Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

Patient characteristics and neighborhood attributes associated with hepatitis C screening and positivity in Philadelphia

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ARTICLE INFO

Keywords:
Hepatitis C screening
Preventive health care services
Social determinants of health
Record linkages
Geographic analysis
Census tracts
Primary care

ABSTRACT

Among patients of an urban primary care network in Philadelphia with a universal hepatitis C virus (HCV) screening policy for patients born during 1945–1965, we examined whether being unscreened and HCV positivity were associated with attributes of the census tracts where patients resided, which we considered as proxies for social health determinants. For patients with at least one clinic visit between 2014 and mid-2017, we linked demographic and HCV screening information from electronic health records with metrics that described the census tracts where patients resided. We used generalized estimating equations to estimate adjusted relative risk ratios (aRRs) for being unscreened and HCV positive. Overall, 28% of 6,906 patients were unscreened. Black race, male gender, and residence in census tracts with relatively high levels of violent crime, low levels of educational attainment and household incomes, and evidence of residential segregation by Hispanic ethnicity were associated with lower aRRs for being unscreened. Among screened patients, 9% were HCV positive. Factors associated with lower risks of being unscreened were, in general, associated with higher HCV positivity. Attributes of census tracts where patients reside are probably less apparent to clinicians than patients' gender or race but might reflect unmeasured patient characteristics that affected screening practices, along with preconceptions regarding the likelihood of HCV infection based on prior screening observations or implicit biases. Approaching complete detection of HCV-infected people would be hastened by focusing on residents of census tracts with attributes associated with higher infection levels or, if known, higher infection levels directly.

1. Introduction

In 2012, the Centers for Disease Control and Prevention (CDC) recommended hepatitis C virus (HCV) screening for all people born during 1945–1965, i.e., "baby boomers," expanding prior guidelines that emphasized screening for those with recognized HCV risks (Smith et al., 2012). This change was driven by the higher prevalence of HCV among baby boomers relative to those who were younger or older, the emergence of highly effective therapies, and the realization that many people with HCV were unaware of their infection (Smith et al., 2012). In response to this recommendation, the Drexel University College of Medicine Physicians Practice Plan in Philadelphia implemented a program that aimed to screen all patients in this birth cohort (Coppock et al., 2020). In this report, we extend a prior assessment of that program, which documented substantial increases in screening (Coppock et al., 2020), by examining whether the attributes of census tracts where patients resided were associated with risks of being unscreened and rates of HCV infection.

Our approach was predicated on the clustering of social determinants of health in neighborhoods (Diez Roux and Mair, 2010; White and Borrell, 2011; Williams and Collins, 2001), including geographic clustering of HCV prevalence, morbidity, and mortality

(Stopka et al., 2017; Butt et al., 2019; Ford et al., 2017). In Philadelphia, the characteristics of the places where people live have also been shown to be associated with several primary care outcomes, including levels of colorectal cancer screening (Buehler et al., 2019), keeping or missing scheduled appointments (Chou et al., 2021), and diabetes and hypertension control (Lê-Scherban et al., 2019), We posited that attributes of places where patients resided might also be associated with risks of being unscreened and HCV positivity among screened patients, which, in turn, might provide insights into location-based strategies to inform the "end game" of achieving complete screening, including hastening detection of all HCV-infected patients within a patient population.

2. Methods

2.1. Setting and patient population

We extracted patient data from electronic health records (EHRs) of the six adult primary care practices of the Drexel University College of Medicine Physicians Practice Plan for all patients who were born from 1945 through 1965 and had at least one clinic visit from January 1, 2014, through July 31, 2017. Extracted variables included HCV antibody testing and results, HCV RNA testing, race/ethnicity (non-Hispanic White, non-Hispanic Black/African American, non-Hispanic Asian [subsequently referred to as White, Black, or Asian, respectively], Hispanic, other/unknown), birth year, gender (male, female), type of health insurance (private, Medicare, Medicare Advantage, Medicaid, uninsured/ unspecified), last recorded address of residence, and clinic site (Clinics 1–6). We use the term "patient characteristics" to describe these variables.

2.2. Geocoding

For the 9,811 patients meeting the above criteria, we used ArcGIS 10.5 (Esri) with the Business Analyst 2016 Composite Address Locator to automatically geocode their addresses of residence (ESRI, 2022), and we classified their census tracts of residence based on geocoded addresses. Census tracts of residence were assigned for 9,411 (96 %), among whom > 99 % of addresses were geocoded automatically and the remainder geocoded manually. The most common reason for an inability to assign a geocode is that the only address listed in the patient's EHR was a post office box number for billing purposes.

2.3. HCV screening and result

As part of the previously described HCV screening and treatment program (Coppock et al., 2020), education and ongoing reminders regarding screening recommendations were provided to clinic physicians, and the clinics' EHR was programmed to scan for evidence of HCV antibody testing among patients born during 1945–1965. Absent such evidence, the EHR prompted physicians to order the test during patient encounters, which they could opt to heed or bypass. As a back-up measure introduced during the study period at several clinic sites, phlebotomists were instructed to check patients' HCV screening status before performing venipuncture and to query physicians about ordering a test if indicated. The intervention emphasized screening among patients who arrived for clinic visits but did not include outreach to schedule screening appointments. During the study period, CDC defined HCV screening as testing with an anti-HCV antibody screening assay (Smith et al., 2012; Alter et al., 2003). One of the two funders for the screening and treatment program (Coppock et al., 2020) required that patients with a recorded HCV RNA test but lacking evidence of an HCV antibody test be classified as unscreened, and the EHR prompted antibody testing for such patients. Thus, we classified HCV screening status (screened/unscreened) based on documented HCV antibody testing and screening results as positive or negative.

2.4. Census tract attributes

We described the populations in each patient's census tract of residence using data from multiple sources and used the term "census tract attributes" to describe these measures. The level of violent crime was defined as the rate of homicides, rapes, aggravated assaults, robberies, and other assaults per 10,000 population as recorded by the Philadelphia Police Department for 2017 (Philadelphia Police Department, 2022; OpenDataPhilly, 2022). Median household incomes and the percentages of residents aged > 25 years who reported completion of high school were obtained from the American Community Survey 5-year aggregate data for 2013–2017. (United States Census Bureau, 2022). We aggregated patients into tercile groups based on levels for each of these census tract attributes (i.e., the number in each group represented one-third of total patients). Residential racial and ethnic segregation was measured by calculating the local G_i^* statistic (ESRI, 2022) which considers the percentage of residents within a census tract and surrounding census tract who are Black or Hispanic, respectively, compared to the overall averages for the city of Philadelphia. The G_i^* statistic was expressed as a z-score, with values > 1.96 indicating a significant level of segregation. We use these census tract metrics rather than a composite measure, such as CDC/Agency for Toxic Substances and Disease Registry social vulnerability index for disaster planning and responses (Agency for Toxic Substances and Disease Registry, 2022), the COVID-19 Community Vulnerability Index (Surgo Ventures, 2022), or the Multilevel Modeling of Disparities to Explain Preterm Delivery Neighborhood Deprivation Index (Messer et al., 2006) because none of these indices included two measures, residential segregation and rates of violent crime, that have been shown previously to be associated with various primary care outcomes in Philadelphia (Buehler et al., 2019; Chou et al., 2021; Lê-Scherban et al., 2019).

2.5. Statistical analysis

Of the 9,811 patients, we excluded those with indeterminate HCV screening results due to reported laboratory error (n = 5), those for whom we were unable to geocode an address of residence (n = 400), those whose address was geocoded to a location outside the city of Philadelphia (n = 2,115), those who had an HCV RNA test recorded in their EHR but not an HCV antibody test (n = 380), and those with missing values for any of the census tract attributes (n = 5). This resulted in a final sample of 6,906 patients. These patients resided in 370 of Philadelphia's 384 census tracts, and the median number of patients per census tract was 13, range 1–144.

Following initial descriptive analyses, we used generalized estimating equations (GEEs) with the log binomial Poisson distribution and an exchangeable correlation structure to estimate adjusted relative risk (aRR) ratios of being unscreened by patient characteristics and census tract attributes. Due to the small sample size of patients who were neither Black nor White, we collapsed race/ethnicity into three categories, White, Black, and all others (Asian, Hispanic, and other/unknown) for model estimations.

Models that examined associations between census tract attributes and screening were adjusted for patient characteristics (year of birth, gender, race/ethnicity, type of insurance, and clinic site where patients were registered). Although risks of being unscreened varied among patients who received their care at different clinic sites (Coppock et al., 2020), we do not present clinic-specific findings given our emphasis on patient characteristics and neighborhood attributes. We first examined each census tract attribute separately in models that controlled for all of the above patient characteristics (group-1 models) and then examined all census tract attributes simultaneously in a model that also controlled for patient characteristics (model–2). All statistical tests are 2-tailed, and aRR estimates are shown with 95 % confidence intervals (CIs). Because of the possibility that patient characteristics or census tract attributes associated with the risk of being unscreened might have differed

between earlier and later years of the study period, as a sensitivity analysis, we examined these associations among previously unscreened patients with clinic visits during the last 19 months of the study period (January 2016 through July 2017). For screened patients (n = 4,998), we examined HCV test results (positive or negative) following the same approach, except that patients who were neither Black nor White (n = 467) were excluded because their number was insufficient for model estimation, resulting in a sample of 4,531 screened patients. Because of the non-linear relationship between birth year and HCV positivity, rather than considering birth year as a continuous variable, we considered birth year in four categories, 1945–1949, 1950–1954, 1955–1959, and 1960–1965. Findings regarding risks of being unscreened and risks of being HCV positive were similar in group-1 models and model-2, although in model-2 fewer associations were statistically significant (p < 0.05); and we present only the model-1 findings.

The study was approved by the Drexel University Institutional Review Board.

3. Results

Among the 6,906 study patients, 59 % were Black, 31 % White, 62 % female, and 61 % were born during 1955–1965; and predominant types of insurance coverage were private insurance (53 %), Medicare or Medicare Advantage (25 %), and Medicaid (20 %) (Table 1).

Overall, 4,998 (72 %) were screened for HCV and 1,908 (28 %) were unscreened. Proportions of patients who were unscreened were similar among men and women and among those born before or after 1955 (Table 2). Asian, Black, and Hispanic patients were less likely to be unscreened than White patients and those with other/unknown race/

Table 1

Characteristics of study patients and attributes of their census tracts of residence.

Patient characteristics		Percentage of Study Patients
All patients (N = 6,906)		100.0 %
Sex	Female	61.6 %
	Male	38.4 %
Year of birth	1945–1954	38.8 %
	1955–1965	61.2 %
Race/ethnicity	Asian	1.3 %
	Black	58.9 %
	Hispanic	4.1 %
	White	30.8 %
	Other/Unknown	4.9 %
Insurance	Uninsured/Unspecified	1.6 %
	Private	52.5 %
	Medicaid	20.5 %
	Medicare	12.0 %
	Medicare Advantage	13.4 %
Attributes of patients' census tracts of residence		
Annual rate of violent crime per 10,000 residents (tercile)	Low (8–148)	33.3 %
	Intermediate (152–314)	33.3 %
	High (314–1,135)	33.3 %
Percentage with high school degree or higher (tercile)	Low (42–82 %)	33.3 %
	Intermediate (82–91 %)	33.3 %
	High (91–100 %)	33.3 %
Median household income (tercile)	Low ($9,945-$29,332)	
	Intermediate ($29,804-$53,799)	33.3 %
	High ($53,935-$149,211)	33.3 %
Black segregation	Segregation*	33.5 %
	No segregation	66.5 %
Hispanic segregation	Segregation*	7.9 %
	No segregation	92.1 %

* Measured as the Getis-Ord Gi statistic > 1.96.

Table 2

Percentage of patients unscreened for HCV and adjusted relative risks (aRRs) and 95 % confidence intervals (CIs) of being unscreened for HCV, by selected patient characteristics and attributes of their census tracts of residence, n = 6,906 patients.

Patient Characteristics		Percentage Unscreened	Adjusted RR of being unscreened*	95 % CI
All patients (N = 6,906)		27.6 %		
Sex	Female	27.8 %	Referent	
	Male	27.3 %	0.93	0.87, 1.00¶
Year of birth	1945–1954	28.2 %	1.01μ	1.00, 1.01μ
	1955–1965	27.2 %		
Race/ethnicity	Black	23.4 %	0.77	0.69, 0.86¶
	Other/Unknown	34.3 %	1.08	0.94, 1.24
	White	33.4 %	Referent	
Insurance	Uninsured/Unspecified	47.8 %	1.67	1.37, 2.03¶
	Medicaid	23.6 %	0.97	0.85, 1.09
	Medicare	28.9 %	1.16	1.03, 1.31¶
	Medicare Advantage	32.8 %	1.34	1.20, 1.49¶
	Private	27.0 %	Referent	
Census tract attributes				
Violent crime rate per 10,000 residents (tercile)	Low (8–148)	32.8 %	Referent	
	Intermediate (152–314)	25.7 %	0.88	0.79, 0.98¶
	High (314–1,135)	24.4 %	0.89	0.78, 1.01
Percent with high school degree or higher (tercile)	Low (42–82 %)	23.4 %	0.86	0.77, 0.97¶
	Intermediate (82–91 %)	27.2 %	0.99	0.90, 1.10
	High (91–100 %)	32.3 %	Referent	
Median household income in US dollars (tercile)	Low ($9,945-$29,332)	24.2 %	0.91	0.80, 1.04
	Intermediate ($29,804-$53,799)	25.9 %	0.90	0.81, 0.99¶
	High ($53,935-$149,211)	32.7 %	Referent	
Black residential segregation	Segregation#	24.6 %	1.02	0.92, 1.12
	No segregation	29.1 %	Referent	
Hispanic residential segregation	Segregation#	20.7 %	0.75	0.65, 0.87¶
	No segregation	28.2 %	Referent	

*Group-1 model that included violent crime rate as the census tract attribute and all patient characteristics (birth year, gender, race/ethnicity, insurance, and clinic site).
¶ p-value < 0.05.
# Measured as the Getis-Ord Gi statistic > 1.96.
μ Adjusted relative risk estimates for 1-year increments in year of birth.

ethnicity (Table 2). The proportion unscreened was lowest among those insured by Medicaid, intermediate among those with private insurance, Medicare or Medicare Advantage, and highest among those who were uninsured or had unknown insurance status (Table 2). The proportion who were unscreened was lowest among those living in census tracts with the highest levels of violent crime and where populations had the lowest levels of educational attainment and median household incomes (Table 2). The proportion unscreened was lower among those living in census tracts with relatively high levels of racial or ethnic residential segregation (Table 2).

In examining risks of being unscreened, aRR estimates and CIs for patient characteristics were virtually identical in all group-1 models, and we present the findings from the model that included violent crime for display (Table 2). Men had a slightly lower aRR of being unscreened

relative to women, and Black patients had a lower aRR of being unscreened than White patients. Patients with Medicare or Medicare Advantage insurance or with no or unspecified insurance had a higher aRR of being unscreened than those with private insurance; and the risk of being unscreened was similar for those with Medicaid and private insurance (Table 2). The proportion unscreened was highest among patients residing in census tracts with the lowest level of violent crime, the highest level of educational attainment, and the highest median household incomes, although not all differences between these and other tercile groups were statistically significant (Table 2). Residence in a census tract with Hispanic residential segregation was significantly associated with a lower risk of being unscreened, but not residence in a census tract with Black residential segregation (Table 2). For the sensitivity analysis that examined screening during the latter part of the study period, there were 2,201 patients who had not been screened by January 1, 2016, among whom 46 % remained unscreened by the end of the study period in July 2017. In examining aRRs for being unscreened among this group, we did not observe a shift in patient characteristics or census tract attributes associated with being unscreened when compared to associations observed for the overall study period (data not shown).

Among the 4,531 Black and White patients who were screened for HCV, 391 (9 %) were positive. Levels of HCV positivity were higher for those born during 1950–1954 and 1955–1959 than in the prior or later birth intervals (Table 3). HCV positivity was higher for male than female patients, for Black than White patients, and for those insured by Medicaid (20 %) than for those with other types of insurance (Table 3). HCV positivity rates varied in a stepwise manner among patients living in census tracts in different terciles for census tract population attributes and were highest among those living in census tracts with the highest level of violent crime, the lowest level of educational attainment, and the lowest median household incomes (Table 3). Smaller increases in HCV positivity rates were observed among patients living in census tracts with Black or Hispanic residential segregation than others (Table 3). In the models, associations between HCV positivity and patient characteristics were consistent with the descriptive findings, with one exception. Black patients were not more likely than White patients to be HCV-positive when other factors were taken into account (Table 3). Higher aRRs for HCV infection were observed in the models for residents of census tracts with intermediate and high relative to low levels of violent crime and low relative to high levels of educational attainment (Table 3).

4. Discussion

Within cities, geographic variations in population attributes such as levels of violent crime, educational attainment, household incomes, and racial/ethnic segregation are associated with multiple health disparities (Diez Roux and Mair, 2010; White and Borrell, 2011; Williams and Collins, 2001). In the urban clinic network we studied, risks of being unscreened for HCV among patients born during 1945–1965 varied by attributes of the census tracts where patients resided, even after taking into account variations by patient characteristics such as gender, race, and type of insurance coverage and despite a clinic program to promote universal screening. Notably, residence in census tracts with relatively high levels of violent crime, low levels of educational attainment and household incomes, and evidence of Hispanic ethnic segregation was associated with lower risks of being unscreened.

Patient characteristics and neighborhood attributes associated with lower risks of being unscreened were generally associated with higher levels of HCV positivity. For example, patients insured by Medicaid, an indicator of low income status, had a relatively low risk for being unscreened and a relatively high risk for being HCV-positive. An exception was that male patients had a 2-fold higher level of HCV positivity than female patients, but the difference in the risk of being unscreened was small, contrary to expectations that risks of being unscreened might be

Table 3
Percentage of Black and White patients screened for HCV who were HCV positive and adjusted relative risks (aRRs) and 95 % confidence intervals (CIs) of being HCV positive, by selected patient characteristics and attributes of their census tracts of residence, n = 4,531 patients.

		Percentage HCV Positive	Adjusted RR of being HCV-positive*	95 % CI
Patient Characteristics (N = 4,531)**		8.6 %		
Sex	Female	6.3 %	Referent	
	Male	12.4 %	1.92	1.59, 2.32¶
Year of birth	1945–1949	7.6 %	Referent	
	1950–1954	9.5 %	1.14	0.79, 1.64
	1955–1959	11.4 %	1.14	0.80, 1.64
	1960–1965	6.1 %	0.57	0.40, 0.80¶
Race/ethnicity	Black	10.2 %	0.95	0.71, 1.29
	White	5.1 %	Referent	
Insurance	Uninsured/ Unspecified	8.5 %	1.84	0.73, 4.69
	Medicaid	20.1 %	2.80	2.05, 3.82¶
	Medicare	10.3 %	1.96	1.37, 2.82¶
	Medicare Advantage	8.3 %	1.78	1.21, 2.60¶
	Private	3.6 %	Referent	
Census tract attributes				
Violent crime rate per 10,000 residents (tercile)	Low (8–148)	4.4 %	Referent	
	Intermediate (152–314)	9.2 %	1.44	1.00, 2.06¶
	High (314–1,135)	11.6 %	1.58	1.10, 2.27¶
Percent with high school degree or higher (tercile)	Low (42–82 %)	11.9 %	1.39	1.00, 1.94¶
	Intermediate (82–91 %)	8.6 %	1.20	0.86, 1.69
	High (91–100 %)	5.0 %	Referent	
Median household income in US dollars (tercile)	Low ($9,945-$29,332)	11.7 %	1.29	0.92, 1.82
	Intermediate ($29,804-$53,799)	8.4 %	1.15	0.83, 1.60
	High ($53,935-$149,211)	5.2 %	Referent	
Black residential segregation	Segregation#	10.1 %	1.07	0.89, 1.29
	No segregation	7.8 %	Referent	
Hispanic residential segregation	Segregation#	11.1 %	1.11	0.79, 1.55
	No segregation	8.4 %	Referent	

*Model-1 adjusted for birth year, gender, race/ethnicity, insurance, and clinic site. Each neighborhood attribute included in a separate model. Findings for patient characteristics presented from model that included violent crime rate as the census tract attribute.
** Excludes patients who were not White or Black.
¶ p-value < 0.05.
# Measured as the Getis-Ord Gi statistic > 1.96.

substantially higher among women given the higher rate of HCV positivity in men. The relatively lower than expected risk of being unscreened for women might reflect greater use of preventive health care services among women than men (Vaidya et al., 2012) and thus more opportunities to assure they were screened.

The higher level of screening among Black than White patients, previously reported in an evaluation of the screening intervention in the clinics we studied (Coppock et al., 2020), persisted with our additional consideration of multiple patient characteristics and census tract attributes in multivariate models. This finding is consistent with higher

levels of HCV screening among Black patients in other clinic-based studies of HCV screening both before and following CDC's 2012 recommendation that all members of the baby boom cohort be screened for HCV (Linas et al., 2014; Bourgi et al., 2016). More complete screening among Black patients might reflect differences in clinicians' aggressiveness in recommending HCV screening based on their prior experience regarding HCV positivity among patients in different racial or ethnic groups. Alternatively, it might reflect perceptions shaped by national surveillance data when HCV incidence was historically higher among Black than White people (Centers for Disease Control and Prevention, 2008), observations regarding higher HCV prevalence among Black than White patients in clinical studies (Linas et al., 2014; Patel et al., 2016), and observations from NHANES before the 2010s when the prevalence of HCV antibodies or chronic infections was higher among Black than White survey participants (Armstrong et al., 2006; Ditah et al., 2014). Higher levels of screening among Black patients might also reflect implicit biases that prompt more complete screening among persons of color (Hall et al., 2015) for an infection transmitted primarily through percutaneous exposure to blood, such as through sharing drug injection equipment (Smith et al., 2012). Regarding associations between the attributes of census tracts where patients resided and variations in screening levels, it is unlikely that clinicians were aware of those attributes in ways that consciously affected their screening HCV practices. Rather, unmeasured patient attributes associated with census tract attributes might have shaped clinicians' perceptions in ways that affected screening.

Among screened patients, rates of HCV-positivity were twice as high among Black than White patients, a difference that did not persist when other patient characteristics and census tract attributes were taken into account in the models. HCV positivity rates also varied among patients living in census tracts with different attributes for each of the attributes we examined, although associations with higher levels of HCV positivity persisted only for residence in census tracts with higher levels of violent crime and lower levels of educational attainment in the multivariate models. These observations align with prior studies that have described urban clusters or "hot spots" of HCV prevalence in Massachusetts or mortality in New York City and the attributes of populations in locations where clusters are located, reflecting social disadvantage and health inequities (Stopka et al., 2017; Ford et al., 2017). More broadly, where people live is an important predictor of health and driver of health disparities, giving rise to growing attention in health care and public health research to "geospatial determinants of health" (Centers for Disease Control and Prevention, 2020) and to social forces, such as structural racism, that underlie geospatial inequities in health determinants (Centers for Disease Control and Prevention, 2021; Yearby, 2020). Attributes of census tracts can reflect or shape social and other health determinants, although explanations for observed associations, or lack of associations, between specific census tract attributes and health are complex, if not elusive (Mohnen et al., 2019; Hillemeier et al., 2003). In some instances, neighborhood environments might complicate or detract from residents' ability to follow health promotion recommendations. In others, neighborhood attributes might foster risky behaviors, such as behaviors associated with HCV infection. Alternatively, neighborhood attributes such as higher rates of violent crime might be indicative of other circumstances that adversely affect health, the use of health care services, or adherence to healthcare recommendations. Regardless of uncertainties regarding the pathways for neighborhood effects on health, our findings emphasize their importance, as seen when the Black-White racial disparity in HCV-positivity disappeared after neighborhood attributes and other personal characteristics and were taken into account.

Within our patient population, cumulative HCV screening increased substantially during the study period (Coppock et al., 2020), and screening levels during the latter part of the study period were considerably lower than overall levels. This suggests that achieving universal screening within a patient population will become increasingly harder

as cumulative screening increases. Because HCV positivity tends to cluster geographically within urban populations (Stopka et al., 2017; Ford et al., 2017), a strategy that makes an extra effort to promote screening among those living in census tracts with attributes associated with higher levels of HCV infection (or, if known, with higher levels of HCV infection directly) would hasten near complete identification of HCV-positive patients within a clinic population. Such an approach would be consistent with prior efforts to accelerate HIV prevention and control in the United States using geographically focused efforts. (Centers for Disease Control and Prevention, 2013).

Our study is subject to multiple limitations. Our findings might not be representative of the baby boom cohort in Philadelphia or that in other cities. We did not evaluate the presence of comorbidities, including recognized risks for HCV infection such as opioid or other drug misuse or signs of hepatic dysfunction, that might have prompted HCV testing for some patients or might have been associated with more frequent clinic visits and thus greater exposure to screening promotion. However, it is unlikely that the substantial increase in screening observed during the study period (Coppock et al., 2020) could be explained by trends in such factors. Because the number of patients whose race/ethnicity was other than non-Hispanic White or Black was relatively small, we were not able to examine specific groups within the "all other" category in models that examined risks for being unscreened, nor were we able to include the "all other" category in models that examined HCV positivity among screened patients. We examined implementation of CDC's 2012 recommendation for universal HCV screening of persons born during 1945–1965 (Smith et al., 2012) during a study period that preceded recommendations for expanded screening in 2020 (Schillie et al., 2020), and our findings might not be applicable to strategies for implementing more recent guidance. Because the clinical service we studied shared a university affiliation with a large Philadelphia hospital that closed in 2019 (Rosenblaum, 2019), with the resulting dispersion of its primary care services to other institutions, follow-up studies of this population are not possible. Finally, record linkages regarding population attributes for patients' census tracts of residence, based on last recorded address, might be incomplete if patients moved during the study period.

In conclusion, we combined information regarding patient characteristics and geospatial data regarding the attributes of census tracts where patients resided to assess HCV screening and positivity among patients born from 1945 to 1965. Despite efforts to promote universal screening, risks for being unscreened were generally lower (i.e., screening was generally higher) among those with personal characteristics and residence in census tracts associated with higher levels of HCV positivity, such as relatively high levels of violent crime and low levels of educational attainment. Within a universal screening program, an outreach strategy that emphasizes screening among residents of census tracts with attributes associated with higher levels of HCV infection would accelerate near complete identification of HCV-infected patients.

CRediT authorship contribution statement

Dong Heun Lee: Conceptualization, Writing – original draft, Writing – review & editing. **Edgar Y. Chou:** Conceptualization, Resources, Writing – review & editing. **Kari Moore:** Conceptualization, Methodology, Project administration, Resources, Writing – review & editing. **Steven Melly:** Conceptualization, Methodology, Resources, Writing – review & editing. **Yuzhe Zhao:** Formal analysis. **Hal Chen:** Formal analysis. **James W. Buehler:** Conceptualization, Project administration, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgements

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