were found in census tracts with high proportions of non-Hispanic black or Hispanic residents. In neighborhoods with strong associations between HCV mortality and poverty or low

educational attainment, low health literacy or lack of financial resources may contribute to geographic inequalities by limiting residents' ability to access HCV care and services. Previous studies have shown that low-income and minority persons tend to seek care in geographic areas where quality of care is lower [36] for all patients, suggesting that HCV prevention and control

Table 1 Associations between hepatitis C mortality count and census tract-level explanatory variables from global Poisson regression, New York City, 2006–2014

Parameter	β Estimate	Std. error	<i>p</i> value	Relative risk ^a	95% Confidence interval
Age					
Age 30–44	0.0254	0.0069	0.0003	1.29	1.13 to 1.48
Age 45–64	0.0399	0.0052	<.0001	1.49	1.34 to 1.65
Age 65	0.0289	0.0044	<.0001	1.34	1.23 to 1.46
Sex					
Male	−0.0181	0.006	0.003	0.83	0.74 to 0.94
Race/ethnicity					
Black, non-Hispanic	0.0079	0.0012	<.0001	1.08	1.06 to 1.11
Hispanic	0.0117	0.0011	<.0001	1.12	1.10 to 1.15
Asian, non-Hispanic ^b	−0.0004	0.0021	0.837	—	—
Other, non-Hispanic ^b	0.0083	0.0083	0.317	—	—
Educational attainment					
≤High school diploma	0.0141	0.0027	<.0001	1.15	1.09 to 1.21
Bachelor's degree	0.0152	0.0046	0.001	1.16	1.06 to 1.24
Some college ^b	0.0011	0.004	0.785	—	—
Socioeconomic indicators					
Poverty	0.0127	0.002	<.0001	1.14	1.09 to 1.18
Uninsured ^b	−0.0039	0.004	0.301	—	—
Primary language spoken					
Non-English speaking					
Household	0.0074	0.0019	<.0001	1.08	1.04 to 1.12
Foreign born					
Foreign born	−0.0227	0.0018	<.0001	0.80	0.77 to 0.83
Household characteristics					
Overcrowding ^b	0.0013	0.0065	0.843	—	—

^aRelative risk for each outcome is reported per 10 unit increase in explanatory variables

^bExplanatory variables found to be insignificant through backward stepwise elimination at $p > 0.05$

services should be placed directly within communities with disproportionately high mortality rates.

HCV mortality was positively associated with the proportion of non-English-speaking households, underscoring the importance of linguistically and culturally appropriate interventions in community health settings. Language barriers marginalize patients from the healthcare system when translation services are unavailable. Conversely, an increase in the proportion of foreign-born residents was associated with a lower risk of HCV mortality. This finding may be a result of the so-called immigrant paradox, where foreign-born immigrants in the USA often have better overall health than their US-born counterparts, despite often having lower socioeconomic position [37, 38]. Future community-level research on this association should be conducted

to tailor HCV services in linguistically and culturally appropriate ways.

The study results can be used to target communities at greatest risk for HCV mortality and to create interventions tailored to neighborhood-specific disparities associated with HCV outcomes. Community-based interventions are particularly advantageous in resource-limited areas, where it is not realistic to fund interventions citywide, as a strategy to move toward HCV elimination [39]. For example, in neighborhoods with the highest poverty, local clinics can offer free testing services, Federally Qualified Health Centers can conduct outreach to engage persons in HCV care, and state and local health departments can place HCV interventions in these neighborhoods. Within communities, HCV public awareness campaigns and interventions

Fig. 4 Geographically weighted Poisson regression parameter estimates for socioeconomic determinants of HCV mortality, New York City, 2006–2014

should be tailored to the sociodemographic characteristics of the neighborhood population. In fact, community-tailored interventions are thought to be more effective than a singular approach to improving health outcomes across subgroups [16, 17].

The results can be used to monitor spatial variation and drivers of HCV mortality across NYC. First, by monitoring geographic and socioeconomic inequalities associated with HCV mortality, we can predict where HCV illness and death are expected to occur to more effectively focus prevention and

treatment services than in the past. Secondly, by monitoring HCV mortality at a neighborhood level, we can assess whether interventions are working effectively within communities in relation to known drivers of HCV mortality. We can work to ensure health improvements are occurring at similar rates for all members of the population or where interventions need to be modified to groups with greatest risk. Lastly, monitoring drivers, such as socioeconomic position, in comparison to HCV mortality, allows identification of new disease

dynamics as they arise, including changes in at-risk populations or risk factors [40]. Without continuous identification and addressing needs of highest-need communities, achieving overall improvements in HCV morbidity and mortality will remain a challenge.

Limitations

The study used CT-level data, and results found at the population level may not be generalizable to individuals. Similarly, the use of CT data may lead to the modifiable area unit problem if analyses were applied to a different geographic unit [41]. However, we believe conducting analysis at the CT level allowed for the most appropriate results of available geographic units. In addition, the model did not account for behavioral or individual-level risk factors for HCV (e.g., injection drug use) which likely drive neighborhood-level patterns of the disease. These behavior factors are not available in surveillance data. The address used in the study represents address at time of death and does not account for length of stay at that address or residential movement. Another limitation is that some persons with chronic HCV infection may not have been diagnosed or had the diagnosis documented on their death certificate. We believe that using the MCODE definition alleviates these concerns and more accurately captured the burden of HCV mortality.

Conclusion

Hepatitis C mortality has been increasing in NYC, and the highest rates have occurred disproportionately in neighborhoods comprising socioeconomically disadvantaged, older, and racial/ethnic minority persons. The findings emphasize the need for increased HCV public awareness and neighborhood-tailored public health interventions defined in part by using geographic analysis. Public health practitioners must identify highest-need communities and offer programs designed to improve health outcomes in HCV at-risk populations. To reduce the burden of HCV death in NYC and across the USA, geographically targeted, evidence-based interventions must be implemented to increase access to care for all communities.

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