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Neighborhood Characteristics, Food Deserts, Rurality, and Type 2 Diabetes in Youth: Findings from A Case-Control Study

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Abstract

Little is known about the influence of neighborhood characteristics on risk of type 2 diabetes (T2D) among youth. We used data from the SEARCH for Diabetes in Youth Case-Control Study to evaluate the association of neighborhood characteristics, including food desert status of the census tract, with T2D in youth. We found a larger proportion of T2D cases in tracts with lower population density, larger minority population, and lower levels of education, household income, housing value, and proportion of the population in a managerial position. However, most associations of T2D with neighborhood socioeconomic characteristics were attributable to differences in individual characteristics. Notably, in multivariate logistic regression models, T2D was associated with living in the least densely populated study areas, and this finding requires further exploration.

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Keywords

type 2 diabetes; neighborhood characteristics; food deserts; socioeconomic status; youth

Introduction

Social determinants of health are receiving increasing attention, as health systems are trying new approaches to preventive care.[1,2] The World Health Organization defines social determinants of health as "the conditions in which people are born, grow, work, and age," [3] emphasizing the educational, economic, social, health-care, and neighborhood contexts in which people live.[4] Similar to obesity and cardiovascular disease, type 2 diabetes mellitus (T2D) in adults is a chronic disease that is well known to be associated with poverty, deprivation, and lower socioeconomic status (SES).[5–10]

It was not until the last two decades that T2D began to emerge among youth (<18 years old), and there is now evidence that the incidence and prevalence of T2D have in fact been increasing in youth populations: a 4.8% annual rise in incidence was reported between 2002 and 2012 by the SEARCH for Diabetes in Youth study,[11] which conducts surveillance in five study centers in the United States (US), with marked increases seen particularly among youth of minority race/ethnicity.[11–14] The SEARCH study reported a prevalence of T2D of 0.46 per 1,000 youth age 10–19 in 2009, a 35% relative increase compared to 2001.[12] In combination with the documented higher levels of health complications among youth with T2D,[15–20] these alarming trend statistics emphasize a need to investigate the risk factors associated with T2D, including consideration of root causes such as social determinants of health.

The focus of research on risk factors for T2D in youth to date has been on individual-level attributes that are thought to influence the nutritional and obesity-related risk factors for T2D.[21–24] A recent case-control study of T2D in youth age 10–17 years based on secondary data conducted in Manitoba, Canada, reported that gestational and pre-gestational diabetes in mothers were both associated with increased T2D risk among youth.[25] This study and others also found that breastfeeding of infants was associated with markedly decreased risk.[21,22] In addition, maternal obesity during pregnancy has also been shown to be associated with increased risk of T2D.[22]

However, very little conclusive evidence exists for factors that could be considered social determinants of risk for T2D in youth. One of the above-mentioned studies showed that low maternal income was associated with increased T2D risk among youth.[25] An analysis of the Chicago Childhood Diabetes Registry from 1994 to 2003 and census-based data on household income on neighborhoods from 1970 to 2000 found that neighborhoods with mostly African-American residents and persistently high poverty levels over time exhibited an increased risk of non–type 1 diabetes in youth compared to neighborhoods that were classified as having stable income diversity (defined as having a socioeconomically diverse population over 30 years).[7] In a multicenter study of young adults, neighborhood socioeconomic disadvantage was associated with higher insulin resistance syndrome scores.[8]

There is a substantial literature describing rural-urban disparities in T2D in adults, with higher prevalence of diabetes in rural than in urban areas.[26–30] However, very little is known about the association of rurality with T2D in youth. One study of children age 2 to 11 years reported a significantly higher prevalence of overweight and obesity in rural compared to urban children that was not explained by socioeconomic status or by dietary or physical activity behaviors, [31] and these findings have been confirmed in other US-based studies.[32] It is not clear what obesity-related behaviors may underlie these associations, as rural children seem to consume more calories per day yet also participate in more exercise.[31] A case control study in Manitoba, Canada, reported equivalent and high proportions of T2D cases and controls residing in rural areas (71% for both groups) and thus did not provide evidence for rurality as a risk factor for T2D.[25]

The concept of a "food desert" has emerged recently, defined by the USDA as "a low-income census tract where either a substantial number or share of residents has low access to a supermarket or large grocery store."[33,34] Residents of food deserts have been shown to travel significantly farther to their grocery store.[35] One mechanism that may explain the reported association of food deserts with obesity[36] is that farther travel may be associated with lower shopping frequency, which has in turn been linked to lower fruit and vegetable intake.[37] Therefore, it is conceivable that residing in a food desert, similar to other low-SES areas, may be a risk factor for the development of T2D in youth.

Thus, the aim of our study was to evaluate the association of multiple neighborhood SES characteristics, considered separately and jointly,[38] rurality, and residing in a USDA-designated food desert, with T2D in ethnically and geographically diverse youth using data from a case-control study of T2D. [21,22,38]

Materials and methods

Study procedures were reviewed and approved by the institutional review boards of the participating institutions, including compliance with the Health Insurance Portability and Accountability Act (HIPAA).

SEARCH for Diabetes in Youth Study

The SEARCH for Diabetes in Youth Study was a six-center (Ohio, Colorado, Washington, South Carolina, Hawaii, and California) observational study that began conducting population-based ascertainment of non-gestational cases of diagnosed diabetes in youth <20 years of age in 2001 (prevalent cases) and 2002 (incident cases) and is ongoing. Details of the SEARCH Study design have been published.[39,40] All eligible cases of diabetes were identified based on networks of pediatric and adult endocrinologists, existing pediatric diabetes databases, hospitals, databases of health plans, and other health-care providers. Case reports were validated through physician reports, medical record reviews, or, in a few instances, self-report of a physician's diagnosis of diabetes.[39] Diabetes type, as assigned by the health-care provider, was categorized as type 1 (T1D) (combining types 1, 1a, and 1b), T2D, and other (including hybrid, maturity onset of diabetes in youth, type designated as "other," type unknown by the reporting source, and missing). The present analysis focuses on cases of T2D.

Case reports were registered anonymously with the Coordinating Center at Wake Forest University in North Carolina using HIPAA-compliant procedures. Identifying information was retained at each field site.

SEARCH Case-Control Study

The SEARCH Case-Control (SEARCH-CC) Study was an ancillary study to SEARCH, conducted at two (Colorado and South Carolina) of the six clinical sites.[21,22,38] Between July 2003 and March 2006, 119 T2D cases ≥10 years of age attended in-person study visits. For the purposes of the SEARCH-CC Study, eligibility of cases was restricted to (i) four counties surrounding the city of Columbia, South Carolina (Richland, Lexington, Orangeburg, and Calhoun) for prevalent cases in 2001 and statewide for incident cases in subsequent years and (ii) selected counties in Colorado (seven counties encompassing the Denver metropolitan area: Adams, Arapahoe, Boulder, Denver, Douglas, Jefferson, and Weld) for prevalent cases in 2001 and incident cases statewide in subsequent years. Control participants were concurrently recruited from primary care offices following the rationale that all SEARCH cases arose from health-care provider offices. Participating primary care offices provided an initial study brochure, and patients and their parents/guardians were asked to complete a one-page information form and an indication of permission for study staff to contact them. Of 1,203 information forms returned by participating practices, 881 (73.2%) patients indicated interest in learning about the study. Of these, 41 were ineligible, 233 later refused explicitly, 389 could not be successfully contacted (passive refusals), and 218 participated as controls in SEARCH-CC. All controls were confirmed as not having diabetes by fasting glucose values obtained during the clinic visit. More extensive details of the SEARCH-CC Study methods have been published.[21]

Individual-level socioeconomic and clinical characteristics of cases and controls

Variables such as age at clinic visit, race/ethnicity, gender, parental education, and household income were obtained for T2D cases as part of SEARCH and for non-diabetic controls as part of SEARCH-CC. Race/ethnicity was categorized as non-Hispanic white versus African American or Hispanic; the latter two groups were combined because there were only five Hispanic T2D cases and four Hispanic control participants. Parental education (parent with the highest education) was categorized as less than high school and high school education or above. Income was categorized as <$25,000, $25,000–74,999, and ≥$75,000. Data collection unique to SEARCH-CC included a perinatal questionnaire completed by the biological mother, which assessed breastfeeding status (i.e., whether the participant was breastfed as a baby) and maternal diabetes. These variables were categorized as yes or no.

Geocoding and geospatial allocation

The geospatial linkage of participants' addresses was conducted in the context of the Spatial Epidemiology of Diabetes project, which was ancillary to SEARCH.[38,41] Addresses of study participants were geocoded at each study site in a standardized manner by a single staff person (JDH). Geocoding was conducted in ArcGIS 9.3 software[42] using the TIGER 2000 Road Network File complemented with ZIP Code Tabulation Areas (ZCTA) data. In South Carolina, this was supplemented with TIGER 2006 vintage Road Network Files to capture realigned street features that were not captured by the TIGER 2000 file.

First, an attempt was made to geocode to the street address level. The addresses that did not match (10.2%) were then allocated to a census tract within the boundaries of the known ZIP Code based on a random assignment imputation method.[43] This method was chosen because the traditional ZIP Code centroid imputation method[44] would have created spurious clusters in those census tracts containing the ZIP Code centroid.

Neighborhood-level characteristics

To determine neighborhood characteristics, basic demographic and socioeconomic descriptions of census tracts were obtained from the US Census 2000 Summary File 1 (SF1) and Summary File 3 (SF3)[45,46], as these were the closest in time to the data collection period (2003–2006). These descriptions were linked to each participant's census tract. Data included population density, median household income, median value of housing, percent minority population, percent population ≥25 years of age with a high school education and above, percent of households receiving social security, and percent of the population ≥16 years of age in managerial positions. We defined neighborhood characteristics by categorizing these census tract attributes as follows: rurality was defined by population density <500 vs. 500–999 vs. 1,000+ residents per square mile; minority population <15% vs. 15–29% vs. 30%+; high school education and above <80% vs. 80–89% vs. 90%+; median household income <$35,000 vs. $35,000-$49,000 vs. $50,000+; median value of housing <$75,000 vs. $75,000-$124,999 vs. $125,000-$174,999 vs. $175,000+; households receiving social security <20% vs. 20–29% vs. 30%+; managerial position <25% vs. 25–39% vs. 40%+.

We also created an area-level composite score of neighborhood socioeconomic status, a neighborhood socioeconomic advantage score, utilizing census tract-level information from the 2000 US census and previously developed methodology. [38,47] First we applied factor analyses to a large set of census tract socioeconomic indicators and identified a primary factor on which four key variables loaded, as described previously. [38] These included (1) percent of households with income derived from interest, dividend and rental sources, (2) median value of housing of owner-occupied housing units, (3) percent of population with college education or more, and (4) percent of population in managerial positions. Subsequently, the neighborhood socioeconomic advantage score was created by summing the Z-scores of the aforementioned four variables, with increasing values representing increasing advantage.

We applied Rural-Urban Commuting Areas (RUCAs) to characterize the census tracts with respect to their rural and urban status. [48] RUCAs are based on the US Census Bureau's definitions of urbanized areas and urban clusters, in conjunction with information on work commuting patterns. The ten-tiered RUCA codes were converted into a four-tiered system as recommended by using only the primary and secondary RUCA codes [49], thereby differentiating urban core from suburban areas, large rural towns, and small towns/isolated rural areas. For statistical modeling, the small and large town categories were combined because of sparse data.

We defined food deserts by obtaining the USDA Economic Research Service food desert measure for each census tract.[33,34] According to this measure, a food desert is an area that is both low income and has low access to a large grocery store/supermarket. A census tract is classified as low income if it meets the US Treasury Department's New Market Tax Credit program eligibility criteria, i.e., a poverty rate of at least 20%, a median family income less than 80% of the statewide median family income for tracts in non-metropolitan areas, or a median family income less than 80% of the metropolitan area median family income for tracts in metropolitan areas.[33,34] A census tract is classified as low access if at least 500 residents or 33% of the tract population resides more than 1 mile from a supermarket in an urban tract or more than 10 miles from a supermarket in a rural tract, based on Euclidean distance.[33]

Statistical analyses

The case-control study included 91 youth with T2D and 202 non-diabetic control youth aged 10–19 years from South Carolina and Colorado. Because no primary care providers were selected as control recruitment sites in upstate South Carolina (Abbeville, Anderson, Cherokee, Greenville, Greenwood, Laurens, Oconee, Pickens, Spartanburg, Union, and York counties) and outside the Denver metropolitan area, we also excluded cases originating in these areas (~10% of total cases, n=33). Furthermore, we excluded cases and controls that could only be allocated to a county level (~2% of total cases and controls, n=6).

We conducted descriptive analyses to determine the frequency distributions or means and standard deviations of various individual- and neighborhood-level characteristics by case status. Generalized linear mixed models (GLIMMIX) in SAS Version 9.4 were used to fit logistic regression models for a dichotomous response (case, control) assuming a binomial distribution and a logit link function and including a random intercept. Logistic regression models were conducted separately for each neighborhood characteristic. In addition to the unadjusted models, two levels of adjustment for potential individual-level confounders were selected, the first including age, gender, race/ethnicity, and study site, and the second adjusting additionally for breastfeeding, mother's diabetes, and parental education and income.

Results

We observed significant differences between T2D cases and non-diabetic controls with respect to individual characteristics, as well as maternal factors (all $p<0.05$; Table 1). Compared to non-diabetic controls, the majority of T2D cases were African-American/ Hispanic (74.7% vs. 44.1%), female (75.8% vs. 60.4%), had parents with lower than high school education (50.5% vs. 26.7%) and a household income of less than $25,000 (42.9% vs. 23.3%). Similarly, compared to controls, a higher proportion of T2D cases were not breast fed (61.5% vs. 32.2%), and a higher proportion of cases were exposed to maternal diabetes in utero (27.6% vs. 5.5%).

Focusing on neighborhood characteristics, T2D cases tended to reside in census tracts with lower population density, small town environments, a larger minority population, lower educational attainment, lower household income, lower housing value, and a lower proportion of the population in a managerial position compared to non-diabetic controls (all p<0.05, Table 1). T2D cases also more frequently resided in food desert census tracts, but this relationship was not statistically significant (p=0.57, Table 1).

Table 2 presents the results of the logistic regression analyses of the association of neighborhood characteristics with T2D. The first column, showing the unadjusted results from separate models, each focusing on one neighborhood characteristic, mirrors the descriptive findings, indicating that T2D cases were about 2.2–4.5 times more likely to live in a census tract characterized as having low population density (<500 residents per square mile), small or large town, a high minority population (30% or more), low household income (<$35,000), low housing value (<$75,000), low percent of population with at least high school education (<80%), and low percent of households receiving social security (<20%) or in managerial positions (<25%). A higher neighborhood socioeconomic advantage score was associated with decreased odds of T2D. Residing in a food desert was not associated with T2D.

Adjustment for individual-level non-modifiable factors such as age, gender, race/ethnicity, and study site (adjustment 1) markedly attenuated the associations of neighborhood characteristics with odds of T2D, including the neighborhood socioeconomic advantage score, except for the association with population density and urbanicity defined by RUCA. The association of food desert residence with odds of T2D changed direction but remained non-significant after adjustment. Further adjustment for maternal diabetes status, breastfeeding, parental education and income (adjustment 2) did not materially change the results. Living in the least densely populated areas (<500 residents per square mile) was associated with significantly higher odds of T2D (OR 3.2, 95% CI 1.4–7.4) compared to living in the most populated areas (≥1,000 people per square mile). This was consistent with the findings based on RUCA, which demonstrated that living in a small or large town environment was associated with significantly higher odds of T2D compared to living in an urban core environment (OR 3.0; 95% CI 1.3–7.4).

Conclusions

Our study suggests that the initially observed unadjusted associations of T2D with a variety of neighborhood-level SES-related contextual factors, including food desert status of the census tract of residence, are heavily influenced by individual-level characteristics (e.g. age, gender, race/ethnicity, study site), few of which are modifiable. This is evident because compared to the unadjusted estimates the adjusted neighborhood characteristic estimates were strongly attenuated and were non-significant, with the exception of population density and RUCA code. The attenuation is likely due to the fact that race/ethnicity and SES are intimately intertwined in the United States.[50] Research has shown that race and ethnicity are often highly correlated with a person's SES,[51] which is in turn associated with selection of residential neighborhood; hence, the adjustment for individual race/ethnicity could in part capture the effect of neighborhood socioeconomic characteristics with respect to T2D development.

Most of the previous studies relating neighborhood characteristics with insulin resistance or diabetes have been ecological or cross-sectional in nature, [5–9] with a majority being focused on adult populations.[5,6,8,9] These studies have shown higher T2D risks in low-SES neighborhoods characterized by deprivation and poverty. [5,6] A recent study conducted in an ecological surveillance framework also showed that youth aged 10–17 years residing in neighborhoods with a predominantly African-American population and high levels of poverty had a 47% higher risk of T2D.[7] However, ecologic studies suffer from the inability to adjust for personal-level attributes.

Few studies on neighborhood characteristics and T2D or related outcomes have had the capacity to control for early life and maternal health–related individual-level risk factors, as was done in our study. A study of young adults which reported that insulin resistance syndrome score was associated with lower neighborhood SES, controlled for personal income and education and reported findings stratified by sex and race/ethnicity.[8] A prospective study among African-American women which reported increased T2D risk in lower-SES neighborhoods adjusted for income and educational status in addition to age, household size, marital status and a number of lifestyle characteristics.[10] To the best of our knowledge, the only other study with information on breastfeeding and maternal diabetes status comparable to our study did not explicitly study neighborhood characteristics beyond the rural designation of the residence.[25]

Our hypothesis that food desert status of the census tract of residence may be associated with odds of T2D was informed by previous research reporting a higher prevalence of obesity in areas designated as food deserts, which is relevant given the key role of obesity in the development of T2D.[36] Moreover, a recent study indicated an increased risk of T2D among residents of neighborhoods with insufficient provision of healthy foods, independent of individual-level risk factors for diabetes.[52] Additionally, residents of food deserts have been shown to have lower levels of serum carotenoids, which are biomarkers for fruit and vegetable intake.[53] In contrast, our study found no evidence for an association between food deserts and odds of T2D in youth. One possible reason for this finding might be the lack of specificity of the USDA’s food desert designation with respect to its defining low access to healthy food, which is based on secondary data only.[34] We have previously shown the significant error inherent in most commercially available secondary data sources on food retail outlets.[54,55] Moreover, the USDA food desert metric does not capture the quality of food available, particularly in rural areas, potentially introducing misclassification that could bias results toward the null.[56,57] Furthermore, the food desert metric uses a different low-access criteria for urban vs. rural areas (1 mile vs. 10 miles) and in this sense inherently adjusts for rural-urban differences.

Our finding that low population density and rurality was a strong predictor of odds of T2D even after adjustments for individual-level characteristics, including parental education and income, is interesting, consistent with a previous national reports on adults,[30] and bears further consideration. In the United States, rural communities have lower access to healthy food[58] and exhibit poorer dietary habits.[27] In addition, rural areas are characterized by fewer nearby destinations that would motivate utilitarian walking, higher single-use land development, and greater numbers of disconnected streets. Studies have shown that higher single-use land development is associated with reduced physical activity,[59] rural areas have less adequate recreational resources for physical activity,[60] and higher land-use mix is associated with decreased mortality.[61] Additionally, more walkable land use has been related to lower BMI, and higher automobile dependency and longer commuting times have been associated with increased odds of obesity. [62,63] Thus, these disparities in the availability of health-promoting built environmental attributes in rural neighborhoods could conceivably contribute to an increased risk of obesity and subsequent T2D. However, contrary to our findings of a strong association of rurality and T2D, a study conducted in Manitoba, Canada, did not find rural residence to be associated with T2D risk, as the proportions of cases and controls from rural areas were equivalent, and no adjustment for rurality was applied in the multivariate models.[25]

Although findings from studies of individual-level risk factors for T2D in youth suggest that prevention of gestational diabetes and obesity and increased initiation of and duration of breastfeeding of the infant may be viable strategies to reduce risk of T2D in youth, [21,22,25] the consequences of our study and other evidence related to neighborhood influences for policy are less clear. Educational attainment and income levels of populations are influenced by a multitude of federal and state policies, but few of these are within the domain of public health. There are significant disparities in the economic and health-related resources between rural and urban areas, some of which may be amenable to higher-level policy interventions. However, research also seems to suggest that the environmental context (e.g., rural vs. urban) needs to be considered when developing programs and policies.[64] For instance, a recent study comparing the association between the built environment and walking behavior in a metropolitan area and a small town (rural area) found evidence for differences of effects between the urban and rural locations: Although there was a positive association between the number of restaurants in the neighborhood and utilitarian walking in the urban sample, there was an inverse association in the small town sample. Moreover, recreational walking in small town settings was associated with perception of slower traffic, whereas that relationship did not hold in a metropolitan area.[64] This suggests that in some instances, different interventions on the same underlying health behavior (e.g., walking) would be advisable in rural compared to urban settings.

There are several strengths and limitations of our study. Our study included youth of diverse race/ethnicity from two different geographic regions and thus allowed us to capture larger neighborhood-level variability to explore the associations of neighborhood socioeconomic characteristics with T2D, but our study was modest in size with respect to the number of T2D cases. We cannot rule out the possibility that access to care and health care utilization habits of cases and controls differed relative to the degree of rurality of their residence (and in turn affected participation in our study), which may have given rise to the association between rurality and T2D. A small amount of misclassification may have been introduced because we geocoded the contact addresses of the study participants, some of which may not have been their residential address. As suggested by Chaix et al., it is possible that neighborhood-related selective study participation could also have biased our results, but this likely had minimal influence, as quantified in a previous study.[65] Lastly, our evaluation of the association of the food environment with T2D was limited to the USDA's food desert definition and did not include information on the quality or healthfulness of the selection of foods provided within stores, as has been done in other studies, nor did it include information on availability of unhealthy food outlets such as fast food retailers.[66,67]

In conclusion, the findings from our study suggest that future studies of neighborhood SES-related characteristics as risk factors for T2D should also incorporate evaluation of processes that may explain the association between rurality and T2D risk. Moreover, considering rural-urban differences in associations between environmental characteristics and very nuanced characterizations of individual lifestyle behaviors will be paramount, as these may point toward relevant context-specific interventions or policies. Our study has additionally shown that neighborhood-level contextual factors that are descriptively associated with T2D, such as food desert status, are likely strongly associated with individual-level risk factors, including race/ethnicity. Disentangling the effects of neighborhood influence from those of personal race/ethnic identity is extremely difficult given the intertwined nature of these characteristics in US populations.[50,51] Last but not least, studies of neighborhood characteristics and T2D in youth will be most informative if paired with detailed individual-level information on pre- and perinatal maternal risk factors and early life exposures of the child, as these factors are also strongly related to social determinants of health and to T2D risk.[21,22,25]

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Reference List

1. Rubin DB, Singh SR, Young GJ. Tax-exempt hospitals and community benefit: new directions in policy and practice. Ann Rev Public Health. 2015;36:545–557. [PubMed: 25785895]
2. Garg A, Jack B, Zuckerman B. Addressing the social determinants of health within the patient-centered medical home: lessons from pediatrics. JAMA. 2013;309:2001–2002. [PubMed: 23619825]
3. WHO. Social determinants of Health. http://www.who.int/social_determinants/en/ 2017 Accessed on 4-26-2017.
4. Office of Disease Prevention and Health Promotion. Social determinants of health. https://www.healthypeople.gov/2020/topics-objectives/topic/social-determinants 2017 Accessed on 4-27-2017.
5. Connolly V, Unwin N, Sherriff P, Bilous R, and Kelly W. Diabetes prevalence and socioeconomic status: a population based study showing increased prevalence of type 2 diabetes mellitus in deprived areas. J Epidemiol & Community Health. 2000; 54[3], 173–177. [PubMed: 10746110]
6. Schlundt DG, Hargreaves MK, McClellan L. Geographic clustering of obesity, diabetes, and hypertension in Nashville, Tennessee. J Ambul Care Manage. 2006;29:125–132. [PubMed: 16552321]
7. Grigsby-Toussaint DS, Lipton R, Chavez N, Handler A, Johnson TP, Kubo J. Neighborhood socioeconomic change and diabetes risk: findings from the Chicago childhood diabetes registry. Diabetes Care. 2010;33:1065–1068. [PubMed: 20150301]
8. Diez-Roux AV, Jacobs DR, Kiefe CI. Neighborhood Characteristics and Components of the Insulin Resistance Syndrome in Young Adults The Coronary Artery Risk Development in Young Adults (CARDIA) Study. Diabetes Care. 2002;25:1976–1982. [PubMed: 12401742]

9. Cubbin C, Sundquist K, Ahlen H, Johansson SE, Winkleby MA, Sundquist J. Neighborhood deprivation and cardiovascular disease risk factors: protective and harmful effects. Scand J Public Health. 2006;34:228–237. [PubMed: 16754580]
10. Krishnan S, Cozier YC, Rosenberg L, Palmer JR. Socioeconomic status and incidence of type 2 diabetes: results from the Black Women’s Health Study. Am J Epidemiol. 2010;171:564–570. [PubMed: 20133518]
11. Mayer-Davis EJ, Lawrence JM, Dabelea D, Divers J, Isom S, Dolan L et al. Incidence Trends of Type 1 and Type 2 Diabetes among Youths, 2002–2012. N Engl J Med. 2017;376:1419–1429. [PubMed: 28402773]
12. Dabelea D, Mayer-Davis EJ, Saydah S, Imperatore G, Linder B, Divers J et al. Prevalence of type 1 and type 2 diabetes among children and adolescents from 2001 to 2009. JAMA. 2014;311:1778–1786. [PubMed: 24794371]
13. Pettitt DJ, Talton J, Dabelea D, Divers J, Imperatore G, Lawrence JM et al. Prevalence of diabetes in U.S. youth in 2009: the SEARCH for diabetes in youth study. Diabetes Care. 2014;37:402–408. [PubMed: 24041677]
14. Liese AD, D’Agostino RB Jr., Hamman RF, Kilgo PD, Lawrence JM, Liu LL et al. The burden of diabetes mellitus among US youth: prevalence estimates from the SEARCH for Diabetes in Youth Study. Pediatrics. 2006;118:1510–1518. [PubMed: 17015542]
15. Maahs DM, Snively BM, Bell RA, Dolan L, Hirsch I, Imperatore G et al. Higher prevalence of elevated albumin excretion in youth with type 2 than type 1 diabetes: the SEARCH for Diabetes in Youth study. Diabetes Care. 2007;30:2593–2598. [PubMed: 17630264]
16. Albers JJ, Marcovina SM, Imperatore G, Snively BM, Stafford J, Fujimoto WY et al. Prevalence and determinants of elevated apolipoprotein B and dense low-density lipoprotein in youths with type 1 and type 2 diabetes. J Clin Endocrinol & Metab. 2008;93:735. [PubMed: 18089692]
17. Petitti DB, Klingensmith GJ, Bell RA, Andrews JS, Dabelea D, Imperatore G et al. Glycemic control in youth with diabetes: the SEARCH for diabetes in Youth Study. J Pediatr. 2009;155:668–672. [PubMed: 19643434]
18. Liu LL, Lawrence JM, Davis C, Liese AD, Pettitt DJ, Pihoker C et al. Prevalence of overweight and obesity in youth with diabetes in USA: the SEARCH for Diabetes in Youth study. Pediatr Diabetes. 2010;11:4–11. [PubMed: 19473302]
19. Wadwa RP, Urbina EM, Anderson AM, Hamman RF, Dolan LM, Rodriguez BL et al. Measures of arterial stiffness in youth with type 1 and type 2 diabetes: the SEARCH for diabetes in youth study. Diabetes Care. 2010;33:881–886. [PubMed: 20067960]
20. Dabelea D, Stafford JM, Mayer-Davis EJ, D’Agostino R, Dolan L, Imperatore G et al. Association of Type 1 Diabetes vs Type 2 Diabetes Diagnosed During Childhood and Adolescence With Complications During Teenage Years and Young Adulthood. JAMA. 2017;317:825–835. [PubMed: 28245334]
21. Mayer-Davis EJ, Dabelea D, Lamichhane AP, D’Agostino RB, Liese AD, Thomas J et al. Breast-Feeding and Type 2 Diabetes in the Youth of Three Ethnic Groups. Diabetes Care. 2008;31:470. [PubMed: 18071004]
22. Dabelea D, Mayer-Davis EJ, Lamichhane AP, D’Agostino RB, Liese AD, Vehik KS et al. Association of intrauterine exposure to maternal diabetes and obesity with type 2 diabetes in youth. Diabetes Care. 2008;31:1422–1426. [PubMed: 18375420]
23. Braun B, Zimmermann MB, Kretchmer N, Spargo RM, Smith RM, Gracey M. Risk factors for diabetes and cardiovascular disease in young Australian aborigines: a 5-year follow-up study. Diabetes Care. 1996;19:472–479. [PubMed: 8732712]
24. Jerrell JM, Tripathi A, Rizvi AA, McIntyre RS. The risk of developing type 2 diabetes mellitus associated with psychotropic drug use in children and adolescents: a retrospective cohort analysis. Prim Care Companion to CNS Disord. 2012;14: pii: PCC.11m01185.
25. Halipchuk J, Temple B, Dart A, Martin D, Sellers EA. Prenatal, Obstetric and Perinatal Factors Associated with the Development of Childhood-Onset Type 2 Diabetes. Can J Diabetes. 2017; In press.
26. Krishna S, Gillespie KN, McBride TM. Diabetes burden and access to preventive care in the rural United States. J Rural Health. 2010;26:3–11. [PubMed: 20105262]

27. Trivedi T, Liu J, Probst J, Merchant A, Jones S, Martin AB. Obesity and obesity-related behaviors among rural and urban adults in the USA. Rural Remote Health. 2015;15:3267. [PubMed: 26458564]
28. Trivedi T, Liu J, Probst JC, Martin AB. The metabolic syndrome: are rural residents at increased risk? J Rural Health. 2013;29:188–197. [PubMed: 23551649]
29. Agency for Healthcare Research and Quality. Health care disparities in rural areas. https://archive.ahrq.gov/research/ruraldisp/ruraldispar.pdf 2017 Accessed on 1-23-2017.
30. O'Connor A, Wellenius G. Rural-urban disparities in the prevalence of diabetes and coronary heart disease. Public Health. 2012;126:813–820. [PubMed: 22922043]
31. Liu JH, Jones SJ, Sun H, Probst JC, Merchant AT, Cavicchia P. Diet, physical activity, and sedentary behaviors as risk factors for childhood obesity: an urban and rural comparison. Childhood Obesity. 2012;8:440–448. [PubMed: 23061499]
32. Johnson JA3, Johnson AM. Urban-rural differences in childhood and adolescent obesity in the United States: A systematic review and meta-analysis. Childhood Obesity. 2015;11:233–241. [PubMed: 25928227]
33. United States Department of Agriculture Economic Research Service. Food Access Research Atlas. http://www.ers.usda.gov/data-products/food-access-research-atlas.aspx 5-11-2013. Accessed on 9-22-2015.
34. Ver Ploeg M. Access to affordable and nutritious food: measuring and understanding food deserts and their consequences: report to Congress. https://www.ers.usda.gov/webdocs/publications/42711/12716_ap036_1_.pdf?v=41055. 2009 Accessed on 11-9-2017.
35. Sohi I, Bell BA, Liu JH, Battersby SE, Liese AD. Differences in Food Environment Perceptions and Spatial Attributes of Food Shopping Between Residents of Low and High Food Access Areas. J Nutr Educ Behav. 2014;46:241–249. [PubMed: 24560861]
36. Chen D, Jaenicke EC, Volpe RJ. Food environments and obesity: household diet expenditure versus food deserts. Am J Public Health. 2016;106:881–888. [PubMed: 26985622]
37. Liese AD, Bell BA, Barnes TL, Colabianchi N, Hibbert JD, Blake CE et al. Environmental influences on fruit and vegetable intake: results from a path analytic model. Public Health Nutr. 2014;17:2595–2604. [PubMed: 24192274]
38. Liese AD, Puett RC, Lamichhane AP, Nichols MD, Dabelea D, Lawson AB et al. Neighborhood level risk factors for type 1 diabetes in youth: the SEARCH case-control study. Int J Health Geogr. 2012;11:1. [PubMed: 22230476]
39. SEARCH Study Group. SEARCH for Diabetes in Youth: a multicenter study of the prevalence, incidence and classification of diabetes mellitus in youth. Control Clin Trials. 2004;25:458–471. [PubMed: 15465616]
40. Hamman RF, Bell RA, Dabelea D, D'Agostino RB, Dolan L, Imperatore G et al. The SEARCH for Diabetes in Youth study: rationale, findings, and future directions. Diabetes Care. 2014;37:3336–3344. [PubMed: 25414389]
41. Liese AD, Lawson A, Song HR, Hibbert JD, Porter DE, Nichols M et al. Evaluating geographic variation in type 1 and type 2 diabetes mellitus incidence in youth in four US regions. Health Place. 2010;16:547–556. [PubMed: 20129809]
42. ArcGIS 9.3 Redlands, CA: Environmental Systems Research Institute (ESRI); 2008.
43. Hibbert JD, Liese AD, Lawson A, Porter DE, Puett RC, Standiford D et al. Evaluating geographic imputation approaches for zip code level data: an application to a study of pediatric diabetes. Int J Health Geogr. 2009;8:54. [PubMed: 19814809]
44. Cayo MR, Talbot TO. Positional error in automated geocoding of residential addresses. Int J Health Geogr. 2003;21:10. [PubMed: 14687425]
45. Bureau of the Census, US Department of Commerce. Census 2000 Summary File 1 (SF1). 2001 Washington, Bureau of the Census.
46. Bureau of the Census, US Department of Commerce. Census 2000 Summary File 3 (SF3). 2001 Washington, Bureau of the Census.
47. Diez-Roux AV, Kiefe CI, Jacobs DR Jr., Haan M, Jackson SA, Nieto FJ et al. Area characteristics and individual-level socioeconomic position indicators in three population-based epidemiologic studies. Ann Epidemiol. 2001;11:395–405. [PubMed: 11454499]

48. United States Department of Agriculture. Rural-Urban Commuting Area Codes. https://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes.aspx 10–12-2016 Accessed on 1-4-2018.
49. Hailu Asnake and Wasserman Cathy. Guidelines for using Rural-Urban classification systems for community health assessment. https://www.doh.wa.gov/Portals/1/Documents/1500/RUCAGuide.pdf 10–27-2016 Accessed on 1-4-2018.
50. American Psychological Association. Ethnic and racial minorities and socioeconomic status. http://www.apa.org/pi/ses/resources/publications/factsheet-erm.aspx. 2011 Accessed on 12-1-2012.
51. House JS, Williams DR. Understanding and reducing socioeconomic and racial/ethnic disparities in health. Promoting Health: Intervention Strategies from Social and Behavioral Research. 2000;81–124.
52. Christine PJ, Auchincloss AH, Bertoni AG, Carnethon MR, S+ínchez BN, Moore K et al. Longitudinal associations between neighborhood physical and social environments and incident type 2 diabetes mellitus: the Multi-Ethnic Study of Atherosclerosis (MESA). JAMA Intern Med. 2015;175:1311–1320. [PubMed: 26121402]
53. Suarez JJ, Isakova T, Anderson CA, Boulware LE, Wolf M, Scialla JJ. Food access, chronic kidney disease, and hypertension in the US. Am J Prev Med. 2015;49:912–920. [PubMed: 26590940]
54. Liese AD, Colabianchi N, Lamichhane AP, Barnes TL, Hibbert JD, Porter DE et al. Validation of 3 food outlet databases: completeness and geospatial accuracy in rural and urban food environments. Am J Epidemiol. 2010;172:1324–1333. [PubMed: 20961970]
55. Liese AD, Barnes TL, Lamichhane AP, Hibbert JD, Colabianchi N, Lawson AB. Characterizing the food retail environment: Impact of count, type and geospatial error in two secondary data sources. J Nutr Educ Behav. 2013;45:435–442. [PubMed: 23582231]
56. Oberle C, Block JP. Identifying rural food deserts: Methodological considerations for food environment interventions. Can J Public Health. 2016;107:ES21.
57. Lebel A, Tremblay L, Oberle C, Girard-Gadreau M, Duguay M, Block J. Identifying rural food deserts: Methodological considerations for food environment interventions. Can J Public Health. 2016;107:5353. [PubMed: 27281523]
58. Morton LW, Blanchard TC. Starved for access: life in rural America's food deserts. Rural Realities. 2007;1:1–10.
59. Frank LD, Sallis JF, Conway TL, Chapman JE, Saelens BE, Bachman W. Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. J Am Plann Assoc. 2006;72:75–87.
60. Findholt NE, Michael YL, Davis MM, Brogoitti VW. Environmental influences on children's physical activity and diets in rural Oregon: Results of a youth photovoice project. Online J Rural Nurs Health Care. 2010;10:11. [PubMed: 26346290]
61. Wu YT, Prina AM, Jones A, Barnes LE, Matthews FE, Brayne C et al. Land use mix and five-year mortality in later life: Results from the Cognitive Function and Ageing Study. Health Place. 2016;38:54–60. [PubMed: 26798962]
62. Brown BB, Yamada I, Smith KR, Zick CD, Kowaleski-Jones L, Fan JX. Mixed land use and walkability: Variations in land use measures and relationships with BMI, overweight, and obesity. Health Place. 2009;15:1130–1141. [PubMed: 19632875]
63. Zhang X, Holt JB, Lu H, Onufrak S, Yang J, French SP et al. Neighborhood commuting environment and obesity in the United States: An urban-rural stratified multilevel analysis. Preventive Med. 2014;59:31–36.
64. Stewart OT, Vernez Moudon A, Saelens BE, Lee C, Kang B, Doescher MP. Comparing associations between the built environment and walking in rural small towns and a large metropolitan area. Environ Behav. 2016;48:13–36.
65. Chaix B, Billaudeau N, Thomas F, Havard S, Evans D, Kestens Y et al. Neighborhood effects on health: correcting bias from neighborhood effects on participation. Epidemiology. 2011;22:18–26. [PubMed: 21150351]
66. Lear SA, Gasevic D, Schuurman N. Association of supermarket characteristics with the body mass index of their shoppers. Nutr J. 2013;12:117. [PubMed: 23941309]

67. Zenk SN, Schulz AJ, Hollis-Neely T, Campbell RT, Holmes N, Watkins G et al. Fruit and vegetable intake in African Americans: income and store characteristics. Am J Prev Med. 2005;29:1–9. [PubMed: 15958245]

Highlights:

- Social determinants may contribute to cardiovascular disease, obesity and diabetes
- The association of neighborhood characteristics with T2D in youth was evaluated
- T2D was associated with living in the least densely populated study areas
- Most T2D-neighborhood associations are attributable to individual-level differences
- The elevated risk of T2D in less densely populated areas requires exploration

Table 1.

Individual- and neighborhood-level characteristics of cases of type 2 diabetes and controls in the SEARCH Case-Control Study

Characteristics	All (n=293)	T2D (n=91)	Control (n=202)	P-value
Individual-level characteristics				
Race/ethnicity, %				
Non-Hispanic white	46.4	25.3	55.9	
African American/Hispanic	53.6	74.7	44.1	<0.0001
Gender, %				
Female	65.2	75.8	60.4	
Male	34.8	24.2	39.6	0.0103
Parental education, %				
Lower than high school	34.1	50.5	26.7	
High school and above	65.9	49.5	73.3	<0.0001
Household income, %				
< $25,000	29.3	42.9	23.3	
$25,000-$74,999	49.5	49.4	49.5	
>$75,000	21.2	7.7	27.2	<0.0001
Breast feeding status, %				
Yes	58.7	38.5	67.8	
No	41.3	61.5	32.2	<0.0001
Maternal diabetes status, %				
Yes	12.2	27.6	5.5	
No	87.8	72.4	94.5	<0.0001
Age at visit	15.1 (2.9)	16.3 (2.8)	14.6 (2.9)	<0.0001
Neighborhood-level characteristics				
Population density (per sq. mile)	3,084 (2,897)	2381 (2,967)	3,401.1 (2,815)	0.0051
Categorized population density, %				0.0002
<500	78 (26.6)	36 (39.6)	42 (20.8)	
500–999	18 (6.1)	9 (9.9)	9 (4.5)	
1000+	197 (67.2)	46 (50.6)	151 (74.8)	
Urban category, n (%)				<0.0001
Small town	16 (5.5)	13 (14.3)	3 (1.5)	
Large town	28 (9.6)	12 (13.2)	16 (7.9)	
Suburban	24 (8.2)	11 (12.1)	13 (6.4)	
Urban core	225 (76.8)	55 (60.4)	170 (84.2)	
Minority population (%)	40.5 (27.7)	49.2 (25.2)	36.7 (28.0)	0.0003
High school education and above (%)	80.8 (14.0)	76.7 (13.8)	82.6 (16.7)	0.0008
Income from interest and others (%)	32.7 (16.9)	27.4 (14.9)	35.2 (17.3)	0.0001
Median household income ($)	46,000 (19,000)	40,000 (17,000)	48,000 (20,000)	0.0007
Median value of housing ($)	135,000 (79,000)	115,000 (85,000)	144,000 (74,000)	0.0035
Household receiving social security (%)	22.5 (9.2)	23.9 (8.5)	22.0 (9.5)	0.0974

Characteristics	All (n=293)	T2D (n=91)	Control (n=202)	P-value
Managerial position (%)	32.6 (13.9)	29.7 (13.1)	33.9 (14.1)	0.0153
Neighborhood socioeconomic advantage score	−0.1 (0.9)	−0.4 (0.9)	0.03 (0.9)	0.0003
Food desert, %	11.6	13.2	10.9	0.5702

Values are means and standard deviations (SD) unless otherwise indicated

Table 2.

Associations of neighborhood characteristics with the odds of development of type 2 diabetes in the SEARCH Case-Control Study

Neighborhood characteristics	Unadjusted OR (95% CI)	Adjustment 1 OR (95% CI)	Adjustment 2 OR (95% CI)
Population density[a]			
<500	**2.81 (1.62, 4.90)**	**2.24 (1.10, 4.58)**	**3.22 (1.40, 7.41)**
500–999	**3.23 (1.23, 8.76)**	2.28 (0.74, 7.02)	3.36 (0.96, 11.8)
1000+	Ref	Ref	Ref
Urban category			
Small and large towns	**4.07 (2.08, 7.97)**	**2.81 (1.24, 6.36)**	**3.04 (1.25, 7.41)**
Suburban	**2.62 (1.10, 6.19)**	2.17 (0.83, 5.65)	2.25 (0.73, 6.97)
Urban core	Ref	Ref	Ref
Minority population			
<15%	Ref	Ref	Ref
15–29%	1.98 (0.79, 4.95)	1.65 (0.61, 4.46)	1.08 (0.33, 3.50)
30%+	**4.53 (2.17, 9.49)**	2.25 (0.93, 5.45)	1.91 (0.66, 5.49)
High school education and above			
<80%	**2.96 (1.65, 5.34)**	1.41 (0.68, 2.90)	0.96 (0.39, 2.41)
80–89%	1.08 (0.50, 2.30)	0.68 (0.29, 1.60)	0.58 (0.22, 1.56)
90%+	Ref	Ref	Ref
Median household income			
<$35,000	**3.28 (1.77, 6.09)**	1.38 (0.63, 3.00)	1.01 (0.38, 2.68)
$35,000-$49,000	1.22 (0.62, 2.40)	0.63 (0.28, 1.42)	0.41 (0.16, 1.10)
$50,000+	Ref	Ref	Ref
Median value of housing			
<$75,000	**3.30 (1.56, 7.00)**	1.16 (0.35, 3.83)	0.74 (0.18, 3.07)
$75,000-$124,999	**2.83 (1.32, 6.07)**	1.12 (0.39, 3.19)	0.81 (0.23, 2.80)
$125,000-$174,999	0.90 (0.38, 2.11)	0.65 (0.25, 1.65)	0.48 (0.16, 1.47)
$175,000+	Ref	Ref	Ref
Household receiving social security			
<20%	Ref	Ref	Ref
20–29%	1.76 (0.98, 3.14)	1.22 (0.62, 2.41)	0.69 (0.31, 1.52)
30%+	**2.19 (1.13, 4.27)**	1.23 (0.56, 2.71)	0.78 (0.31, 1.96)
Managerial position			
<25%	**2.15 (1.13, 4.09)**	1.02 (0.47,2.20)	0.75 (0.30, 1.90)
25–39%	**2.04 (1.06, 3.94)**	1.36 (0.64,2.88)	1.29 (0.54, 3.07)
40%+	Ref	Ref	Ref
Food desert status			
Yes	1.24 (0.58, 2.64)	0.74 (0.32, 1.68)	0.58 (0.22, 1.50)
No	Ref	Ref	Ref
Income from interest and others (+5%)	**0.97 (0.96, 0.99)**	1.00 (0.97, 1.02)	1.02 (0.89, 1.17)

Neighborhood characteristics	Unadjusted OR (95% CI)	Adjustment 1 OR (95% CI)	Adjustment 2 OR (95% CI)
Neighborhood socioeconomic advantage score	**0.62 (0.47, 0.81)**	0.90 (0.63, 1.29)	1.07 (0.68, 1.67)

[a]Population density is given as residents per square mile.

Unadjusted: neighborhood characteristics alone

Adjustment 1: Age, gender, race/ethnicity, study site

Adjustment 2: Age, gender, race/ethnicity, study site, and breastfeeding, mother's diabetes, parental education, parental income