SSM - Population Health 12 (2020) 100646

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: http://www.elsevier.com/locate/ssmph

Short Report

Neighborhood context and kidney disease in Philadelphia

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ARTICLE INFO

Keywords:
Kidney disease
Urban health
Health disparities
Social context

ABSTRACT

Neighborhood context might influence the risk of chronic kidney disease (CKD), a condition that impacts approximately 10% of the United States population and is associated with significant morbidity, mortality, and costs. We included a sample of 23,692 individuals in Philadelphia, Pennsylvania, who were seen in a large academic primary care practice between January 1, 2016 and December 31, 2017. We used generalized linear equations to estimate the associations between indicators of neighborhood context (e.g., proximity to healthy foods stores, neighborhood walkability, social capital, crime rate, socioeconomic status) and CKD, adjusted for age, sex, race/ethnicity, and insurance coverage. Among those with CKD, secondary outcomes were poor glycemic control (hemoglobin A1c $\geq$ 6.5%) and uncontrolled blood pressure (systolic $\geq$ 140 mm Hg and/or diastolic $\geq$ 90 mm Hg). The cohort represented residents from 97% of Philadelphia census tracts. CKD prevalence was 10%. When all neighborhood context metrics were considered collectively, only lower neighborhood socioeconomic index (a composite assessment of neighborhood income, educational attainment, and occupation) was associated with a higher risk of CKD (lowest tertile vs. highest tertile: adjusted relative risk [aRR] 1.46 [1.25, 1.69]; mid-tertile vs. highest-tertile: aRR 1.35 [1.25, 1.52]). Among those with CKD, compared to residence in the most walkable neighborhoods (i.e., where most essential resources are accessible by foot), residence in neighborhoods with mid-level WalkScore® (i.e., where only some essential neighborhood resources are accessible by foot) was independently associated with poor glycemic control (aRR 1.20, 95% CI 1.01–1.42). These findings suggest a potential role for measures of neighborhood socioeconomic status in identifying communities that would benefit from screening and treatment for CKD. Studies are also needed to determine mechanisms to explain why residence in neighborhoods not easily navigated by foot or car might hinder glycemic control among people with CKD.

Introduction

Chronic kidney disease (CKD) affects approximately 10% of the United States (US) population, or more than 30 million people, and is its ninth leading cause of death (Statistics CfaCfH. 20, 2013; Coresh et al., 2007; Saran et al., 2019). However, despite the high prevalence and health consequences of CKD, less than 10% of Americans with CKD are aware of their condition (Hoerger et al., 2015). Among those who progress to end-stage kidney disease (ESKD), 30% initiate dialysis with little-or-no pre-dialysis care from a kidney disease specialist (Saran et al., 2019). Given the large human and financial costs of CKD to the US, the U.S. Department Health and Human Services launched the Advancing American Kidney Health Initiative in 2019. This initiative has called for improved identification of US populations at risk for CKD and has set a goal for a 25% decrease in the incidence of ESKD in the US by 2030 (Bieber & Gadegbeku, 2019; Government US, 2019).

An individual's socioeconomic status (SES) is typically defined by income, educational attainment, and occupation. An individual's SES can affect their health by influencing lifestyle, social support, and access to resources and services, such as healthcare. A host of observational studies document the association between individual-level SES and a variety of CKD outcomes, including disease progression, dialysis modality selection, and kidney transplant access (Banerjee et al., 2017; Barker-Cummings et al., 1995; Bruce et al., 2010; Crews et al., 2010;

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https://doi.org/10.1016/j.ssmph.2020.100646
Received 23 April 2020; Received in revised form 10 August 2020; Accepted 10 August 2020
Available online 17 August 2020

Hall, 2018; Maziarz et al., 2015; Morton et al., 2016; Purnell et al., 2013; Vart et al., 2015; Young et al., 1994). However, health status is not only influenced by one's own attributes, but by the attributes of their area of residence, or neighborhood context. Neighborhood context encompasses the social, economic, and physical features of the residential community (Lapidis et al., 2020). Specifically, it includes the neighborhood's collective SES (e.g., median household income), access to nutritious food, crime rate, transportation, space for recreational activity (sidewalks and parks), racial and ethnic composition, and shared culture (i.e, social capital – the strength of social bonds between resident and accepted behavioral norms) (Lapidis et al., 2020). Neighborhood context can impact an individual's health by affecting access to health-promoting resources and influencing health-related behaviors. It has been associated with increased risk of hypertension, cardiovascular disease, obesity, and diabetes (Christine et al., 2015; Diez Roux, Merkin et al., 2019; Foster et al., 2008; Kershaw et al., 2013; Mujahid et al., 2011).

Compared with individual-level SES, less is known about the independent associations between neighborhood context and CKD. Previous studies have identified associations between median neighborhood household income, educational level, and racial composition with CKD, CKD progression, dialysis-dependence, and kidney transplantation (Byrne et al., 1994; Hall et al., 2008; Hao et al., 2015; Karter et al., 2002; Klag et al., 1997; Patzer et al., 2015; Rodriguez et al., 2007; Shoham et al., 2007; Volkova et al., 2008). However, many of these investigations were geographically limited, and included individuals who were recruited from largely rural areas into prospective cohort studies (Merkin et al., 2005; Shoham et al., 2007). Furthermore, only a few studies have investigated the full breadth of neighborhood context features, which include built environment (e.g., transportation resources and walkability), social capital, and neighborhood safety in addition to traditional SES metrics (Bowe et al., 2017; Hicken et al., 2019). Therefore, due the heterogeneity of previous study populations and exposure variables, there remain substantial gaps in the understanding of how the broad range of neighborhood context features might influence CKD prevalence, especially within urban populations.

Philadelphia, Pennsylvania, is an important setting in which to examine the potential influence of neighborhood context on CKD. Philadelphia is the sixth most populous city in the US, with large population of non-Hispanic Blacks (41%) and Hispanics (14%), racial and ethnic groups that are known to be at higher risk for CKD than non-Hispanic Whites (Assessment PsCH, 2018; Desai et al., 2019; Hsu et al., 2003). Among 1.5 million residents, 25% of Philadelphians live below the federal poverty level (i.e., annual household income of <$25,000 for a family of four), and nearly 12% live in deep poverty (i.e., < $12,500 annually), the highest prevalence of deep poverty among the 10 largest US cities (The State of Philadelphians Living in Poverty, 2019). The city is also highly segregated, with one racial or ethnic group forming a majority in 84% of its 381 census tracts (Philadelphia TDoPHotCo, 2018).

The goal of this study was to examine the neighborhood context of a large, diverse cohort of adult Philadelphia-area residents who were seen for primary care in an academic health system. We sought to investigate the relationship between CKD and a broad range of social, economic and physical features of neighborhoods by census tract. We also examined the associations between neighborhood context, blood pressure control, and glycemic control among individuals with CKD. We hypothesized that low neighborhood-level SES, lack of neighborhood resources, and low neighborhood-level social capital would be associated with higher risk of CKD. Further, among those with CKD, we hypothesized that less affluent neighborhood characteristics would be linked with poor glycemic and blood pressure control, both of which are risk factors for CKD and CKD progression.

Methods

Study design and description of patient cohort and geocoding

Individuals were included in the study cohort if they were ≥18 years old and received primary care at one of 13 Philadelphia-based clinics affiliated with a large academic health system between January 1, 2016 and December 31, 2017. Individuals were excluded if they did not live within Philadelphia or if their address was not able to be geocoded. Geocoding of patients' addresses was performed using ArcGIS 10.5 with the Business Analyst 2016 Composite Address Locator and assigned to the census tract of residence (ESRI, 2018). The protocol was submitted to the Institutional Review Board which determined that it was exempt from review.

Exposures – neighborhood characteristics

Using multiple data sources, we determined the following neighborhood characteristics of individuals in the cohort (Supplemental Table 1): 1) density of healthy food stores per km (Coresh et al., 2007) within 800 m of a 30 m grid (derived from the 2014 National Establishment Time Series Database); 2) census tract-level Walk Score® from 2015 (created by Walk Score Research Services); 3) violent crime rate per 10,000 population as recorded by Philadelphia Police Department 2016–2017 (i.e., homicides, rapes, aggravated assaults, robberies, other assaults; 4) median household income; 5) population density (km (Coresh et al., 2007)) based on five-year estimates for the census tract; 6) % Hispanic residents; 7) % non-Hispanic Black residents; 8) % residents >25 years-old with at least a high school diploma; 9) % residents living below the federal poverty level (per five-year estimate for census tracts from 2013 to 2017 from the American Community Survey); 10) perceived social capital (derived from the 2015 Southeastern Pennsylvania Household Health Survey); and 11) socioeconomic index (Diez Roux, Merkin et al., 2019; Rundle et al., 2009; Kaufman et al., 2015; Street Smart Walk Sc, 2010; Department PP; OpenDataPhilly, 2019; Diez-Roux, Kiefe et al., 2019; Buehler et al., 2019; Le-Scherban et al., 2019; Southeastern Pennsylvania, 2015; American Communities Survey, 2013). The SES index was developed from the 2013–2017 American Community Survey using factor analysis as described elsewhere (Diez Roux, Merkin et al., 2019). It incorporates the following variables: median value of occupied housing units, % persons ≥ 25 years-old with at least high school diploma, % persons > 25 years-old with at least a bachelor's degree, % with management, professional, and related occupation, median household income, and % of households with interest, dividends, or net rental income.

Outcomes

The primary outcome was CKD, defined as either an ambulatory eGFR of <60 ml/min/1.73 m^2 and/or an ICD-9 code for kidney disease (see **Supplemental Appendix** for a list of codes). The secondary outcomes were ascertained among those with CKD, and were uncontrolled blood pressure (BP), defined as at least one occasion of systolic BP ≥ 140 mm Hg and/or diastolic BP ≥ 90 mm Hg, and poor glycemic control, defined as at least one hemoglobin A1c ≥ 6.5%.

Covariates

Models were adjusted for patients' age, sex, race/ethnicity, and insurance type, as ascertained from the electronic health record. We categorized insurance as commercial, Medicare, Medicare Advantage, or Medicaid. We identified the following comorbidities through ICD-9 codes in the medical record: human immunodeficiency virus (HIV) status, coronary artery disease, hypertension, and hepatitis C virus (HCV) status. Individuals were considered to have active HCV if they had both an assay with detectable HCV RNA or a diagnostic code for hepatitis C. Individuals were classified as having diabetes if they had a diagnostic code for diabetes mellitus (see **Supplemental Appendix**) or a hemoglobin A1C $\geq$ 6.5%. We ascertained smoking status from clinical documentation in the medical record and categorized patients with documentation of either current or previous tobacco smoking as a smoker. We also captured body mass index (BMI) from the first encounter in the medical record during the study period.

Statistical analysis

In the primary analysis, we used generalized estimating equations with the log Poisson distribution and an exchangeable correlation structure to estimate adjusted risk ratios for associations between CKD and individual and neighborhood characteristics. Neighborhood characteristics were categorized in tertiles. First, we examined unadjusted models with each neighborhood characteristic modeled separately (Model 1 in Table 2). Then, we added age, sex (male or female), and race/ethnicity (non-Hispanic white, non-Hispanic Black, Hispanic, non-Hispanic Asian, non-Hispanic other) as adjustment to the previous models (Model 2 in Table 2). As a proxy for individual income, we then adjusted for individual insurance coverage (commercial, Medicaid, Medicare, Medicare Advantage) (Model 3 in Table 2). In our final model (Model 4 in Table 2), we included age, sex, race/ethnicity, insurance status and, for neighborhood characteristics, density of healthy food stores, Walk Score®, percentage non-Hispanic Black, percentage Hispanic, violent crime rate per 10,000 population, socioeconomic index, and social capital. Education, income and poverty were not included in the final model, as they were highly correlated (correlation coefficients ranged from 0.72 to 0.84), and were components of the socioeconomic index. We also examined models in which population density was included as an additional covariate in the fully adjusted model (Model 5 in the **Supplemental Appendix**). Of note, we did not adjust for comorbidities (e.g. obesity, diabetes and hypertension) in the multivariable models because these factors might lie along the causal pathway to CKD. In a sensitivity analysis, we examined whether results were similar if CKD was defined as either 1) eGFR <60 ml/min/1.73 m^2 or 2) an ICD-9 code for CKD. We also examined whether CKD was an effect modifier of associations between neighborhood characteristics and blood pressure and blood glucose control, respectively. We used SAS® (v9.4) for statistical analyses. All statistical tests are 2-tailed, and risk ratio estimates are shown with 95% confidence intervals (CIs). We considered statistical tests to be statistically significant when p-values were <0.05.

Results

Study cohort description

The final analytic cohort was comprised of 23,692 individuals (Fig. 1) from 13 primary care clinics. The cohort included residents of 369 of Philadelphia's 381 census tracts. In the overall cohort, 60% were female; 46% non-Hispanic Black; 33% non-Hispanic white; 5% Hispanic; 3% non-Hispanic Asian; and 11% non-Hispanic other. The majority (54%) had health insurance from a commercial plan, whereas 26% were Medicaid beneficiaries and 10% were Medicare beneficiaries. The average age was 43.5 (±16.6) years. The overall prevalence of diabetes in the cohort was 11%; hypertension, 27%; coronary artery disease, 4%; HIV, 6%; and hepatitis C, 4%. Nearly half (42%) had a documented history of tobacco use.

CKD prevalence in the cohort was 10%. Compared to those without CKD, those with CKD were older (63 vs. 41 years; $p < 0.001$); more likely to self-identify as non-Hispanic Black (68% vs. 44%; <0.001); and more likely to have Medicare for primary insurance coverage (33% vs. 7%; <0.001). In addition, those with CKD had a higher burden of all measured comorbidities than those without CKD. Patients with CKD had a mean of 7.6 clinic visits over the study period, while those without CKD had 3.5 visits (Table 1).

Neighborhood characteristics and prevalence of CKD by census tract

CKD prevalence varied substantially across census tracts and was 16–28% in 68 census tracts (Fig. 2). In general, the prevalence of CKD across census tracts in Philadelphia closely mirrored that of neighborhood poverty (Fig. 2), with higher (i.e., >13%) CKD prevalence in many of the census tracks in which 32% or more residents have incomes that are under the federal poverty level.

Association between neighborhood characteristics and CKD

In unadjusted models, lower neighborhood walkability, lower % of high school graduates, lower median household income, higher % of residents living below the federal poverty line, higher % of non-Hispanic Black residents, higher violent crime rate, and lower neighborhood social capital were associated with higher CKD prevalence ($p < 0.05$ for all) (Table 2). Higher % of Hispanic residents was associated with lower prevalence of CKD in unadjusted models (highest tertile vs. lowest tertile: RR 0.78 [0.69, 0.88]; mid-tertile to lowest tertile: RR 0.81 [0.70,

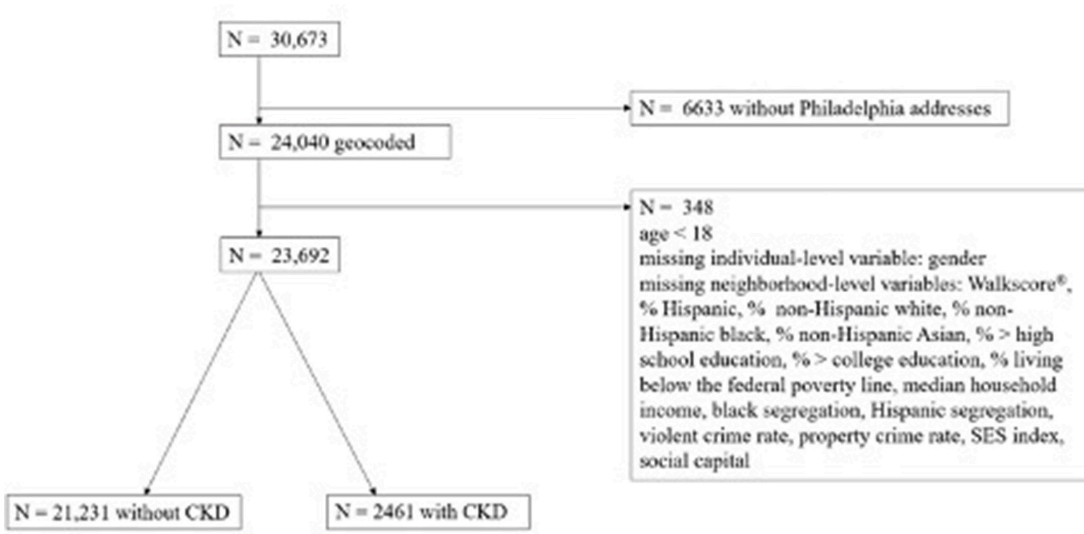

Fig. 1. Assembly of the analytical cohort.

Table 1
Baseline characteristics by chronic kidney disease status.

Characteristic	Category	Total sample	CKD Diagnosis		P-value
		N = 23,692	NO	YES	
			N = 21,231 (89.6%)	N = 2461 (10.4%)	
Person-level					
Age	Age at first visit in years (mean (std))	43.5 (16.6)	41.3 (15.3)	62.9 (14.9)	<0.001
Race/ethnicity	Non-Hispanic Asian	803 (3.39%)	768 (3.62%)	35 (1.42%)	<.0001
	Non-Hispanic Black	11,013 (46.48%)	9335 (43.97%)	1678 (68.18%)	
	Hispanic or Latino	1237 (5.22%)	1108 (5.22%)	129 (5.24%)	
	Non-Hispanic Other	2716 (11.46%)	2649 (12.48%)	67 (2.72%)	
	Non-Hispanic White	7923 (33.44%)	7371 (34.72%)	552 (22.43%)	
Sex	Female	14,289 (60.31%)	12,843 (60.49%)	1446 (58.76%)	0.0958
	Male	9403 (39.69%)	8388 (39.51%)	1015 (41.24%)	
Insurance	Missing	625 (2.64%)	605 (2.85%)	20 (0.81%)	<.0001
	Commercial	12,779 (53.94%)	12,281 (57.84%)	498 (20.24%)	
	Medicaid	6052 (25.54%)	5547 (26.13%)	505 (20.52%)	
	Medicare	2401 (10.13%)	1581 (7.45%)	820 (33.32%)	
	Medicare Advantage	1835 (7.75%)	1217 (5.73%)	618 (25.11%)	
Clinic visits	Per subject during the study period (mean (std))	3.9 (3.8)	3.5 (3.2)	7.6 (6.1)	<0.001
Hepatitis C	No	22,847 (96.43%)	20,626 (97.15%)	2221 (90.25%)	<.0001
	Yes	845 (3.57%)	605 (2.85%)	240 (9.75%)	
HIV	No	22,244 (93.89%)	20,102 (94.68%)	2142 (87.04%)	<.0001
	Yes	1448 (6.11%)	1129 (5.32%)	319 (12.96%)	
Coronary artery Disease	No	22,811 (96.28%)	20,769 (97.82%)	2042 (82.97%)	<.0001
	Yes	881 (3.72%)	462 (2.18%)	419 (17.03%)	
Smoking status	Missing	473 (2%)	442 (2.08%)	31 (1.26%)	<.0001
	No	13,238 (55.88%)	12,216 (57.54%)	1022 (41.53%)	
	Yes	9981 (42.13%)	8573 (40.38%)	1408 (57.21%)	
Diabetes	No	21,160 (89.31%)	19,629 (92.45%)	1531 (62.21%)	<.0001
	Yes	2532 (10.69%)	1602 (7.55%)	930 (37.79%)	
Hypertension	No	17,230 (72.72%)	16,471 (77.58%)	759 (30.84%)	<.0001
	Yes	6462 (27.28%)	4760 (22.42%)	1702 (69.16%)	
Neighborhood-level					
Healthy food stores within 800 m	1(0)	6845 (28.89%)	6118 (28.82%)	727 (29.54%)	<.0001
	2(0.5–0.9)	9880 (41.70%)	8777 (41.34%)	1103 (44.82%)	
	3(1.4–5.9)	6967 (29.41%)	6336 (29.84%)	631 (25.64%)	
Walk Score®	1(20.4–77.9)	7831 (33.05%)	7008 (33.01%)	823 (33.44%)	<.0001
	2(78.0–85.9)	7843 (33.10%)	6890 (32.45%)	953 (38.72%)	
	3(86.0–99)	8018 (33.84%)	7333 (34.54%)	685 (27.83%)	
% > = high school education	1 (41.9%-81.8%)	7843 (33.10%)	6814 (32.09%)	1029 (41.81%)	<.0001
	2 (82.0%-91.3%)	7953 (33.57%)	7057 (33.24%)	896 (36.41%)	
	3 (91.5%-100%)	7896 (33.33%)	7360 (34.67%)	536 (21.78%)	
Median household income (U.S. dollars)	1(9945–30786)	7901 (33.35%)	6781 (31.94%)	1120 (45.51%)	<.0001
	2(31,124–57027)	7894 (33.32%)	7087 (33.38%)	807 (32.79%)	
	3(57,039–149,211)	7897 (33.33%)	7363 (34.68%)	534 (21.7%)	
% below poverty level	1(0.7%-16.8%)	7751 (32.72%)	7112 (33.5%)	639 (25.97%)	<.0001
	2(16.8%-32.1%)	8018 (33.84%)	7251 (34.15%)	767 (31.17%)	
	3(32.4%-67.9%)	7923 (33.44%)	6868 (32.35%)	1055 (42.87%)	
SES Index	1((-10.66)-(-2.68))	7894 (33.32%)	6796 (32.01%)	1098 (44.62%)	<.0001
	2((-2.67)-4.46)	8132 (34.32%)	7277 (34.28%)	855 (34.74%)	
	3(4.47–14.1)	7666 (32.36%)	7158 (33.71%)	508 (20.64%)	
Social capital	1(0.56–0.59)	7905 (33.37%)	6977 (32.86%)	928 (37.71%)	<.0001
	2(0.59–0.63)	7937 (33.50%)	7047 (33.19%)	890 (36.16%)	
	3(0.63–0.72)	7850 (33.13%)	7207 (33.95%)	643 (26.13%)	
% Hispanic	1(0–3.23%)	7900 (33.34%)	6930 (32.64%)	970 (39.41%)	<.0001
	2(3.28%-7.27%)	8099 (34.18%)	7329 (34.52%)	770 (31.29%)	
	3(7.27%-90.63%)	7693 (32.47%)	6972 (32.84%)	721 (29.3%)	
% Non-Hispanic Black	1(0–12.4%)	7920 (33.43%)	7359 (34.66%)	561 (22.8%)	<.0001
	2(12.73%-70.11%)	7851 (33.14%)	7086 (33.38%)	765 (31.08%)	
	3(70.19%-99.85%)	7921 (33.43%)	6786 (31.96%)	1135 (46.12%)	
Violent crime rates (per 10,000 persons)	1(7.56–144.18)	7965 (33.62%)	7402 (34.86%)	563 (22.88%)	<.0001
	2(144.4–305.96)	7812 (32.97%)	6997 (32.96%)	815 (33.12%)	
	3(306.63–1134.59)	7915 (33.41%)	6832 (32.18%)	1083 (44.01%)	
Population density (persons per square km)	1(113.53–6053.78)	7888 (33.29%)	7105 (33.47%)	783 (31.82%)	<.0001
	2(6055.46–9358.54)	7946 (33.54%)	7010 (33.02%)	936 (38.03%)	
	3(9370.49–32498.47)	7858 (33.17%)	7116 (33.52%)	742 (30.15%)	

Abbreviations: CKD—Chronic Kidney Disease; std—Standard Deviation; HIV—Human Immunodeficiency Virus; m—meter; SES—Socioeconomic Status; km—kilometer; US—United States.

0.94]). After adjustment for age, race/ethnicity, sex, and individual insurance type, % of high school graduates, median household income, and the SES index retained significant associations with CKD. In a fully adjusted model with all neighborhood characteristics as well as age, race/ethnicity, sex and insurance, only the SES index retained a statistically significant association with prevalent CKD (lowest tertile vs. highest tertile: aRR 1.46 [1.25, 1.69]; mid-tertile vs. highest-tertile: aRR 1.35 [1.21, 1.52]) (Table 2). Results were robust in sensitivity analyses that defined CKD by either eGFR <60 ml/min/1.73m2 or an ICD-9 code for CKD (Supplemental Tables 5 and 6).

Table 2
Association between neighborhood characteristics and chronic kidney disease.

Characteristic	Category	Model 1* RR (95% CI)	Model 2** aRR (95% CI)	Model 3*** aRR (95% CI)	Model 4*** aRR (95% CI)
Healthy food within 800 m	1 (0)	1.12 (0.9, 1.29)	1.05 (0.95, 1.16)	1.05 (0.95, 1.16)	1.04 (0.94, 1.15)
	2 (0.5–0.99)	1.06 (0.94, 1.20)	1.00 (0.91, 1.10)	1.00 (0.91, 1.10)	0.99 (0.90, 1.08)
	3 (1.49–5.97)	1.00	1.00	1.00	1.00
Walk Score®	1 (20.48–78)	1.30 (1.12, 1.51)	0.99 (0.90, 1.09)	1.01 (0.92, 1.11)	0.98 (0.89, 1.09)
	2 (78.09–86)	1.48 (1.28, 1.71)	1.08 (0.98, 1.19)	1.07 (0.97, 1.17)	0.98 (0.88, 1.08)
	3 (86.25–99)	1.00	1.00	1.00	1.00
% ≥ high school education	1 (41.9%-81.85%)	1.73 (1.48, 2.03)	1.28 (1.14, 1.42)	1.22 (1.10, 1.36)	
	2 (82.04%-91.36%)	1.60 (1.36, 1.89)	1.23 (1.11, 1.38)	1.21 (1.08, 1.35)	
	3 (91.51%-100%)	1.00	1.00	1.00	
Median household income	1 (9945–30786)	1.90 (1.63, 2.21)	1.35 (1.20, 1.51)	1.27 (1.14, 1.43)	
	2 (31,124–57027)	1.46 (1.25, 1.71)	1.21 (1.08, 1.36)	1.20 (1.08, 1.35)	
	3 (57,039–149,211)	1.00	1.00	1.00	
% below poverty level	1 (0.76%-16.84%)	1.00	1.00	1.00	
	2 (16.84%-32.11%)	1.16 (0.99, 1.35)	1.06 (0.96, 1.16)	1.03 (0.94, 1.14)	
	3 (32.45%-67.96%)	1.41 (1.23, 1.61)	1.15 (1.04, 1.27)	1.08 (0.98, 1.19)	
% non-Hispanic Black	1 (0–12.4%)	1.00	1.00	1.00	1.00
	2 (12.73%-70.11%)	1.25 (1.07, 1.47)	1.05 (0.93, 1.18)	1.06 (0.95, 1.19)	0.96 (0.85, 1.07)
	3 (70.19%-99.85%)	1.76 (1.52, 2.03)	1.06 (0.93, 1.20)	1.08 (0.95, 1.23)	0.92 (0.79, 1.06)
% Hispanic	1 (0–3.23%)	1.00	1.00	1.00	1.00
	2 (3.28%-7.27%)	0.81 (0.70, 0.94)	0.95 (0.87, 1.03)	0.94 (0.87, 1.02)	0.93 (0.86, 1.01)
	3 (7.27%-90.63%)	0.78 (0.69, 0.88)	1.03 (0.95, 1.12)	1.02 (0.94, 1.11)	1.00 (0.91, 1.11)
Violent crime rates	1 (7.56–144.18)	1.00	1.00	1.00	1.00
	2 (144.4–305.96)	1.28 (1.09, 1.51)	1.10 (0.99, 1.22)	1.07 (0.96, 1.19)	0.99 (0.89, 1.11)
	3 (306.63–1134.59)	1.54 (1.34, 1.78)	1.17 (1.06, 1.29)	1.10 (0.99, 1.21)	1.00 (0.89, 1.13)
SES Index	1 ((-10.66)-(-2.68))	2.00 (1.71, 2.34)	1.41 (1.25, 1.58)	1.36 (1.21, 1.52)	1.46 (1.25, 1.69)
	2 ((-2.67)-4.46)	1.62 (1.37, 1.92)	1.30 (1.17, 1.46)	1.30 (1.17, 1.45)	1.35 (1.21, 1.52)
	3 (4.47–14.1)	1.00	1.00	1.00	1.00
Social capital	1 (0.56–0.59)	1.20 (1.04, 1.38)	1.09 (0.99, 1.20)	1.06 (0.97, 1.17)	0.96 (0.87, 1.06)
	2 (0.59–0.63)	1.30 (1.13, 1.50)	1.14 (1.05, 1.24)	1.12 (1.03, 1.22)	1.03 (0.94, 1.13)
	3 (0.63–0.72)	1.00	1.00	1.00	1.00

Abbreviations: RR-relative risk; aRR-adjusted relative risk; CI-Confidence Interval; m—Meters; SES—Socioeconomic Status.
Model 1: Unadjusted.
Model 2: Adjusted for age, race/ethnicity, and sex.
Model 3: Adjusted for age, race/ethnicity, sex, and insurance type.
Model 4: All neighborhood measures modeled jointly in the same model. Also adjusted for age, race/ethnicity, sex, insurance type.

Association between neighborhood characteristics and blood pressure and glycemic control in patients with CKD

Among those with CKD and documented BP measures (n = 2441), 66% (n = 1605) had an uncontrolled BP on at least one occasion during the study period (Table 3). Age was similar when comparing those with and without uncontrolled BP (mean 63 vs 62 years, p = 0.16). In unadjusted analyses, those with uncontrolled BP were more likely to live in neighborhoods with higher violent crime rates, lower median household income, lower educational attainment, lower social capital, lower SES index, and a higher percentage of residents who are non-Hispanic Blacks. In multivariable models adjusted for age, race/ethnicity, sex, insurance status, and all neighborhood characteristics, no neighborhood characteristics retained a significant association with uncontrolled BP among those with CKD.

Among those with CKD who had at least one measured hemoglobin A1c during the study period (n = 2008), poor glycemic control (i.e., hemoglobin A1c > 6.5%) was observed in 42% (n = 838) (Table 4). Age was similar when comparing those with and without poor glycemic control (mean 63 vs 63 years, p = 0.49). Unadjusted analyses showed a higher likelihood of poor glycemic control in non-Hispanic Blacks living in neighborhoods with high violent crime rates, lower median household income, lower educational attainment, lower social capital, and lower SES index. In models adjusted for age, race/ethnicity, sex, insurance status, and all neighborhood characteristics, residence in neighborhoods with mid-level WalkScore® (relative to the most walkable neighborhoods) was significantly associated with poor glycemic control (aRR 1.20, 95% CI 1.01–1.42) among those with CKD. Among those without CKD, lower neighborhood walkability defined by WalkScore® and lower neighborhood SES index were independently associated with poor blood pressure control in multivariable models adjusted for other neighborhood characteristics, whereas lower SES index was independently associated with poor blood glucose control (see **Supplemental Appendix**).

Discussion

In this study, we characterized Philadelphia neighborhoods by factors including access to healthy food stores, walkability, violent crime rate, social capital, and SES (median household income, education level, etc.) and found that several of these neighborhood indicators were associated with CKD prevalence. However, when these neighborhood context features were considered collectively in multivariable models, neighborhood SES (measured by the SES index) was the only one to retain a statistically significant association with CKD risk. Furthermore, among those with CKD, the middle-tier of neighborhood walkability (WalkScore®) was associated with worse glycemic control than neighborhoods with the lowest and highest walkability. Our findings indicate that in an urban setting, neighborhood-level SES and walkability may influence the risk of CKD and CKD progression.

The SES index is a composite of multiple SES factors, including median household income; median value of housing units; percentage of residents in executive/managerial/professional occupations; percentage of households with interest, dividend, or rental income; percentage of residents with a high school diploma; and percentage of residents with a college diploma. It was devised to circumvent the challenge of disentangling highly-correlated features of SES, such as education and income, on clinical outcomes, and has been associated with stroke and

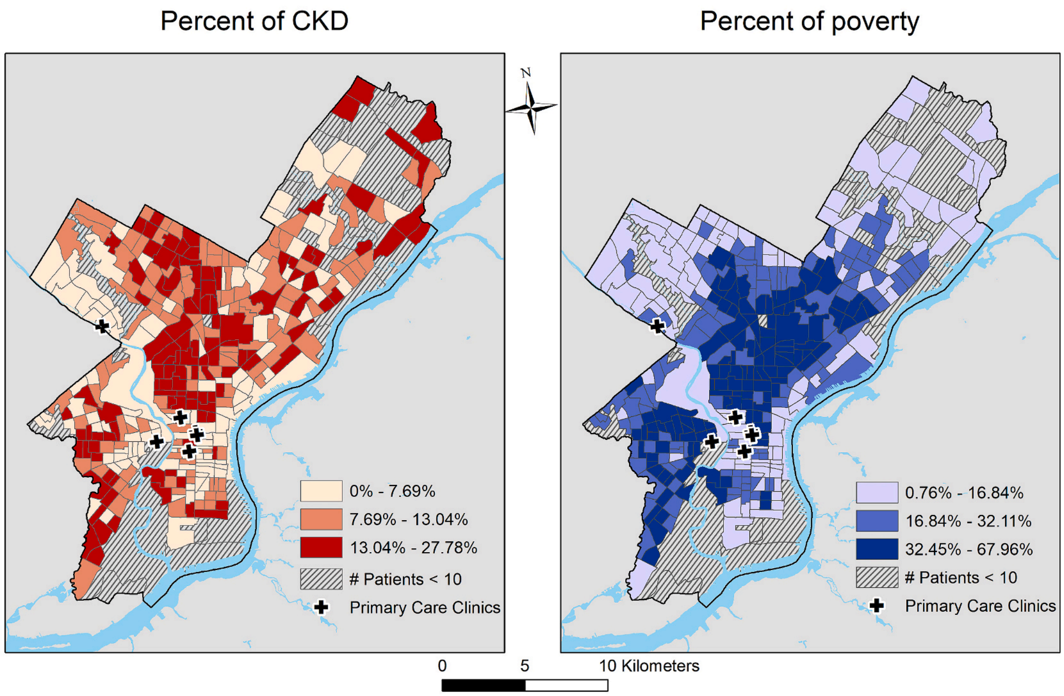

Fig. 2. Distribution of chronic kidney disease and percentage of residents living below the federal poverty line across philadelphia census tracts.

cardiovascular disease (Diez Roux, Merkin et al., 2019; Diez-Roux, Kiefe et al., 2019; Howard et al., 2016). We found an independent association between lower neighborhood SES index and CKD risk. Further, among those without CKD, lower SES was associated with poor blood pressure and glycemic control, respectively. One potential explanation for our findings is that the SES index might be a surrogate marker for access to health-promoting resources. The general educational attainment of a community influences its health literacy, which represents its members' ability to obtain, process, and understand basic health information and services to make appropriate health decisions (Parker et al., 2003). Specifically, activities inherent to health literacy can include communicating health history with medical providers, participating in self-care and chronic disease management, and understanding math concepts such as probability and risk, all of which may be determinants of CKD risk and outcomes (Parker et al., 2003; Healthy People 2020). The financial well-being of a community represents available capital for resources like healthy food, safe living conditions, and quality healthcare. Therefore, neighborhood-level socioeconomic characteristics, if favorable, might overcome other neighborhood-level barriers to health (e.g., violent crime and lack of proximity to healthy food). A similar phenomenon was observed by Bowe et al. using nationwide, county-level data from the Veteran's Administration to examine the association between a wide variety of neighborhood context measures (health-related behaviors, healthcare accessibility, socioeconomic characteristics, transit/housing availability, air and water quality, community safety) and rapid eGFR loss (>5 ml/min/1.73 m^2/year). Veterans residing in counties with the least-favorable scores for all varieties of neighborhood context experienced significantly more rapid eGFR loss than residents in counties with the most-favorable scores, but healthcare accessibility and SES were the only measures to show a significant difference between mid-level and most-favorable scores (Bowe et al., 2017). As in our study, these findings underscore the relative importance of neighborhood-level SES compared to other neighborhood-level characteristics in CKD risk and outcomes.

The results of our study also suggest that there is an association between neighborhood walkability and glycemic control among CKD patients and blood pressure control among those without CKD. This finding is consistent with observations from cohorts that did not specify the subjects' CKD status (Le-Scherban et al., 2019; Tabaei et al., 2018). Interestingly, in our study only mid-level WalkScore® (i.e., the middle of three tiers of walkability) retained statistical significance with worse glycemic control among CKD patients after adjustment for all neighborhood context factors. An explanation for this might be that a mid-level WalkScore® can be described as a "somewhat walkable" neighborhood. This contrasts with the highest tertile of WalkScore®, where residents can accomplish most or all errands by walking, and the lowest tertile, where residents require a car to accomplish nearly all activities. Conversely, among those without CKD, the lowest tertile of WalkScore® was associated with poor blood pressure control, relative to the most walkable neighborhoods. Often, there is residual confounding of WalkScore® by SES. That is, the most walkable neighborhoods tend to be in "downtown" areas with close proximity to shopping districts with higher real estate values, and the least walkable neighborhoods, suburban-like communities also characterized by higher real estate values. This was the case in our cohort. However, the associations we observed between WalkScore® and glycemic control and blood pressure control, respectively, remained statistically significant after adjustment for the SES index. Among those with CKD, our findings could suggest that the physical structure of somewhat walkable neighborhoods might be a barrier to accessing the resources needed to achieve glycemic control (e.g., medical facilities and pharmacies). Poor glycemic control is a risk factor for CKD progression, particularly in the early course of diabetes (de Boer & Group, 2014; Holman et al., 2008; Warren et al., 2018). Conversely, among those without CKD, the least walkable neighborhoods might promote a sedentary lifestyle, a risk factor for poor blood pressure control (Dempsey et al., 2018). The results of our study suggest that interventions to improve access to health care resources and neighborhood walkability might have measurable impacts on CKD risk factors, and that neighborhood context should be considered when evaluating factors that might influence CKD progression (Richardson, Ghosh-Dastidar, & Collins, 2020).

The social constructs of race and ethnicity are often examined as risk factors for CKD. Non-Hispanic Blacks experience higher rates of CKD progression and ESKD and lower rates of kidney transplantation than other groups (Klag et al., 1997; Mehrotra et al., 2008; Whittle et al., 1991). Reasons for these differences likely include both genetic

Table 3
Neighborhood characteristics of individuals with chronic kidney disease, stratified by blood pressure control status.

Characteristic	Overall Cohort with CKD and >1 BP measurement Mean (SE) Median (IQR)	Uncontrolled BP[a] Mean (SE) Median (IQR)		P-value
	N = 2441	NO N = 836 (34.3%)	YES N = 1605 (65.7%)	
Healthy food stores per sq km within 800 m	0.83 (0.81) 0.5 (0, 1.49)	0.86 (0.85) 0.5 (0, 1.49)	0.82 (0.78) 0.5 (0, 0.99)	0.20
Walk Score®	79.68 (12.3) 81.86 (74.79, 87)	79.11 (14.31) 81.67 (74, 88.08)	79.97 (11.1) 81.86 (75, 86.25)	0.12
% persons ≥ high school	83.48% (9.61) 84.04 (78.37, 90.58)	84.3% (9.91) 85.01 (78.54, 92.23)	83.05% (9.43) 83.27 (78.18, 89.82)	<0.01
median household income	39759.68 (22641.9) 32,984 (21,750, 53,233)	43603.69 (24154.09) 37,130 (24941.5, 59,063)	37757.43 (21550.5) 31,332 (21,106, 50,208)	<.0001
% persons below poverty level	28.85% (15) 30.19 (15.77, 38.93)	26.46% (15.02) 26.53 (13.42, 36.27)	30.09% (14.84) 31.29 (16.97, 40.96)	<.0001
SES Index	−0.66 (5.51) −2.11 (−4.85, 3.43)	0.12 (5.84) −1.37 (−4.64, 4.74)	−1.06 (5.29) −2.36 (−5.09, 1.67)	<.0001
Social capital	0.61 (0.03) 0.6 (0.59, 0.63)	0.61 (0.03) 0.61 (0.59, 0.64)	0.61 (0.03) 0.6 (0.59, 0.62)	0.0001
% Hispanic	9.23% (14.5) 4.53 (2.46, 8.4)	9.39% (14.79) 4.51 (2.43, 8.45)	9.15% (14.35) 4.53 (2.51, 8.34)	0.70
% Non-Hispanic Black	54.87% (34.54) 65.01 (15.34, 88.2)	49.44% (36.01) 53.86 (10.19, 87.33)	57.71% (33.41) 68.42 (24, 88.36)	<.0001
Population Density in sq km	8022.6 (4022.12)	8124.55 (4379.12)	7969.5 (3823.34)	0.39
Violence crime rates per 10,000 population	322.25 (214.6) 273.21 (156.65, 455.99)	304.92 (220.37) 247.69 (136.47, 418.44)	331.27 (211.04) 276.6 (165.89, 473.7)	0.004

Abbreviations: CKD—chronic kidney disease; BP—blood pressure; SE−standard error; IQR—interquartile range; m—meters; SES—socioeconomic status; sq—square; km–kilometers.
[a] Uncontrolled blood pressure defined as ≥ 140 mmHg systolic and/or ≥ 90 mm Hg diastolic on at ≥ 1 measurement.

Table 4
Neighborhood characteristics of individuals with chronic kidney disease, stratified by glycemic control status.

Characteristic	Overall Cohort with CKD and ≥ Hemoglobin A1C Measurement Mean (SE) Median (IQR)	Poor Glycemic Control[a] Mean (SE) Median (IQR)		P-value
	N = 2008	NO N = 1170 (58.2%)	YES N = 838 (41.7%)	
Healthy food stores per sq km within 800 m	0.84 (0.81) 0.5 (0, 1.49)	0.85 (0.84) 0.5 (0, 1.49)	0.83 (0.78) 0.5 (0, 0.99)	0.62
Walk Score®	80.11 (11.5) 82 (75, 87)	80.25 (12.08) 82.5 (75, 87.86)	79.92 (10.63) 81.67 (75, 86)	0.52
% persons ≥ high school	83.06% (9.54) 83.36 (78.09, 89.64)	83.61% (9.5) 84.12 (78.09, 90.4)	82.29% (9.56) 82.98 (77.88, 88.82)	<0.01
Median household income	38315.21 (21661.13) 32265.5 (21,495, 50,556)	39555.83 (22496.95) 33,026 (21,667, 52,465)	36583.07 (20323.93) 30,638 (21,106, 45,610)	<0.01
% persons below poverty level	29.65% (14.82) 30.85 (16.95, 40.55)	29.21% (15.35) 30.2 (15.77, 40.66)	30.27% (14.03) 31.49 (18.41, 40.38)	0.10
SES Index	−0.95 (5.38) −2.23 (−5.08, 1.78)	−0.56 (5.64) −2.07 (−4.85, 3.43)	−1.48 (4.95) −2.42 (−5.35, 1.09)	<0.001
Social capital	0.61 (0.03) 0.6 (0.59, 0.62)	0.61 (0.03) 0.6 (0.59, 0.63)	0.61 (0.03) 0.6 (0.59, 0.62)	0.01
% Hispanic	9.36% (14.52) 4.57 (2.46, 8.46)	8.84% (14.13) 4.51 (2.42, 8.34)	10.07% (15.04) 4.88 (2.51, 9.21)	0.06
% Non-Hispanic Black	56.55% (33.81) 66.76 (20.1, 88.2)	55.13% (34.64) 65.01 (17.23, 88.2)	58.54% (32.55) 68.85 (25.9, 88.2)	0.02
Violence crime rates per 10,000 population	329.43 (213.69) 276.6 (164.15, 466.81)	329.36 (223.25) 272.63 (157.52, 466.81)	329.53 (199.71) 287.94 (168.94, 466.81)	0.98
Population Density in sq km	8107.09 (3929.34)	8162.81 (3951.11)	8029.3 (3899.77)	0.45

Abbreviations: sq—square; km—kilometer; RR-relative risk; aRR-adjusted relative risk; CI-Confidence Interval; km—kilometer.
[a] Poor Glycemic Control Defined as Hemoglobin A1C > 6.5% on ≥1 Measurement.

predisposition as well as a long-term consequence of structural racism (Beydoun et al., 2017; Parsa et al., 2013). Previous studies have observed that residence in predominantly Black neighborhoods is associated with lower rates of transplantation wait-listing (Arriola, 2017; Peng et al., 2018). However, less is understood about the relationship of Hispanic ethnicity and CKD, at both an individual and neighborhood level. Some studies have shown similar incidence of CKD progression among Hispanics as non-Hispanic Blacks, but the risk is attenuated by adjustment for important comorbidities and SES factors (Fischer et al., 2016). We found evidence of a significant unadjusted association between non-Hispanic Black neighborhood racial composition and CKD. However, this association was no longer statistically significant after adjustment for individual-level age, sex, race, ethnicity, insurance, and other neighborhood characteristics. A reverse relationship was observed for residents of predominantly Hispanic neighborhoods, but this association was also substantially attenuated after multivariable adjustment. In combination with our other findings, these results suggest that neighborhood SES might be a more reliable marker of CKD risk than neighborhood racial composition.

To meet the ambitious goals of the Advancing American Kidney Health Initiative, US health care providers are in need of tools to identify more people with CKD in its earlier stages (Bieber & Gadegbeku, 2019; Government US, 2019). Our findings suggest that consideration of social determinants of health, at a neighborhood level, should be fundamental to the redesign of CKD care. Metrics such as the SES index might be a useful tool for both policymakers and physicians when creating programs to addresskidney health. Indeed, experts recommend that integrating neighborhood-level social determinants of health into electronic health records could provide physicians with insights on typically unmeasured drivers of health status (Cantor & Thorpe, 2018). Our results suggest that integration of the SES index into electronic health records could provide a quick snapshot of the collective health literacy and financial well-being of an individual patient's neighborhood of residence and therefore, serve as another tool to stratify CKD risk. In addition, low SES neighborhoods should be the targets of on-site CKD screening and awareness programs, particularly to reach residents who might have difficulty accessing the healthcare system.

The study has several strengths, including its large sample size and its granular data on neighborhood social context in a contemporary urban population struggling with the highest deep poverty rate of all large UScities. Our cohort characteristics largely mirrored those of the overall Philadelphia population. CKD prevalence in our cohort was similar to the US national CKD prevalence. However, there are also limitations to this study. For example, due to its cross-sectional design, we could not assess casual relationships between neighborhood context and CKD progression. We were also unable to adjust for individual-level SES beyond insurance type. Generalizability of our findings might also be a concern given our focus on a single academic health system in Philadelphia. There is also the potential for selection bias given that our study only included Philadelphia residents who utilized primary care, as well as susceptibility to misclassification bias from the use of billing codes to identify some comorbid conditions and potentially, errors in BP measurement. However, our approach was well-suited to examine the potential utility of neighborhood metrics, and specifically the SES index, as tools to screen for at-risk individual patients in the primary care setting and to design interventions for diagnosing and treating CKD in at-risk neighborhoods in Philadelphia.

In conclusion, in a large cohort of adults from Philadelphia, we found that the SES of a neighborhood might influence the risk of CKD. The SES index, in particular, could be a valuable tool to help achieve the goals of the Advancing American Kidney Health Initiative if it can identify which US communities are at highest risk for CKD. Additionally, our findings that neighborhood WalkScore® is independently associated with poor glycemic control in CKD patients and poor blood pressure control in those without CKD indicate that interventions to enhance neighborhood walkability should be tested to improve CKD and related outcomes. Further investigation in longitudinal urban cohorts is necessary to examine whether SES index and other neighborhood characteristics might influence CKD progression.

Author statement

Suzanne Boyle: Funding acquisition, Conceptualization, Investigation, Methodology, Data Curation, Writing-Original Draft Preparation, Review, and Editing; **Yuzhe Zhao:** Methodology, Formal Analysis, Visualization, Writing-Original Draft Preparation, Review, and Editing; **Edgar Chou**: Conceptualization, Writing-Original Draft Preparation, Review, and Editing; **Kari Moore:** Conceptualization, Methodology, Formal Analysis, Writing-Original Draft Preparation, Review, and Editing, Supervision; **Meera Harhay:** Funding acquisition, Conceptualization, Methodology, Writing-Original Draft Preparation, Review, and Editing, Supervision

Ethics statement

The authors declare that there are no financial or personal relationships with other people or organizations that could have inappropriately influenced or biased their work.

Financial conflicts of interest

The authors declare no financial conflicts of interest.

Acknowledgements

This research was supported by the Drexel University Urban Health Collaborative pilot award program. MNH is supported by NIH grants - K23DK105207 and R01DK124388.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2020.100646.

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