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Association of community socioeconomic deprivation with evidence of reduced kidney function at time of type 2 diabetes diagnosis

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ABSTRACT

Background: While there are known individual-level risk factors for kidney disease at time of type 2 diabetes diagnosis, little is known regarding the role of community context. We evaluated the association of community socioeconomic deprivation (CSD) and community type with estimated glomerular filtration rate (eGFR) when type 2 diabetes is diagnosed.

Methods: This was a retrospective cohort study of 13,144 adults with newly diagnosed type 2 diabetes in Pennsylvania. The outcome was the closest eGFR measurement within one year prior to and two weeks after type 2 diabetes diagnosis, calculated using the Chronic Kidney Disease Epidemiology Collaboration (CKD-Epi) equation. We used adjusted multinomial regression models to estimate associations of CSD (quartile 1, least deprivation) and community type (township, borough, city) with eGFR and used adjusted generalized estimating equation models to evaluate whether community features were associated with the absence of diabetes screening in the years prior to type 2 diabetes diagnosis.

Results: Of the participants, 1279 (9.7%) had hyperfiltration and 1377 (10.5%) had reduced eGFR. Women were less likely to have hyperfiltration and more likely to have reduced eGFR. Black (versus White) race was positively associated with hyperfiltration when the eGFR calculation was corrected for race but inversely associated without the correction. Medical Assistance (ever versus never) was positively associated with reduced eGFR. Higher CSD and living in a city were each positively associated (odds ratio [95% confidence interval]) with reduced eGFR (CSD quartiles 3 and 4 versus quartile 1, 1.23 [1.04, 1.46], 1.32 [1.11, 1.58], respectively; city versus township, 1.38 [1.15, 1.65]). These features were also positively associated with the absence of a type 2 diabetes screening measure.

Conclusions: In a population-based sample, more than twenty percent had hyperfiltration or reduced eGFR at time of type 2 diabetes diagnosis. Individual- and community-level factors were associated with these outcomes.

1. Introduction

An estimated 34.1 million U.S. adults have diabetes, including 7.3 million adults who have not yet been diagnosed (Centers for Disease Control and Prevention (CDC), 1999; National Diabetes Statistics Report, 2021). Worldwide, forty to fifty percent of individuals with diabetes go on to develop diabetes related kidney disease (Thomas et al., 2016). Diabetes related kidney disease is the leading cause of end stage kidney disease and increases risk for all-cause and cardiovascular mortality (Thomas et al., 2016). Timely detection is critical to preventing disease progression and reducing the risk of end stage renal disease (Bakris et al., 2011). Thus, the American Diabetes Association recommends estimating glomerular filtration rate (GFR) at time of type 2 diabetes diagnosis and annually thereafter (American Diabetes Association, 2020). However, at the time of diabetes diagnosis, up to one-third of individuals already have evidence of kidney disease (Bakris et al., 2011). While there are known individual-level risk factors for kidney disease at time of diagnosis, there is little known regarding the role of community context (Fang & Selvin, 2021).

Community socioeconomic deprivation, a multidimensional measure of community-level socioeconomic characteristics (e.g. community

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Abbreviations:

CKD-Epi	Chronic Kidney Disease Epidemiology Collaboration equation
eGFR	estimated glomerular filtration rate
GFR	glomerular filtration rate

poverty rate) may be a common cause of type 2 diabetes and kidney disease. Community socioeconomic deprivation has been associated with onset of type 2 diabetes (Bilal et al., 2018; Schwartz et al., 2021) as well as measures of poor kidney health, including rapid GFR decline, end stage renal disease, hemodialysis survival, and chronic kidney disease (Bowe et al., 2017; Boyle et al., 2020; Lapedis et al., 2020). The stress of living in a socioeconomically deprived area (Richardson et al., 2021) may increase the risk of both type 2 diabetes and kidney impairment either directly, through disruption of the hypothalamic -pituitary-adrenal axis (Joseph & Golden, 2017), or through stress-related health behaviors (e.g., poor diet, lack of physical activity) that may lead to risk factors of both diseases, including obesity, hypertension, and hyperglycemia (Bilal et al., 2018; Jiminez et al., 2019; Mohammed et al., 2019; Schwartz et al., 2021) (Fig. 1, pathway 1).

Kidney disease at time of type 2 diabetes diagnosis may also indicate delayed detection of type 2 diabetes (Fig. 1, pathway 2). Studies estimate that type 2 diabetes is diagnosed four to twelve years after disease onset (Clark et al., 2000; Porta et al., 2014). Typically, early in the course of type 2 diabetes, diabetes-induced structural and dynamic changes cause an increase in GFR known as hyperfiltration (Fang & Selvin, 2021; Narva & Bilous, 2015). After a few years, the GFR declines due to increasing kidney damage and, after about ten years into the disease course, can drop to below 60 mL/min/1.73 m^2 (Tonnejick et al., 2017). Thus, GFR at time of type 2 diabetes diagnosis could vary depending upon when during the course of disease an individual is diagnosed. Hyperglycemia may go undetected for a longer time among individuals living in socioeconomically deprived communities due to poor transportation access; lack of social support that encourages utilization of preventive health services (e.g., screenings); and lack of social networks that exchange health information (Fernandes et al., 2015; Veldhius et al., 2020). Little is known regarding the association between community socioeconomic deprivation and type 2 diabetes diagnosis delays.

To date, no study has evaluated whether community socioeconomic deprivation is associated with kidney function at time of type 2 diabetes diagnosis or whether such associations account for geographic disparities in kidney health. Such information could help identify high risk populations to prioritize for earlier screening for type 2 diabetes. The objectives of this study were to determine the proportion of individuals with hyperfiltration and reduced GFR at time of type 2 diabetes diagnosis and to evaluate associations between community socioeconomic deprivation, community type, and kidney outcomes. We used electronic health record (EHR) data from a health system in Pennsylvania to evaluate GFR at time of type 2 diabetes diagnosis among 13,144 adults. Understanding the relation between community socioeconomic deprivation and kidney health at diabetes diagnosis is critical to informing programs that promote kidney health and prevent disease progression for those at highest risk.

2. Methods

2.1. Study population and design

This study was conducted by Geisinger-Johns Hopkins Bloomberg School of Public Health, one of four academic research centers in the Diabetes LEAD (Location, Environmental Attributes, and Disparities) Network, a collaboration funded by the Centers for Disease Control and Prevention dedicated to providing scientific evidence to develop targeted interventions and policies to prevent type 2 diabetes and related health outcomes across the U.S. (Hirsch et al., 2020). Using previously reported methods (Schwartz et al., 2021), we identified adults older than 18 years of age with newly diagnosed diabetes between 2008 and 2016. Patients included those with a Geisinger primary care provider, who represent the general population in the region (Casey et al., 2018).

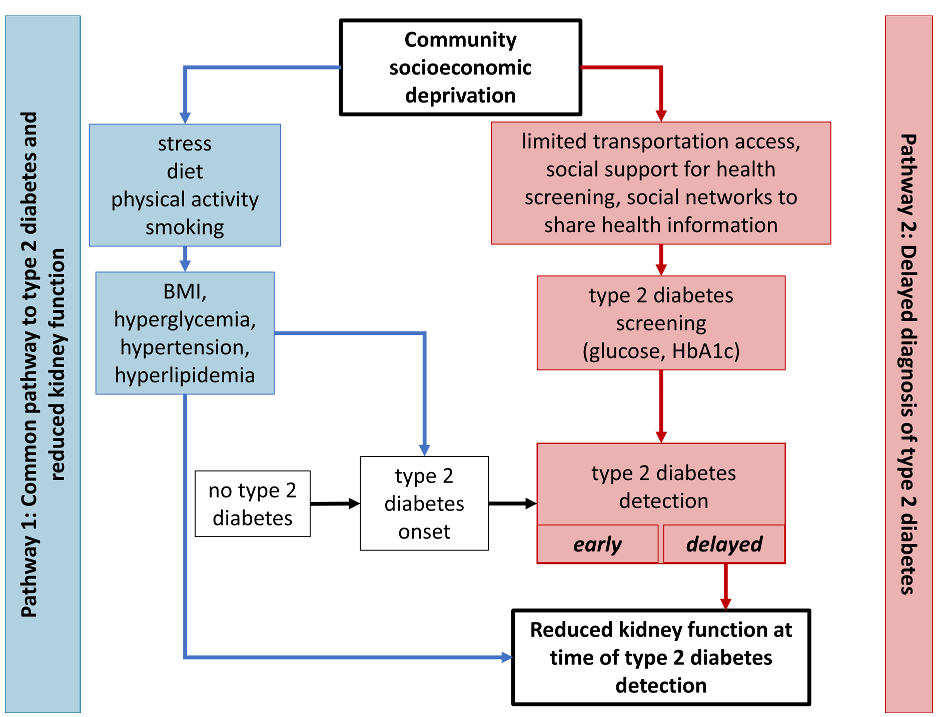

Fig. 1. Conceptual framework representing two of the potential pathways through which community socioeconomic deprivation (CSD) may be associated with reduced kidney function at time of type 2 diabetes detection.

The study area included 37 counties in central and northeastern Pennsylvania. This study was approved by the Geisinger Institutional Review Board.

2.2. Identification of newly diagnosed type 2 diabetes

Individuals with type 2 diabetes were identified using an algorithm that relied on encounter diagnoses, diabetes-relevant medication orders, and laboratory test results (Schwartz et al., 2021). To ensure diabetes was newly diagnosed, we required individuals to have at least one encounter with the health system at least two years prior to diagnosis, without evidence of diabetes. We estimated the date that the health system recognized type 2 diabetes as the date that the case met the criteria for type 2 diabetes diagnosis (hereafter referred to as "detection date"). To be included in the study, individuals had to have at least one serum creatinine value within one year prior to and two weeks after diagnosis of type 2 diabetes.

2.3. Measurement of community socioeconomic deprivation

We obtained patient addresses from the EHR, geocoded them to the street level using ArcGIS version 10.4 (ESRI Inc., Redlands, CA), and assigned to one of three administrative community types of the residential location based on previously described methods (Schwartz et al., 2011). The approach combined Pennsylvania's minor civil divisions, which represent behaviorally- and policy-relevant boundaries, with city census tracts to divide densely populated cities. These administrative community types included townships (rural/suburban areas), boroughs (small towns), and city census tracts (urban) and represent a continuum of lower to higher population density and land use mix (Poulsen et al., 2021). We measured community socioeconomic deprivation based on the sum of the z-transformed values of six indicators using data from the Decennial Census (2000 only) and American Community Survey (2006–2010, 2011–2015): percent unemployed, percent with less than a high school education, percent below poverty level, percent on public assistance, percent not in the workforce, and percent of households without a car (Schwartz et al., 2021). The index was assigned as the closest measure prior to the year of detection and quartiled, with the highest quartile (quartile 4) representing the most socioeconomically deprived communities.

2.4. Estimation of GFR

We measured GFR using the estimated GFR (eGFR) from the Chronic Kidney Disease Epidemiology Collaboration (CKD-Epi) equation (Levey et al., 2009), which accounts for sex, race, and body surface area, using the serum creatinine value. For Black individuals, the output of the CKD-Epi equation is multiplied by 1.159, increasing the calculated value by approximately 16 percent to account for previously reported differences in serum creatinine levels by race (Diao et al., 2020). However, as described in more detail below, we conducted sensitivity analyses that did not apply the aforementioned adjustment for Black individuals, as recent studies have called for the removal of this adjustment due to concerns that this correction might delay care for Black individuals (Diao et al., 2020; Vyas et al., 2020). We categorized eGFR as (American Diabetes Association, 2020; Reboldi et al., 2018): (1) normal: eGFR $\geq$ 60 mL/min/1.73 m^2 and $\leq$ 95th percentile for age and sex based on data from the National Health and Nutrition Examination Survey (NHANES) (Petrov et al., 2016, pp. 75–81); (2) hyperfiltration: eGFR $>$ 95th percentile; and (3) reduced eGFR: eGFR $<$ 60 mL/min/1.73 m^2.

2.5. Analysis

The analysis goals were to determine the proportion of individuals with hyperfiltration and reduced eGFR among adults with newly detected type 2 diabetes, and to evaluate the association of community socioeconomic deprivation and administrative community type with these kidney outcomes. We first evaluated bivariate associations between individual-level characteristics, community socioeconomic deprivation, and administrative community type with eGFR categories. Next, we used multinomial regression (reference = normal eGFR) with a random intercept for community to estimate odds ratios (OR) and 95% confidence intervals (CI).

In model 1 we included the following individual-level variables: age (years; centered linear, quadratic, and cubic terms to allow for nonlinearity), sex (female versus male), race (Black, all other races [Asian, Native Hawaiian or other Pacific Islander, American Indian or Alaska Native] versus White), ethnicity (Hispanic versus non-Hispanic), and Medical Assistance as a surrogate for family socioeconomic status (ever versus never) (24). Races other than White and Black were collapsed into a single category due to the small number of individuals who were not in these race categories. We did not include hypertension or body mass index in the model, as we hypothesized that both of these factors were likely mediators of the association between community socioeconomic deprivation and kidney health at time of type 2 diabetes diagnosis (Fig. 1). In model 2, we added community socioeconomic deprivation (quartile 1, least deprived) versus quartiles 2, 3, and 4) to model 1. Finally, in model 3 we added administrative community type (township versus borough and city) to model 1. We did not include community socioeconomic deprivation and administrative community type in the same model due to collinearity between the two measures. For all models we added smoking status to evaluate potential confounding of associations between community measures and kidney outcomes. For all models we also conducted a sensitivity analysis with two modified approaches to measuring kidney function: 1. CKD-Epi without the race correction for Black individuals, 2. CKD- Epi with the race correction, but hyperfiltration was defined as $>$ 95th percentile for race, as well as for age and sex, using NHANES data (Centers for Disease Control and Prevention, 2012).

In a secondary analysis, we explored whether characteristics were associated with delayed detection of type 2 diabetes. While it was not possible to quantify the time between onset and detection of type 2 diabetes, we evaluated individual- and community-level factors in relation to history of type 2 diabetes screening, based on the presence/absence of a screening test for diabetes (fasting glucose, random glucose, glycated hemoglobin [HbA1c]) in two time windows: two and five years prior to type 2 diabetes diagnosis. We created generalized estimating equation models with robust standard errors with the screening measures as the outcome (absent versus present), adjusting for the aforementioned covariates. Community socioeconomic deprivation and community type were again evaluated separately. We evaluated community socioeconomic quartiled and then as a continuous variable, assigning individuals the median value of the relevant quartile of community socioeconomic deprivation.

3. Results

Among 15,267 adults with newly diagnosed type 2 diabetes, 13,144 had a serum creatinine measure within one year prior and two weeks after diagnosis. The median time between the serum creatinine value and the date of type 2 diabetes detection was zero days, indicating serum creatinine was measured on the same date as type 2 diabetes detection. The 2483 adults who were missing a serum creatinine value did not differ by race, ethnicity, community socioeconomic deprivation, or community type. Analyses was confined to the 13,144 individuals with a serum creatinine measure.

The mean age at diabetes detection was 55.9 years (Table 1). The majority of individuals were White (97.2%) and 97.7% of the individuals were non-Hispanic, consistent with the demographics in the region. More than half (59.7%) of individuals lived in townships, compared with 29% in boroughs and 11.2% in cities. Among individuals living in cities, 78.5% lived in communities at the highest level of

Table 1

Selected characteristics of adults with new onset type 2 diabetes (n = 13,144).

Variable	
Sex, female, n (%)	6354 (48.3)
Age at diagnosis, years, mean (SD)	55.9 (14.2)
Age at diagnosis, n (%)	
19 to < 30 years	515 (3.9)
30 to < 40 years	1273 (9.7)
40 to < 50 years	2581 (19.6)
50 to < 60 years	3667 (27.9)
60 to < 70 years	2971 (22.6)
>70 years	2137 (16.3)
Race, n (%)	
White	12,771 (97.2)
American Indian/Alaska Native	10 (0.1)
Asian	53 (0.4)
Black	255 (1.9)
Native Hawaiian/Pacific Islander	32 (0.2)
Mixed race	11 (0.1)
Other	2 (0.02)
Hispanic ethnicity, n (%)	305 (2.3)
Medical Assistance[a], ever, n (%)	2309 (17.6)
Smoking status, n (%)	
Current	2236 (17.0)
Former	5064 (38.5)
Never	5817 (44.3)
At least one glucose or HbA1c measure in the two years prior to T2D diagnosis, n (%)	6568 (50.0)
At least one glucose or HbA1c measure in the five years prior to T2D diagnosis, n (%)	7351 (65.8)[b]
Time between serum creatine measure and type 2 diabetes diagnosis, median (IQR)	0, (0, 0)
eGFR, mL/min/1.73m^2, n (%)[c]	
Normal	10,488 (79.8)
Hyperfiltration	1279 (9.7)
Reduced eGFR	1377 (10.5)
Community socioeconomic deprivation, n (%)	
Quartile 1 (least deprived)	2518 (19.2)
Quartile 2	3549 (27.0)
Quartile 3	3510 (26.7)
Quartile 4 (most deprived)	3567 (27.1)
Community of residence, n (%)	
Borough	3826 (29.1)
City	1470 (11.2)
Township	7848 (59.7)

Abbreviations: eGFR: estimated glomerular filtration rate; HbA1c: glycated hemoglobin; LDL: low-density lipoprotein; SD: standard deviation; T2D: type 2 diabetes; IQR: interquartile range.

[a] Ever used Medical Assistance as a payor for a Geisinger clinical encounter.

[b] Among 11,170 individuals who had been in the medical record for at least five years prior to type 2 diabetes diagnosis.

[c] eGFR closest to diagnosis of type 2 diabetes within 12 months before and 2 weeks after diagnosis: Normal is 60 mL/min/1.73 m^2 and ≤95th percentile for age and sex based on NHANES data, hyperfiltration is > 95th percentile for age and sex based on NHANES data, reduced eGFR is < 60 mL/min/1.73 m^2.

community socioeconomic deprivation (quartile 4), compared to 39% in boroughs and 11.5% in townships (data not shown). At time of type 2 diabetes detection, 10,488 (79.8%) had a normal eGFR value, 1279 (9.7%) had evidence of hyperfiltration, and 1377 (10.5%) had evidence of reduced eGFR.

3.1. Unadjusted associations with kidney outcomes

In unadjusted analyses, hyperfiltration was more common among males (versus females). Nearly half of individuals who were Black had hyperfiltration, compared to less than 10% among those who were White (9.0%) or Asian (5.7%). (Table 2). Among individuals living in the least deprived communities, 8.3% had hyperfiltration at time of type 2 diabetes detection, compared to 9.8% of those in the most deprived communities. In townships, 11.4% of residents had hyperfiltration

Table 2

eGFR results[a] by selected characteristics of adults newly diagnosed with type 2 diabetes.

Variable	eGFR normal	eGFR hyperfiltration	reduced eGFR	Comparison across three eGFR categories[c]
Sex, n (ROW %)				
Female	5211 (82.0)	347 (5.5)	796 (12.5)	$p < 0.001$
Male	5277 (77.7)	932 (13.7)	581 (8.6)	
Age at diagnosis, n (ROW %)				
19 to < 30 years	439 (85.2)	73 (14.2)	3 (0.6)	$p < 0.001$
30 to < 40 years	1073 (84.3)	178 (14.0)	22 (1.7)	
40 to < 50 years	2216 (85.9)	306 (11.9)	59 (2.3)	
50 to < 60 years	3231 (88.1)	260 (7.1)	176 (4.8)	
60 to < 70 years	2185 (73.5)	420 (14.1)	366 (12.3)	
>70 years	1,34 (62.9)	42 (2.0)	751 (35.1)	
Race, n (ROW %)				
White	10,261 (80.4)	1149 (9.0)	1361 (10.7)	$p < 0.001$
American Indian/Alaska Native	6 (60.0)	2 (20.0)	2 (20.0)	
Asian	49 (92.5)	3 (5.7)	1 (1.9)	
Black	124 (48.6)	118 (46.3)	13 (5.1)	
Native Hawaiian/ Pacific Islander	28 (87.5)	4 (12.5)	0 (0.0)	
Mixed race	11 (100)	0 (0.0)	0 (0.0)	
Other	2 (100)	0 (0.0)	0 (0.0)	
Hispanic ethnicity, n (ROW %)				
Non-Hispanic	10,236 (79.7)	1234 (9.6)	1369 (10.7)	$p < 0.001$
Hispanic	252 (82.6)	45 (14.8)	8 (2.6)	
Medical Assistance, n (ROW %)[b]				
Ever	1899 (82.2)	274 (11.9)	136 (5.9)	$p < 0.001$
Never	8589 (79.3)	1005 (9.3)	1241 (11.5)	
Smoking status				
Current	1805 (80.7)	319 (14.3)	112 (5.0)	$p < 0.001$
Former	3956 (78.1)	496 (9.8)	612 (12.1)	
Never	4710 (81.0)	462 (7.9)	645 (11.1)	
Community socioeconomic deprivation[c]				
Quartile 1 (least deprived)	2062 (81.9)	210 (8.3)	246 (9.8)	$p = 0.011$
Quartile 2	2853 (80.4)	353 (10.0)	343 (9.7)	
Quartile 3	2765 (78.8)	366 (10.4)	379 (10.8)	
Quartile 4 (most deprived	2808 (78.7)	350 (9.8)	409 (11.5)	
Community of residence, n (ROW %)				
Borough	3078 (80.5)	359 (9.4)	389 (10.2)	$p = 0.053$
Census tract in city	6280 (80.0)	752 (9.6)	816 (10.4)	
Township	1130 (76.9)	168 (11.4)	172 (11.7)	

Abbreviations: BMI: body mass index; eGFR: estimated glomerular filtration rate; HbA1c: glycated hemoglobin; LDL: low-density lipoprotein; T2D: type 2 diabetes.

[a] eGFR closest to diagnosis of type 2 diabetes within 12 months before and 2 weeks after diagnosis: Normal is 60 mL/min/1.73m^2 and ≤ 95th percentile for age and sex based on NHANES data, hyperfiltration is >95th percentile for age and sex based on NHANES data, reduced eGFR is <60 mL/min/1.73m^2.

[b] Ever used Medical Assistance as a payor for a [blinded review] clinical encounter.

[c] Chi-square test for categorical variables and F-test for continuous variables.

compared to 9.4% in boroughs, and 9.6% in cities.

Bivariate associations with reduced eGFR differed from associations with hyperfiltration (Table 2). Reduced eGFR was more common among females (versus males) and more common among White individuals than Black. As expected, the proportion of individuals with reduced eGFR increased with age. Reduced eGFR was less common among Hispanic individuals (versus non-Hispanic). A higher proportion of individuals with no history of Medical Assistance (versus ever Medical Assistance) had reduced kidney function. Reduced eGFR was present in 11.7% of individuals living in townships, 10.2% in boroughs, and 10.4% cities. Among individuals living in the least deprived communities, 9.8% had reduced eGFR at time of new onset type 2 diabetes diagnosis, compared to 11.5% of those in the most deprived communities.

3.2. Adjusted associations with kidney outcomes

In model 1, sex (female versus male) was inversely associated with hyperfiltration (OR: 0.35 [95% CI: 0.30, 0.40]) (Table 3). The odds of hyperfiltration among those who were Black was more than eight times the odds among White individuals (8.7 [6.53, 11.68]). In contrast, sex (female versus male) was positively associated with reduced eGFR (1.25 [1.10, 1.42]) and race was not associated with reduced eGFR. Ethnicity (Hispanic versus non-Hispanic) was inversely associated with reduced eGFR (0.42 [0.19, 0.96) while a history of Medical Assistance (versus no history of Medical Assistance) was positively associated with reduced eGFR (1.63 [1.31, 2.03]).

Model 2 (Table 3) resulted in slight attenuations of the previously described associations. Community socioeconomic deprivation was not associated with hyperfiltration at time of type 2 diabetes detection, but was associated with reduced eGFR. Specifically, quartiles 3 and 4 (versus quartile 1) were each associated with higher odds of reduced eGFR, (1.23 [1.04, 1.46], 1.32 (1.11, 1.58], respectively). A test for trend indicated a trend of higher deprivation associated with greater risk of reduced eGFR ($p < 0.0001$).

In model 3 (Table 3) community type was not associated with hyperfiltration at time of type 2 diabetes detection, but was associated with reduced eGFR. Specifically, living in a city (versus township) was associated with higher odds of reduced eGFR at time of type 2 diabetes detection (1.38 [1.15, 1.65]). Smoking was not included in the final models. There was no evidence that smoking status confounded associations between community-level factors and kidney outcomes (data not shown). Moreover, smoking could be a potential mediator of the association between community socioeconomic deprivation and kidney

Table 3
Adjusted associations of individual- and community-level features with eGFR categories[a] within one year prior and two weeks after type 2 diabetes diagnosis in three multinomial models (reference: normal eGFR).

	Hyperfiltration Odds ratio (95% confidence interval)			Reduced eGFR Odds ratio (95% confidence interval)		
	Model 1: individual-level factors	Model 2: model 1 + community socio-economic deprivation	Model 3: model 1 + community type	Model 1: Individual-level factors	Model 2: model 1 + community socio-economic deprivation	Model 3: model 1 + community type
Age-centered (years)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.10 (1.09, 1.11)	1.10 (1.09, 1.11)	1.10 (1.09, 1.11)
Age centered-squared (yrs.)	0.99 (0.99, 0.99)	0.99 (0.99, 0.99)	0.99 (0.99, 0.99)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Age centered-cubed (yrs.)	0.99 (0.99. 0.99)	0.99 (0.99, 0.99)	0.99 (0.99, 0.99)	0.99 (0.99, 1.00)	0.99 (0.99, 0.99)	0.99 (0.99, 1.00)
Female vs. male	0.35 (0.30, 0.40)	0.35 (0.30, 0.40)	0.35 (0.30, 0.39)	1.25 (1.10, 1.42)	1.24 (1.09, 1.41)	1.24 (1.09, 1.41)
Race (vs. White)						
Black	8.7 (6.53, 11.68)	8.62 (6.45, 11.54)	8.62 (6.4, 11.5)	1.68 (0.98, 2.89)	1.63 (0.95, 2.80)	1.59 (0.92, 2.73)
All other races	0.90 (0.47, 1.72)	0.90 (0.47, 1.72)	0.90 (0.47, 1.71)	0.32 (0.09, 1.14)	0.34 (0.10, 1.18)	0.33 (0.09, 1.15)
Hispanic vs. non-Hispanic	1.26 (0.89, 1.79)	1.26 (0.89, 1.78)	1.24 (0.88, 1.76)	0.42 (0.19, 0.96)	0.41 (0.18, 0.94)	0.40 (0.18, 0.91)
Medical Assistance ever vs. never[b]	1.11 (0.95, 1.31)	1.10 (0.94, 1.30)	1.11 (0.95, 1.30)	1.63 (1.31, 2.03)	1.56 (1.25, 1.95)	1.58 (1.26, 1.97)
Community socioeconomic deprivation (vs. quartile 1) [c]		1.16			1.05	
Quartile 2		(0.97, 1.40) 1.16			(0.87, 1.26) 1.23	
Quartile 3		(0.97, 1.39) 1.13			(1.04, 1.46) 1.32	
Quartile 4		(0.94, 1.36)			(1.11, 1.58)	
Community type (vs. township)						
Borough			0.97 (0.84, 1.12)			1.04 (0.91, 1.20)
City			1.07 (0.87, 1.31)			1.38 (1.15, 1.65)

[a] eGFR closest to diagnosis of type 2 diabetes within 12 months before and 2 weeks after diagnosis: Normal is 60 mL/min/1.73 m^2 and ≤95th percentile for age and sex based on NHANES data, hyperfiltration is > 95th percentile for age and sex based on NHANES data, reduced eGFR is < 60 mL/min/1.73 m^2.

[b] At least one clinical encounter associated with billing to Medical Assistance.

[c] Quartile 1 is least deprived and quartile 4 is most deprived. Abbreviations: CSD: Community socioeconomic deprivation; eGFR: estimated glomerular filtration rate.

function. Thus smoking status was excluded from final models.

3.3. Sensitivity analysis: CKD-Epi calculation

Removing the race correction from the CKD-Epi equation changed the proportion of Black individuals with hyperfiltration from 46.3% to 5.1% (Table A1). Retaining the correction for race, but using a hyperfiltration 95th percentile cut-off based on race, resulted in 11.4% of Black individuals classified as having hyperfiltration. In all three models, using the CKD-Epi equation without the race correction drastically altered the association of race with hyperfiltration, with the odds ratio (95% CI) declining from greater than 8 to less than one, changing being Black (versus White) from being a risk to being protective of hyperfiltration (Tables 3 and A2). Being Black was also positively associated with reduced kidney function when the race correction was not applied. When hyperfiltration was defined as > 95th percentile for race, as well as for age and sex, race was no longer associated with hyperfiltration or reduced kidney function (Table A3). Associations with community socioeconomic deprivation, community type, and Medical Assistance did not change based on how kidney function was measured.

3.4. Associations with type 2 diabetes screening measures

All individuals had at least two years of data in the EHR and were included in evaluating screening measures in the two years prior to type 2 diabetes detection, while analysis of screening in the prior five years was confined to the subset of 11,170 individuals with at least five years of data. The proportion of individuals without a diabetes screening measure in the two years prior to type 2 diabetes detection increased as community socioeconomic deprivation increased slightly, ranging from 48% in the least deprived communities to 52% in the most deprived communities ($p = 0.006$, data not shown). The proportion of individuals without a diabetes screening measure in these five years increased from 31% in the least deprived community to 37% in the most deprived community, $p < 0.001$, data not shown). Community socioeconomic deprivation, measured as a continuous variable, was positively associated with the absence of a diabetes screening measure in both the two and five year periods ($p < 0.001$).

In fully adjusted models of the absence of a diabetes screening measure, Medical Assistance was positively associated with the absence of a diabetes screening measure in both the two (1.11 [1.01, 1.22]) and five year periods (1.23 [1.10, 1.37]) prior to type 2 diabetes detection (Table A4). In adjusted models (not shown) community socioeconomic deprivation, measured as a continuous variable, was positively associated with the absence of a diabetes screening measure in both the two and five year periods ($p < 0.001$).

The absence of a diabetes screening measure in the two years prior to type 2 diabetes detection was more common in cities (57%) compared to boroughs (50%) and townships (49%) ($p < 0.001$). A similar trend was observed for the five year period (cities 43%, boroughs 35%, townships 32%, $p < 0.001$). In a model additionally adjusted for administrative community type, the odds ratios for cities (versus townships) was 1.31 (1.13, 1.52) for the two year period and 1.44 (1.25, 1.66) for the five year period (Table A5).

4. Discussion

This study found that people living in socioeconomically deprived communities and in urban communities have higher odds of reduced eGFR at time of type 2 diabetes detection than those living in less deprived and rural communities in central and northeastern Pennsylvania. These community features were not associated with hyperfiltration. To our knowledge, this is the first study to evaluate the associations of community socioeconomic deprivation and community type with hyperfiltration and reduced eGFR at the time of type 2 diabetes detection. We hypothesize that our observed associations are likely mediated by multiple pathways, including delayed diagnosis of type 2 diabetes and common causes of type 2 diabetes and poor kidney health, including stress, poor diet, and limited physical activity (Fig. 1). These findings may help identify individuals most likely to benefit from close monitoring of risk factors for poor kidney health at time of type 2 diabetes detection.

In this population-based sample from Pennsylvania, 9.7 percent of individuals had hyperfiltration and 10.5 percent had reduced eGFR at the time of type 2 diabetes detection. Our estimate of reduced eGFR was slightly higher than that from an NHANES study which estimated that 9.9 percent of individuals in the U.S. with type 2 diabetes had reduced eGFR within the first two years after diagnosis (Fang & Selvin, 2021). Similar to Fang and colleagues (2021) who reported an association of income and education with reduced eGFR within the first two years of diagnosis, we observed an association of Medical Assistance with reduced eGFR. However, the prior study did not evaluate area-level socioeconomic deprivation, whereas we found that individuals living in the most deprived communities had more than 30 percent higher likelihood of reduced eGFR, independent of individual-level association of socioeconomic status and eGFR.

Fang and colleagues (2021) hypothesized that the association between individual-level socioeconomic status and poor kidney health at time of type 2 diabetes diagnoses was due to delays in type 2 diabetes detection. Low socioeconomic status presents a number of potential barriers to diabetes screening, including limited access to transportation and childcare, health literacy challenges, and lack of work schedule flexibility (Zha et al., 2019; Stormacq et al., 2019). While Medical Assistance provides some coverage for the cost of diabetes screening (Ku et al., 2017), eligibility for Medical Assistance is based on state and federal guidelines regarding poverty. Thus, despite coverage for diabetes screening, individuals on Medical Assistance likely still face the aforementioned. socioeconomic barriers to type 2 diabetes screening (Zha et al., 2019).

Similarly, community socioeconomic deprivation is theorized to pose barriers to preventive care, such as diabetes screening, through a range of potential pathways, including poor access to transportation services, lack of social networks that share health information, and shared medical mistrust (Benkert et al., 2019; Veldius et al., 2020). Consistent with this hypothesis, we did not observe an association of community socioeconomic deprivation with hyperfiltration at the time of type 2 diabetes detection. This difference may be explained by the differential timing of hyperfiltration and reduced eGFR in the natural history of type 2 diabetes. Hyperfiltration typically occurs earlier in the natural history of type 2 diabetes than does reduced eGFR (Narva & Bilous, 2015). Thus, longer delays in diabetes diagnosis could increase the risk of having reduced eGFR, as opposed to hyperfiltration, at time of type 2 diabetes detection. Further supporting this hypothesis, we found that the proportion of individuals with a history of screening within two and five years prior to type 2 diabetes detection dropped as community socioeconomic deprivation increased, consistent with a study of screening practices conducted in Ontario (Fernandes et al., 2015).

The co-occurrence of reduced eGFR at time of type 2 diabetes detection in socioeconomically deprived areas may also be due to common causal pathways (Fig. 1, pathway 1). Based on a national study of veterans, Bowe et al. (2017) reported that eGFR decreases more rapidly in more socioeconomically deprived communities. Similarly, community socioeconomic deprivation has been associated with newly diagnosed type 2 diabetes (Bilal & Diez-Roux 2018; Schwartz et al., 2021). The stress of living in more socioeconomically deprived communities may influence health behaviors, such as poor diet and limited physical activity, that could accelerate eGFR decline and increase type 2 diabetes risk, resulting in reduced eGFR at time of type 2 diabetes diagnosis (Bowe et al., 2017).

There is little known regarding the role of community type and diabetes related kidney disease in the U.S. and no prior study on community type and eGFR at time of type 2 diabetes detection. Similar to type 2 diabetes incidence (Schwartz et al., 2021; Bilal & Diez-Roux 2018), the proportion of individuals with reduced eGFR was highest in rural communities compared to urban communities. However, after adjusting for demographic and socioeconomic factors, the individuals living in urban communities were more at risk for reduced eGFR at time of type 2 diabetes detection than residents of rural communities. Individuals in urban communities were also at a higher risk of not having had a diabetes screening in the two and five year periods prior to type 2 diabetes detection than residents of rural communities. Due to the strong overlap in our region between community socioeconomic deprivation and administrative community type, we were unable to include these two factors in the same model. However, given the high proportion of cities in the highest quartile of socioeconomic deprivation, we hypothesize the associations with community type were likely largely driven by differences in socioeconomic deprivation and, thus, could be explained by previously described pathways between community socioeconomic deprivation and kidney health (Fig. 1). Alternatively, the association between urban communities and reduced kidney function could be explained by unmeasured environmental threats to kidney health (e.g., air pollution) that are more common in urban than in rural areas (Bowe et al., 2018).

In addition to community features, risk for hyperfiltration and reduced kidney function differed by sex. While men had a greater risk of hyperfiltration at time of diabetes diagnosis, women had a greater risk of reduced eGFR. The link between sex and kidney health among adults with type 2 diabetes remains inconclusive (Maric-Bilkan, 2020; Piani et al., 2021). Previously observed sex differences have been attributed to differences in hormones and health behaviors (Piani et al., 2021). Differences in kidney outcomes at time of type 2 detection may also indicate differences in duration of type 2 diabetes prior to detection. Women are more likely to have diagnosis and/or treatment delays for other conditions (Bugiardini et al., 2017; Wang et al., 2019). However, we did not observe sex differences in screening leading up to type 2 diabetes detection.

Racial differences in kidney function have been previously reported, with racial minorities being at increased risk for diabetes related kidney disease (Bhalla et al., 2013). Our findings add to this evidence, revealing racial disparities in hyperfiltration at time of type 2 diabetes detection. However, the association between race and hyperfiltration diverged depending upon the equation used to calculate eGFR and the approach to defining hyperfiltration. When we used the original CKD-Epi equation (correcting for race), Black individuals were at more than eight times the risk of hyperfiltration compared to White individuals. However, being Black was protective of hyperfiltration when we used the CKD-Epi equation without the race correction. When the race correction was not applied, being Black was also positively associated with reduced kidney function. Some researchers and clinicians advocate for removal of the race correction when calculating eGFR, based on concerns that the adjustment negatively impacts access to care among Black individuals. Proponents of the race adjustment fear that removal of the correction could lead to overdiagnosis and overtreatment of Black patients (Diao et al., 2020; Vyas et al., 2020). Our findings suggest that the way race is considered when determining kidney function could have a dramatic effect on research findings, and ultimately could influence care.

Strengths of this study included using objective EHR data for diabetes diagnoses, rather than self-report, and longitudinal EHR data to determine the timing of type 2 diabetes diagnosis, serum creatinine, and diabetes screening measures. Additionally, we measured community socioeconomic deprivation in behaviorally and socially relevant contexts rather than at the county or zip code level (Schwartz et al., 2011). There were some limitations to the study. First, the findings may not be generalizable to populations with different sociodemographic characteristic from different regions of the U.S., particularly in regions with more racial diversity, though our findings are likely generalizable for the region studied. The study was not designed to evaluate race as a primary exposure of interest and, thus, may have been underpowered to detect true associations between race and kidney health. Second, there is a possibility of residual confounding, as both community socioeconomic deprivation and community type are associated with the presence of environmental threats to health (e.g., air pollution) as well as community assets (e.g., healthcare resources) that have been found to impact kidney health (Bowe et al., 2018). Finally, as with most studies of community and health, there may have been some self-selection bias, wherein individuals choose to live in communities based on preferences and health behaviors (e.g., desire for walkability, access to health foods), leading to spurious findings. However, prior studies have found only small associations between health and neighborhood environment choice (James et al., 2015).

5. Conclusions

In a population-based sample, more than twenty percent had hyperfiltration or reduced eGFR at time of type 2 diabetes diagnosis. Individual- and community-level factors were associated with these outcomes. Women, individuals with a history of Medical Assistance, and individuals who resided in socioeconomically deprived and in urban communities were at a greater risk of reduced eGFR at the time of type 2 diabetes detection. Race was associated with hyperfiltration at time of diabetes diagnosis, but the direction of the association varied based on whether eGFR equation was race-adjusted. There is some evidence that differences in screening practices may explain community-level associations with reduced eGFR, as both living in communities of higher levels of socioeconomic deprivation and in urban communities was associated with a higher risk of the absence of a laboratory test for type 2 diabetes in the years leading up to diagnosis. It may be beneficial to evaluate the impact of earlier and more geographically-targeted screening for type 2 diabetes and other risk factors of poor kidney outcomes among subgroups at greatest risk for the presence of hyperfiltration and reduced eGFR at the time of type 2 diabetes diagnosis.

Data availability statement

Data are available upon reasonable request. Deidentified data are available upon request with IRB approval and a data use agreement.

Disclosure

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Author statement

Annemarie G. Hirsch: conceptualization, methodology, validation, investigation, writing – original draft, writing – review and editing, visualization, supervision, project administration, funding acquisition; Cara M. Nordberg: formal analysis, data curation, validation, writing – review and editing; Alexander Chang: methodology, writing – review and editing; Melissa N. Poulsen: methodology; writing – review and editing; Katherine A. Moon: methodology; writing – review and editing; Karen R. Siegel: writing – review and editing; Deborah B. Rolka: writing – review and editing; Brian S. Schwartz: conceptualization, methodology, writing – review and editing, visualization, supervision, funding acquisition.

Declaration of competing interest

The authors have no conflicts of interest to report.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2021.100876.

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