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Urban and rural differences in new onset type 2 diabetes: Comparisons across national and regional samples in the diabetes LEAD network

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ABSTRACT

Introduction: Geographic disparities in diabetes burden exist throughout the United States (US), with many risk factors for diabetes clustering at a community or neighborhood level. We hypothesized that the likelihood of new onset type 2 diabetes (T2D) would differ by community type in three large study samples covering the US.

Research design and methods: We evaluated the likelihood of new onset T2D by a census tract-level measure of community type, a modification of RUCA designations (higher density urban, lower density urban, suburban/small town, and rural) in three longitudinal US study samples (REGARDS [REasons for Geographic and Racial Differences in Stroke] cohort, VADR [Veterans Affairs Diabetes Risk] cohort, Geisinger electronic health records) representing the CDC Diabetes LEAD (Location, Environmental Attributes, and Disparities) Network.

Results: In the REGARDS sample, residing in higher density urban community types was associated with the lowest odds of new onset T2D (OR [95% CI]: 0.80 [0.66, 0.97]) compared to rural community types; in the Geisinger sample, residing in higher density urban community types was associated with the highest odds of new onset T2D (OR [95% CI]: 1.20 [1.06, 1.35]) compared to rural community types. In the VADR sample, suburban/small town community types had the lowest hazard ratios of new onset T2D (HR [95% CI]: 0.99 [0.98, 1.00]). However, in a regional stratified analysis of the VADR sample, the likelihood of new onset T2D was consistent with findings in the REGARDS and Geisinger samples, with highest likelihood of T2D in the rural South and in the higher density urban communities of the Northeast and West regions; likelihood of T2D did not differ by community type in the Midwest.

Conclusions: The likelihood of new onset T2D by community type varied by region of the US. In the South, the likelihood of new onset T2D was higher among those residing in rural communities.

1. Introduction

Diabetes places significant health and economic burdens on communities, particularly in the United States (US), where 1 in 10 Americans has diabetes and the age-adjusted prevalence of diabetes increased significantly between 1999 and 2016 (CDC, 2020). Approximately 90–95% of all diabetes cases in the US are type 2 diabetes (T2D) (CDC, 2020). Identifying sociodemographic and lifestyle factors related to T2D risk at the individual level, such as age, race, income, education level, smoking status, diet and physical activity (Bellou et al., 2018), is important for T2D prevention and control. Individuals at risk of developing T2D are more likely to have prediabetes, be overweight, have low

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physical activity levels, be older than 45 years of age, or be African American, Hispanic/Latino American, American Indian, or Alaska Native (CDC, 2021). However, there is also a substantial risk of T2D onset attributable to neighborhood or contextual-level factors, including access to care and transportation, neighborhood socioeconomic status, physical activity and leisure environment, food environment, and environmental pollution (Bowe et al., 2020; Cunningham et al., 2018; Hill-Briggs et al., 2021; Kolak & Talen, 2019; Siegel & Albright, 2021). Given the large and growing population at risk for T2D across the US, adequate T2D prevention efforts cannot ignore the many neighborhood, environmental, and contextual factors that are associated with T2D and may be more salient in some regions and community types than others (Myers et al., 2017). Longitudinal studies may also consider potential urbanicity and regional differences to understand T2D risk and prevention.

The sociodemographic and geographic burdens of T2D are uneven throughout the US (Barker et al., 2011) and are closely linked at the neighborhood level (Hill-Briggs et al., 2021). While many researchers have focused on addressing the role of these risk factors in T2D in the context of urban areas due to neighborhood deprivation, crime and lack of healthful neighborhood resources such as healthy food outlets and walkable environments (Boslaugh et al., 2004; Dendup et al., 2019; Lê-Scherban et al., 2019), it has been reported that adults living in rural areas had a higher crude prevalence of T2D than those in urban areas (O'Connor & Wellenius, 2012). Compared to urban areas in the US, rural areas have also experienced the least amount of improvement in the prevalence of risk factors for T2D such as high blood pressure and cholesterol levels and experience higher rates of obesity, another primary risk factor for T2D (EA et al., 2018; Mercado et al., 2021). Further, while T2D mortality appears to be declining in most metropolitan areas in the Northeast and Midwest over time, rates of T2D mortality remained mostly unchanged in rural communities, particularly in the rural South (Callaghan et al., 2020). However, several of these studies are ecological and/or cross sectional in nature and focus on diabetes-related comorbidities and outcomes instead of T2D incidence; few epidemiologic studies have explicitly evaluated the role community type (e.g., strata along the continuum from urban to rural) plays in identifying geographic risk factors for new onset T2D across the US, which could be useful for targeting interventions and prevention efforts (O'Connor & Wellenius, 2012; Zang et al., 2021). For instance, using various definitions of community types, a case-control study in Pennsylvania showed that patients living in city census tracts in urban clusters and urbanized areas had greater odds of new onset T2D than those living in rural areas or townships (Schwartz et al., 2021). A longitudinal study of 36,224 middle to older age adults in the US also found that, over a mean follow-up of 5 years, diabetes incidence was higher among individuals living in urban areas (Dendup et al., 2019). These findings suggest that community type could influence T2D risk, with higher incidence of T2D in urban vs. rural areas; studies that explicitly evaluate T2D risk by community type and geographic region of the US can help identify location-specific risk factors for T2D and target areas for T2D prevention interventions.

The goal of this work was to evaluate the longitudinal associations between community type and T2D in three different study samples: VADR (Veterans Administration Diabetes Risk) cohort, Geisinger health system, and the REGARDS (REasons for Geographic and Racial Differences in Stroke) cohort. Each of these samples covered distinct geographies and represented different regions and subpopulations of the US, with the VADR sample covering all regions of the contiguous US. As a first step in understanding the geographic and regional factors associated with new onset T2D, we evaluated how community type (i.e., higher density urban, lower density urban, suburban/small town, and rural), measured at the census tract level, is associated with new onset T2D, independent of individual-level risk factors and possible T2D-relevant domains within census tracts. In this specific study, we evaluated the extent to which individual-level risk factors (e.g., age, sex, race/ethnicity) moderated the associations between community types and T2D onset. Because the VADR cohort spans across the US, we also evaluated whether region moderates the associations between community type and T2D in this population. We hypothesized that the risk of T2D onset would differ by community type with higher T2D incidence in urban community types, although we suspected that there would be some regional differences in these associations across the country.

2. Materials and methods

2.1. Study samples and designs

We used data from the Location, Environmental Attributes and Disparities (LEAD) Network, which is a collaborative research network among the Centers for Disease Control and Prevention (CDC), Drexel University, New York University (NYU), University of Alabama at Birmingham (UAB) and Geisinger/Johns Hopkins University (Geisinger/JHU). Descriptions of each of the study samples have been described in detail elsewhere (Hirsch et al., 2020); each of the three study samples used includes only participants who were free of T2D at baseline. Briefly, the VADR cohort from the NYU study site utilized VA electronic health record (EHR) data with a retrospective cohort design (2008–2016) (Avramovic et al., 2020). We also included EHR data from Geisinger, a health system in Pennsylvania, examined through a case-control design (2008–2016) nested in the open, dynamic cohort that Geisinger patients represent (Schwartz et al., 2021). Lastly, the third study population comes from the REGARDS study, a prospective community-based cohort study (Howard et al., 2005). This study's participants were at least 45 years of age at enrollment and resided in all regions of the US but not all states, and were heavily concentrated in the Southeastern US, in a geographic area commonly referred to as the "Stroke Belt" due to its high incidence of stroke and stroke mortality (Howard & Howard, 2020). This region is also referred to as the "Diabetes Belt" for its higher incidence of diagnosed diabetes (Barker et al., 2011). Unlike the VADR and Geisinger study populations, the REGARDS study did not use EHR data; instead, this study relied on data from a cohort specifically enrolled and followed for research purposes, using a longitudinal cohort design for a study period of 2003–2016.

2.2. Definition of community type and region

We used the LEAD network classification of community type, which characterizes census tracts in the contiguous US (n = 72,359) as: higher density urban (n = 17,143, 24%), lower density urban (n = 25,715, 36%), suburban/small town (n = 11,783, 16%), or rural (n = 17,723, 24%). This measure is a land-area modification of the United States Department of Agriculture (USDA) Rural Urban Commuting Area (RUCA) Codes; the method for the development of this modified definition of community type measure is described in detail elsewhere (McAlexander et al., 2022). Briefly, RUCA codes include 10 different categories at the census tract level, defined largely by the proportion of population within a census tract that commutes to a US Census-defined Urbanized Area (UA) or Urban Cluster (UC) (US Census Bureau, 2010). Rather than the population's commuting activity, the LEAD Network classified census tracts into four community types based on the proportion of land area within each tract contained within a UA or UC. This LEAD community type specification yielded greater differentiation of community types within large metropolitan areas into higher density urban tracts and lower density urban tracts and was more representative of the land area within a census tract as opposed to the commuting patterns of the majority of those living within the census tract (McAlexander et al., 2022). We used the US Census definition of geographic region, which classifies states in the contiguous US into four distinct regions: West, Midwest, Northeast, and South.

2.3. Outcome assessment

Across all study samples, participants had to be free of T2D (as defined below) prior to the start of the study to be eligible for inclusion. Given the nature of the data available to each study (i.e., EHR vs. longitudinal cohort) identification of new onset T2D differed slightly by study population. Outcome assessment for each of the study populations was done using the following criteria:

- VADR cohort: at least 2 inpatient or outpatient encounters with diabetes diagnosis International Classification of Diseases (ICD)-9/10 codes; or any prescription of diabetes medication (excluding metformin or acarbose alone); or one encounter with diabetes ICD-9/10 code and at least 2 elevated hemoglobin A1C (HbA1c) laboratory results (≥6.5%).
- Geisinger: among patients with at least two primary care encounters with the Geisinger system an EHR algorithm identified patients with T2D based on diagnoses, prescription of diabetes medication (excluding metformin or acarbose alone), or glucose (≥126 mg/dL fasting, ≥200 mg/dL random) and HbA1c (≥6.5%) laboratory results.
- REGARDS: either a fasting glucose of ≥126 mg/dL or a non-fasting glucose of ≥200 mg/dL, or the use of oral diabetes medications or insulin.

2.4. Statistical methods

The primary goal of the analysis was to evaluate how the likelihood of new onset T2D differed across study populations by LEAD community type. To evaluate this association, each site utilized mixed models to account for the nesting of persons within census tracts when appropriate, as was the case for the VADR and Geisinger samples. For the VADR sample, analyses relied on piecewise exponential (PWE) survival models, assuming a constant hazard function within intervals over time and using generalized linear mixed effects regression models (GLMER) with a Poisson link function and an offset of the logarithm of time-at-risk during each interval to estimate hazard ratios of new onset T2D. For the Geisinger sample, analysis relied on generalized estimating equations (GEE) with a logit link owing to the case-control design. For the REGARDS cohort, analyses employed GEE using a logit link function, exchangeable correlation matrix and robust standard errors to estimate the odds of new onset T2D at follow-up. Because census tracts represented in this cohort typically have few individuals per tract and GEE allows the covariance within a tract to be treated as a nuisance parameter, this approach allowed estimation of the mean parameters in an unbiased fashion. Hence, odds ratios were estimated for the Geisinger and REGARDS populations.

Each study site built their models in parallel evaluating associations between LEAD community type and T2D onset, adjusting for covariates determined *a priori*: race/ethnicity, gender, age, and an individual-level income indicator, whose measurement differed slightly by study site. In the VADR sample, this variable was a binary indicator of either disability or low-income status (Y/N) that served as a proxy for individual socioeconomic status. In the Geisinger sample, this variable was a binary indicator of ever having received Medical Assistance for health insurance, a needs-based program based on family socioeconomic status; in the REGARDS sample, income was a categorical variable of self-reported annual household income in the following categories: less than $20,000, $20,000 - $34,000, $35,000 - $74,000, and $75,000 and higher. For descriptive purposes, we collapsed these categories into annual incomes of < $35,000 and ≥ $35,000. Models run in the VADR sample also included adjustment for a quadratic age variable to account for a nonlinear association between age and diabetes. After evaluating a base model with adjustment for these covariates, we also adjusted for the census tract-level variable for the proportion of the population living below the federal poverty level, quartiled across all census tracts in the contiguous US.

In addition to the base model, we also evaluated effect modifiers identified *a priori*. Each site assessed, separately, cross products of the four-category LEAD community type variable with race/ethnicity, sex, and age. If any of these cross-product terms were globally significant ($p < 0.05$), analyses were then stratified by the effect modifier and all results were compared across the three study samples. Lastly, because the VADR sample encompassed the study areas representing both the Geisinger and the REGARDS samples, we replicated our primary analysis of LEAD community type and new onset T2D in the same census tracts as represented by Geisinger and REGARDS but using the national data from the Veterans specific VADR sample.

3. Results

The REGARDS study participants were comparatively older than the Geisinger and the VADR participants due to differences in the original study inclusion criteria (Table 1). The mean age of participants was relatively similar by T2D status in the REGARDS, Geisinger, and VADR samples. While REGARDS and Geisinger had considerable proportions of both males and females, as expected most of the veterans in the VADR cohort (91.7% and 95.1% among those who did not and those who did develop T2D, respectively) were male. The three samples differed by racial composition: Geisinger was almost exclusively a non-Hispanic White population (>95% in both T2D status groups), REGARDS consisted of non-Hispanic Black and non-Hispanic White individuals only, while the VADR cohort was more racially and ethnically diverse (Table 1). Those who developed T2D in each of the samples had a 30%–80% higher proportion of non-Hispanic Black participants compared to those who did not develop T2D (REGARDS 46.3% vs. 30.8%; Geisinger 1.8% vs. 1.1%; VADR 20.0% vs. 15.4%, Table 1).

The individual-level income indicator varied across the study samples as well. Almost a third of the REGARDS study sample had an annual household income <$35,000 among those who did not develop T2D, with 41% of those who did develop T2D reporting annual income in this category (Table 1). The VADR cohort had more than a third (37.5% and 40.2% among those who did not develop T2D and those who did develop T2D, respectively) who were considered low income for insurance purposes, whereas only 11.3% and 18.6% (among those without and with T2D, respectively) of the Geisinger population used Medical Assistance for health insurance at least some of the time. The differences in proportions of participants considered low income may be due to differences in the definitions of individual-level income indicators across sites. However, in all three samples, there was a slightly higher proportion of lower-income individuals among those who developed T2D versus those who did not.

The distribution of the study samples across community types differed for the three cohorts as well (Table 1), with the Geisinger sample having greater representation in rural areas (≥50% rural, 31% in suburban/small town among both T2D groups, and 10.9% and 11.9% in lower density urban and 5.2% and 6.5% in higher density urban among those without and those with T2D, respectively), the VADR sample being more equally distributed across the four community types (29.1% and 29.3% in rural, 22.6% and 21.4% in suburban/small town, 36.8% and 36.6% in lower density urban, and 11.5% and 12.7% in higher density urban among those without and those with T2D, respectively), and REGARDS participants living in rural and urban areas (24.1% and 20.5% in rural, 20.0% and 19.3% in suburban/small town, 40.1% and 42.6% in lower density urban and 15.9% and 17.7% in higher density urban among those without and those with T2D, respectively) (Table 1).

Compared to the rural participants, Geisinger participants in higher density urban tracts (OR = 1.22; 95% CI = 1.09–1.36) and lower density urban tracts (OR = 1.12; 95% CI = 1.04–1.20) had higher odds of T2D, but those in suburban/small town tracts had statistically similar odds (OR = 1.04; 95% CI = 0.98–1.10) in models adjusting for age, race/ethnicity, sex, and individual-level income indicator (Table S1 and

Table 1
Baseline characteristics of each study sample, by diabetes status.

Diabetes status	Study sample					
	REGARDS (UAB)[a]		Geisinger/JHU [b]		VADR (NYU)[c]	
	No Diabetes	Diabetes	No Diabetes	Diabetes	No Diabetes	Diabetes
	n = 9799	**n = 1409**	**n = 79,435**	**n = 15,888**	**n = 3,561,281**	**n = 539,369**
Variable						
Age at enrollment (mean, SD)	63.2 (8.6)	62.2 (7.8)	54.85 (15.3)	54.88 (15.1)	58.9 (17.8)	62.5 (12.3)
Sex						
Male, n (%)	4356 (44.4)	679 (48.9)	40,447 (50.9)	8090 (50.9)	3,266,635 (91.7)	512,920 (95.1)
Female, n (%)	5463 (55.6)	710 (51.1)	38,988 (49.1)	7798 (49.1)	294,574 (8.3)	26,439 (4.9)
Race/ethnicity[d]						
White, non-Hispanic, n (%)	6777 (69.2)	757 (53.7)	76,971 (96.9)	15,112 (95.1)	2,424,107 (76.9)	359,649 (72.6))
White, Hispanic, n (%)			896 (1.1)	317 (2.0)		
Black, non-Hispanic, n (%)	3022 (30.8)	652 (46.3)	905 (1.1)	293 (1.8)	485,642 (15.4)	99,013 (20.0)
Black, Hispanic, n (%)			78 (0.1)	25 (0.2)		
Other, non-Hispanic, n (%)			465 (0.6)	114 (0.7)	48,508 (1.5)	8296 (1.7)
Other, Hispanic, n (%)			120 (0.2)	27 (0.2)		
Hispanic, n (%)					164,941 (5.2)	24,236 (4.9)
Asian, non-Hispanic, n (%)					30,365 (1.0)	4473 (0.9)
Individual SES[d]						
No receipt of Medical Assistance, n (%)			70,444 (88.7)	12,934 (81.4)		
Annual household income, n (%)						
< $35,000	3076 (31.4)	577 (41.0)				
≥ $35,000	5658 (57.7)	698 (49.5)				
Refused	1065 (10.9)	134 (9.5)				
NYU income variable/indicator, n (%)						
Disabled					1,211,517 (34.6)	192,341 (36.0)
Low income					1,312,331 (37.5)	214,927 (40.2)
None of the above					973,825 (27.8)	127,074 (23.8)
Smoking status[d]						
Current, n (%)	1029 (10.5)	216 (15.3)	14,831 (18.7)	3272 (20.6)	534,290 (40.2)	76,216 (41.2)
Former, n (%)	3846 (39.3)	568 (40.3)	22,773 (28.7)	5260 (33.1)		
Never, n (%)	4893 (49.9)	619 (43.9)	40,469 (51.0)	6963 (43.8)		
Unknown, n (%)	31 (0.3)	6 (0.4)	1362 (1.7)	393 (2.5)		
Former OR never, n (%)					793,900 (59.8)	109,001 (58.9)
Community type						
Higher density urban, n (%)	1561 (15.9)	246 (17.7)	4121 (5.2)	1039 (6.5)	410,382 (11.5)	68,286 (12.7)
Lower density urban, n (%)	3936 (40.1)	591 (42.6)	8665 (10.9)	1890 (11.9)	1,311,459 (36.8)	197,583 (36.6)
Suburban/small town, n (%)	1956 (20.0)	268 (19.3)	24,886 (31.3)	5009 (31.5)	803,678 (22.6)	115,603 (21.4)
Rural, n (%)	2366 (24.1)	284 (20.5)	41,763 (52.6)	7950 (50.0)	1,035,762 (29.1)	157,897 (29.3)
Quartiles of percent of population living below poverty line						
Q1, n (%)	1891 (19.3)	171 (12.1)	16,051 (20.2)	2736 (17.2)	847,391 (23.8)	116,647 (21.6)
Q2, n (%)	2016 (20.6)	246 (17.5)	25,140 (31.7)	4834 (30.4)	972,494 (27.3)	141,056 (26.2)
Q3, n (%)	2350 (24.0)	346 (24.6)	22,829 (28.7)	4764 (30.0)	971,879 (27.3)	150,687 (27.9)
Q4, n (%)	3541 (36.1)	645 (45.8)	15,415 (19.4)	3553 (22.4)	766,512 (21.5)	130,552 (24.2)
Missing, n (%)	1 (0.01)	1 (0.07)	0 (0)	1 (0.01)	3005 (0.1)	427 (0.1)

[a] UAB: University of Alabama at Birmingham.
[b] JHU: Johns Hopkins University. Characteristics reported at each event for diabetes onset or for control selection.
[c] VADR: Veterans Affairs Diabetes Risk; NYU: New York University.
[d] Reported differently at each site.

Fig. 1, Model 1). Results for Geisinger participants were largely unchanged with the additional adjustment of quartiles of census tract level of percent of the population living below the federal poverty level (Table S1 and Fig. 1, Model 2). In contrast, in the REGARDS study, participants in higher density urban community types had lower odds of T2D (OR = 0.79; 95% CI = 0.66–0.96) compared to those in rural areas, while those in lower density urban (OR = 0.99; 95% CI = 0.85–1.15) and in suburban/small town (OR = 1.08; 95% CI = 0.91–1.28) community types had similar odds. Similar to Geisinger, additional adjustment for the percent of the population with income below the federal poverty level within the census tract only weakly attenuated the associations in the REGARDS population (Table S1 and Fig. 1, Model 2). In the VADR cohort, the association between community type and T2D was much weaker. In the model adjusting for sex, age, race/ethnicity, and individual-level income indicator, those in higher density urban tracts had approximately 3% higher risk of T2D than those in rural tracts, while in the fully adjusted model the risk was 1% lower in lower density urban and suburban/small town tracts than in rural tracts, and the risk among those in higher density urban tracts was not statistically different from rural tracts (Table S1 and Fig. 1).

In models testing for effect modification, the association between new onset T2D with community type did not significantly vary by age, race/ethnicity, sex, or individual-level income indicator in the REGARDS or Geisinger population (all interaction term p values > 0.05 for global tests of significance, model results not shown). Conversely, all the interaction terms in the VADR sample were statistically significant, however, the effect size estimates were not meaningfully different across the strata (all HRs <1.08, Tables S2–S4).

In the VADR sample, the association between T2D and community type varied significantly across the geographic regions in the US (interaction p-value <0.0001, Table 2). In the Southern US, T2D risk was 3–5% higher among those residing in rural tracts than urban areas and suburban/small towns. On the contrary, in the Northeast and West regions results were more variable; risks were generally 3–10% higher in urban areas (both lower and higher density) compared to rural areas using models adjusting for age, quadratic age, sex, race/ethnicity, and individual income, but results were generally non-significant for suburban/small town areas and for models adding quartiles of census tract

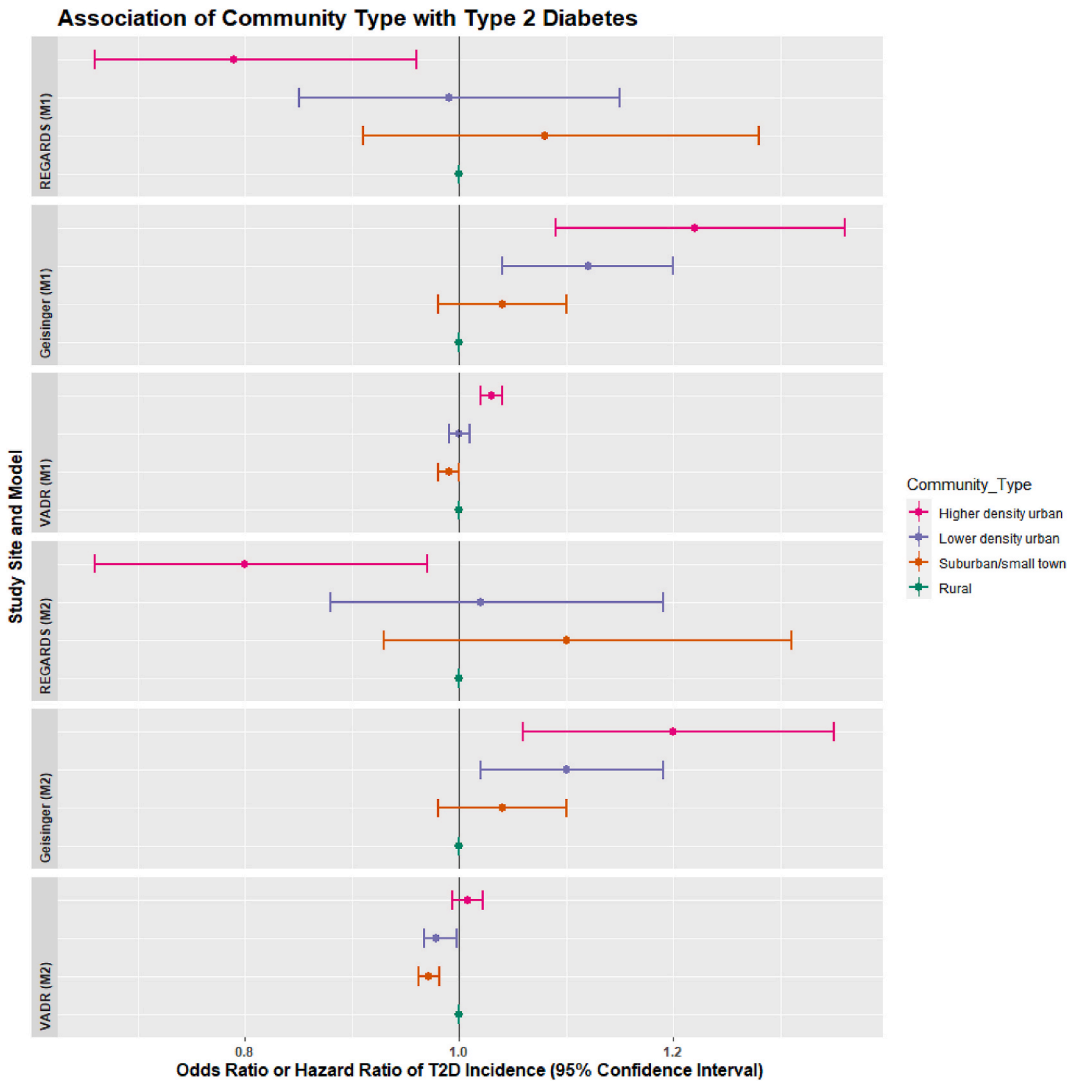

Fig. 1. Adjusted associations of community type with type 2 diabetes onset, by study site
Model 1: Adjusted for female sex, age (including quadratic age in VADR sample), race/ethnicity, and individual-level income flag
Model 2: Model 1 and adjustment for quartile of census tract level percent poverty.

level percent poverty. Results for the Midwest region did not significantly differ by community type after adjusting for quartiles of census tract level percent poverty. Sensitivity analyses using only the VADR sample data and restricting to census tracts that represented the REGARDS and Geisinger populations revealed inferentially similar associations as the primary analyses for each sample (Fig. 2), suggesting that the disparate results in the REGARDS and Geisinger samples (Fig. 1) could be attributed to regional rather than sample differences.

4. Discussion

This study compared associations of a census tract-level measure of community type with new onset T2D in three study samples representing differing geographies in the US. We found that higher density urban community types were associated with the highest likelihood of new onset T2D in the Geisinger sample in Pennsylvania, whereas higher density urban community types were associated with the lowest likelihood of new onset T2D in the REGARDS sample, drawn primarily from the Southern US; and there was no clear pattern of associations between community type and new onset T2D in the national VADR sample. When LEAD community type was evaluated without stratification by US census region, results across the three samples reflected different associations between community type and T2D. However, when viewing our results within the regional contexts of the US, results in the three study samples were supportive of each other. In the South, rural community type was associated with the highest likelihood of new onset T2D, 3%–5% greater than other community types in this region. Although longitudinal studies showing greater T2D risk in the rural South are lacking, our findings are consistent with a recent cross-sectional study suggesting rural communities in the South of the US have elevated risk for diabetes mortality (Barker et al., 2011; Callaghan et al., 2020). Similarly, the rural South has been highlighted as a region of high risk for adverse cardiovascular outcomes (Harrington et al., 2020). Our findings in the Geisinger population, in Pennsylvania, are also consistent with previous findings of greater T2D risk in cities compared to more rural townships (Schwartz et al., 2021). While we have not been able to identify any other longitudinal studies of T2D onset by region and community type in the US, our findings are consistent with the findings of a longitudinal study showing that rural communities in the US South have been experiencing increases in hypertension-related mortality over time compared to both rural and urban communities in other census regions (Nambiar et al., 2020).

While the three samples in the Diabetes LEAD Network have different population characteristics and respective geographic coverage,

Table 2
Region-stratified hazard ratios of type 2 diabetes onset in Veterans Affairs Diabetes Risk (VADR) sample by community type.

Community types	Total			Northeast			South			Midwest			West		
	HR	Lower 95% CI	Upper 95% CI	HR	Lower 95% CI	Upper 95% CI	HR	Lower 95% CI	Upper 95% CI	HR	Lower 95% CI	Upper 95% CI	HR	Lower 95% CI	Upper 95% CI
Model 1															
Higher density urban	1.029	1.015	1.043	1.068	1.033	1.103	0.958	0.935	0.981	1.040	1.010	1.071	1.096	1.064	1.129
Lower density urban	0.999	0.989	1.010	1.026	0.998	1.054	0.971	0.956	0.986	1.037	1.015	1.060	1.042	1.016	1.069
Suburban/ small town	0.990	0.980	0.999	0.990	0.965	1.015	0.970	0.957	0.984	1.028	1.009	1.048	1.014	0.988	1.040
Rural (ref)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Model 2															
Higher density urban	1.008	0.994	1.022	1.034	0.999	1.069	0.948	0.926	0.972	0.997	0.967	1.027	1.088	1.057	1.121
Lower density urban	0.978	0.967	0.988	0.998	0.970	1.026	0.957	0.942	0.972	0.994	0.971	1.017	1.025	0.999	1.052
Suburban/ small town	0.971	0.962	0.981	0.975	0.950	1.000	0.962	0.949	0.976	1.000	0.980	1.020	1.008	0.982	1.034
Rural (ref)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Model 1: Adjusted for age, quadratic age, sex, race/ethnicity, and income disability flag. P-value for interaction term <0.0001.
Model 2: Adjusted for age, quadratic age, sex, race/ethnicity, income disability flag, and quartile of census tract level percent poverty. P-value for interaction term <0.0001.

a major strength of the Diabetes LEAD Network and this study is that the VADR cohort, while consisting of a unique patient population of mostly male veterans, had geographic coverage that overlapped the geographic extent of both the REGARDS and Geisinger samples. This allowed us to evaluate the same community measures in the same geographies with different study populations and a harmonized analytic approach. Consistency of associations across these three samples gives us confidence in our findings and underscores the importance of assessing regional differences in community type when analyzing the risk of developing T2D.

A challenge to interpreting these results is the inability to completely disentangle the association between individual-level sociodemographic factors and census tract-level measures of neighborhood socioeconomic status. However, the primary findings of this study illustrate that additional adjustment for the census tract level measure of percent of the population living below the federal poverty level did not drastically change results, except possibly for those in the VADR sample. Although the changes in the magnitude of the associations in the VADR sample were small after adjustment for quartile of census tract-level poverty, the association for those in higher density urban areas was no longer statistically significant. This finding could be reflective of the noted regional differences in the association between community type and T2D and limited availability of individual-level socioeconomic indicators for additional analyses; it could also be indicative of the very small effect size for these model results in the overall VADR sample, in which the point estimate only changed from 3% to 1% with the additional adjustment of quartile of census tract level percent poverty. Since it is difficult to modify neighborhood socioeconomic status, future studies should evaluate the impact of modifying community resources (e.g., healthy food access, green spaces, and physical activity venues) within the contexts of community type and region of the US, and their potential for reducing T2D risk.

A major strength of this study is the intentional design of the Diabetes LEAD Network, which harmonized analytic approaches across three large population-based samples. In each of these different study samples, new onset T2D was evaluated in samples of individuals without T2D at baseline as a function of a census tract-level measure of LEAD community type: higher density urban, lower density urban, suburban/ small town, and rural. Unlike previous urban/rural designations used in epidemiologic studies (Euler et al., 2019; Yaghjyan et al., 2019; Weeks et al., 2004), the LEAD community type measure used in this analysis was designed to reduce methodological and inferential challenges in place-based research such as non-overlapping distributions of place-based variables and differential item functioning of measures by community types. In contrast to RUCA designations, the LEAD community type measure was defined by the land area of the census tract as opposed to commuting patterns of individuals within census tracts. Using this measure that is more reflective of the land area within a census tract, we found higher likelihood of T2D in more urban areas of the US, except in the South, where likelihood of T2D was higher in rural areas. Potential reasons for this disparity warrant further investigation and may include disparities in obesity, hypertension, access to health care and health care delivery, and the availability and accessibility of healthful resources such as healthy food and opportunities for physical activity (Auchincloss et al., 2009; Nambiar et al., 2020).

5. Conclusion

Our findings suggest that there are regional and community type-specific risks for the development of T2D independent of individual-level risks for T2D; the effect size of regional and community type-specific risk estimates are smaller than for individual risks for the development of T2D. Future studies may consider examining these risk factors so that interventions for the prevention of T2D can be targeted to different regional and community contexts in the US. While our study was able to demonstrate that regional and community type differences in T2D onset exist in the US, we did not identify specific intervention targets for the prevention of T2D. However, our findings provide valuable context for anyone undertaking T2D prevention and intervention work, such that a “one size fits all” approach (i.e., treating all community types and region in the same manner) is likely not sufficient for all regions and community types of the US, and particular efforts can be focused on the rural South of the US and in higher density urban environments of the Northeast and West. While community type specific risk estimates for T2D proved to be small in magnitude in this study, interventions targeting geographic areas and community types with relatively higher T2D risk could have a substantial population impact on the prevention of T2D.

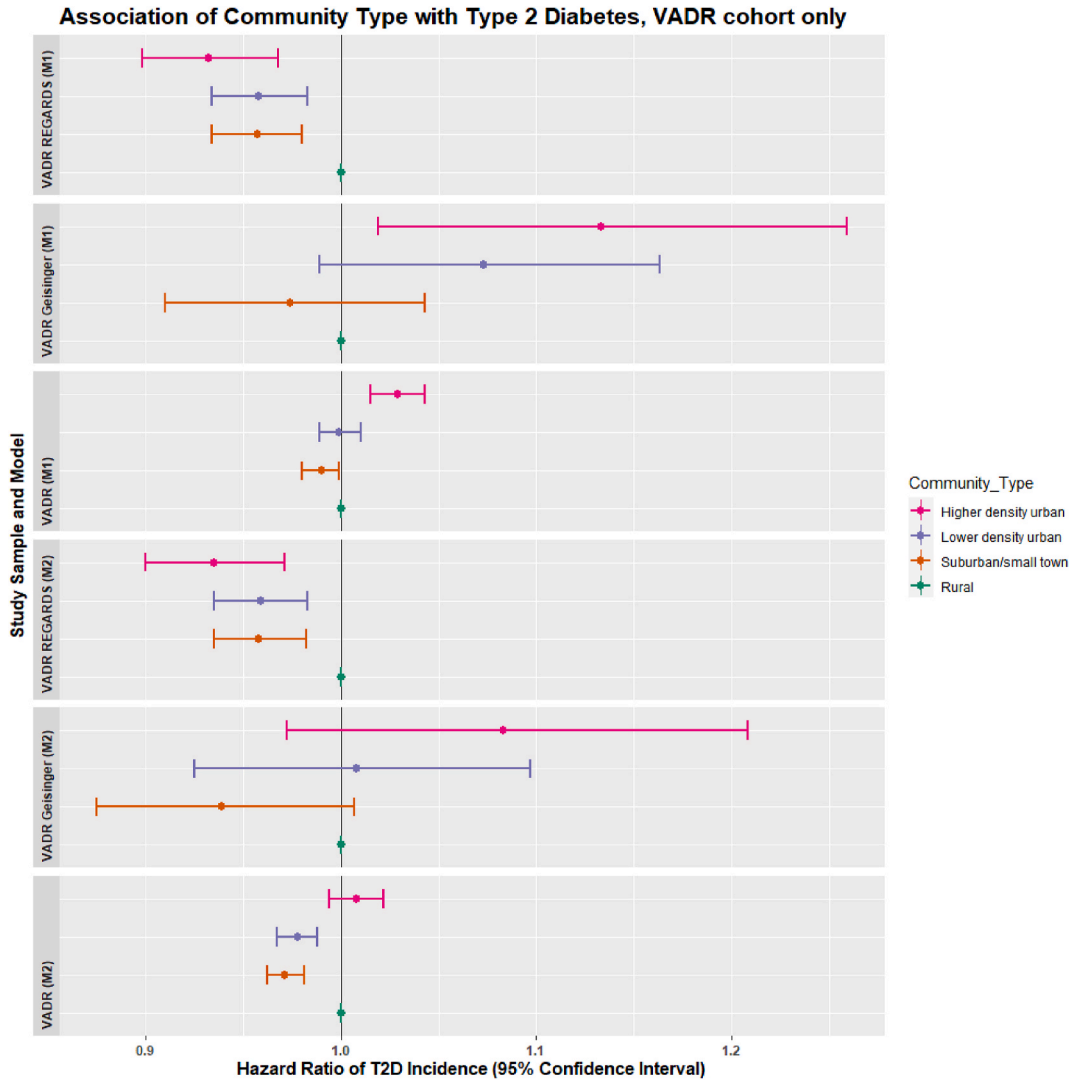

Fig. 2. Sensitivity analysis of adjusted associations of community type with type 2 diabetes onset in the VADR sample, including only census tracts represented by each study population
Model 1: Adjusted for female sex, age, quadratic age, race/ethnicity, and individual-level income flag
Model 2: Model 1 and adjustment for quartile of census tract level percent poverty.

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Author contributions

Tara P. McAlexander: Conceptualization, Writing – original draft, review & editing, Project administration, Data curation, Formal analysis; Gargya Malla: Writing – original draft, review & editing; Jalal Uddin: Writing – original draft, review & editing; David C. Lee: Writing – original draft, review & editing, Funding acquisition; Brian S. Schwartz: Conceptualization, Writing – review & editing, Funding acquisition, Supervision; Deborah B. Rolka: Writing – review & editing, Karen R. Siegel: Writing – review & editing; Rania Kanchi: Data curation, Formal analysis, Writing – review & editing; Jonathan Pollak: Data curation, Formal analysis; Linda Andes: Writing – review & editing, April P. Carson: Supervision, Funding acquisition, Writing – review & editing; Lorna E. Thorpe: Methodology, Supervision, Formal analysis, Funding acquisition, Writing – review & editing; Leslie A. McClure: Methodology, Supervision, Funding acquisition, Writing – review & editing.

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Authors have none to disclose.

Ethical statement

Human subjects research was approved by the Institutional Review Boards of the University of Alabama at Birmingham (#300000957), Geisinger (#2017–0534), and New York University (#01667). Analytic work at the Drexel University Coordinating Center was deemed not human subjects research by the Drexel University IRB (#1707005552).

Declaration of competing interest

Authors have none to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2022.101161.

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