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Neighborhood Environments and Diabetes Risk and Control

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Abstract

Purpose of Review The objective of this review is to highlight the evidence on the association between contextual characteristics of residential environments and type 2 diabetes, to provide an overview of the methodological challenges and to outline potential topics for future research in this field.

Recent Findings The link between neighborhood socioeconomic status or deprivation and diabetes prevalence, incidence, and control is robust and has been replicated in numerous settings, including in experimental and quasi-experimental studies. The association between characteristics of the built environment that affect physical activity, other aspects of the built environment, and diabetes risk is robust. There is also evidence for an association between food environments and diabetes risk, but some conflicting results have emerged in this area.

Summary While the evidence base on the association of neighborhood socioeconomic status and built and physical environments and diabetes is large and robust, challenges remain related to confounding due to neighborhood selection. Moreover, we also outline five paths forward for future research on the role of neighborhood environments on diabetes.

Keywords Diabetes · Residential environments · Neighborhoods · Social epidemiology

Introduction

Diabetes trends in the last 30 years are worrisome [1–3]. Estimates vary by method and definition of diabetes, but national data from the USA show an increase from a prevalence of diagnosed and undiagnosed diabetes from 5.5% in the period 1998–1994 (9.7 million adults) to 10.8% in the period 2011–2014 (25.5 million adults) [4]. Worldwide, prevalence is around 8 to 9% in adults, and has increased twofold over the last three decades [5].

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There are large disparities in diabetes burden by social factors [6]. In particular, individuals of lower socioeconomic status have higher rates of diabetes and lower rates of diabetes control [7, 8]. Moreover, there are large disparities in diabetes prevalence by country [7], across regions within countries [7, 9], and by neighborhood [6]. Cities and neighborhoods have many opportunities for the prevention of cardiovascular diseases and diabetes [10]. Urban environments are uniquely dense, involving a large number of social interactions and human-made characteristics. Thus, policy changes at this level are important and can affect substantial numbers of people [10].

Historically, and until relatively recently, most epidemiologic studies of diabetes have focused on individual-level factors as predictors of diabetes prevalence, incidence, or control. However there has been growing interest in identifying how various features of the contexts in which individuals live and work affect health [11]. Neighborhoods have emerged as important contexts because they have features that may influence the distribution of individual-level risk factors (like diet or physical activity) or may interact with individual level factors [12]. Given strong residential segregation by race and socioeconomic status, neighborhood factors may also contribute to inequities in disease risk by these factors.

This review focuses on diabetes prevalence, incidence, and control and the influence of two sets of environmental factors: neighborhood socioeconomic status and the built and physical environment. We focus on neighborhood socioeconomic status as a marker of general living conditions in neighborhoods. In particular, neighborhood socioeconomic status is usually measured using markers of the socioeconomic features of the residents in the area, aggregated into deprivation indices. Establishing the link between neighborhood socioeconomic status with health outcomes is important in that such associations can point to areas of increased disease risk, and highlight the social gradient that exists for many health outcomes [12].

The actionability of the findings related to neighborhood socioeconomic status and diabetes outcomes may be lower than for links to specific contextual characteristics that are more amenable to change [12]. For this reason, we also focus on the built and physical environments as potential pathways through which the living conditions proxied by neighborhood socioeconomic status affect diabetes risk. The built environment is defined as the set of human-made physical surroundings of a neighborhood. To better conceptualize the built environment and its association with diabetes risk, we look at characteristics of the built environment that may have an effect on diet (food environment), physical activity (physical activity environment), smoking and drinking (tobacco and alcohol environments), and stress and inflammation (noise, pollution, traffic, and other exposures).

Figure 1 shows the conceptual framework for this review. In summary, a series of built and physical and social environment factors influences the natural history of diabetes. These environmental domains are, in turn, influenced by area-level socioeconomic status. The natural history of diabetes is greatly simplified, summarized as a condition caused by a caloric intake/expenditure imbalance, leading to obesity and subsequent insulin resistance, that leads to diabetes incidence and lack of control, with subsequent complications. In this review, we focus on diabetes risk and lack of control.

The objective of this narrative review is to provide an overview of the evidence base regarding the association between contextual characteristics of urban environments and type 2 diabetes risk and control. This review is structured in four parts. First, we provide a conceptual overview of the overall association between neighborhood socioeconomic status and the diabetes risk and control. Second, we review domains of the built and physical environment associated with these same diabetes outcomes. Third, we summarize methodological challenges in the study of this association. Last, we outline paths forward for future research in this area.

Neighborhood Socioeconomic Status

The link between neighborhood socioeconomic status and diabetes prevalence, incidence, or control is robust. Table 1 summarizes the results of 24 studies across several settings, published since 2010. Most studies used four or more neighborhood socioeconomic status-related indicators (education, income, employment, etc.) to create a composite index. The advantage of doing this is that multiple items will provide a multidimensional and more robust measure of the construct than any single item. Neighborhood deprivation has been associated with increased diabetes prevalence and incidence and worse rates of control. A series of studies using electronic health records (EHR) from half a million people in urban areas of Sweden have looked at the association of neighborhood deprivation, as measured using a principal component analysis of four variables, and diabetes incidence, finding consistently that increased neighborhood deprivation was associated with increased incidence after adjusting for covariates, including individual-level socioeconomic status (SES) [19, 20]. Other studies in the USA, Germany, and Australia have also found increased diabetes prevalence with increased

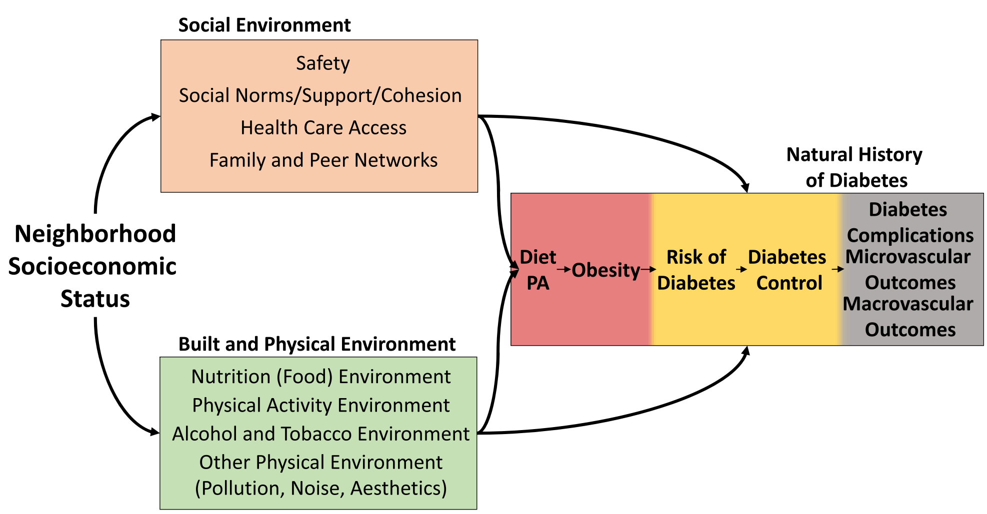

Fig. 1 Conceptual framework

Table 1 Studies looking at the association between neighborhood socioeconomic status and diabetes risk or control (sorted by outcome)

	Outcome	Exposure	Source	*N*	Setting	Year	Ref.
People with diabetes	CHD	PCA (4 variables)	EHR	334 K	Sweden	2012	[13]
	CVD	Income	EHR	600 K	Canada	2012	[14]
	Eye disease	Pampalon Deprivation Index	EHR	2 M	Sweden	2015	[15]
	Foot ulcer	SIMD (7 domains)	EHR	16 K	UK	2013	[16]
	Control	Socio-economic Rank (5 variables)	EHR	75 K	Israel	2010	[17]
	Control	Townsend Index	EHR	24 K	UK	2012	[18]
People free of diabetes at baseline	Incidence	PCA (4 variables)	EHR	512 K	Sweden	2013	[19]
	Incidence	PCA (4 variables)	EHR	512 K	Sweden	2015	[20]
	Incidence	PCA (4 variables)	Experiment	61 K	Sweden	2016	[21]
	Incidence	Unemployment	Cohort	7 K	Germany	2015	[22]
	Prevalence	% below Federal Poverty Line	Survey	4.5 K	USA	2014	[23]
	Prevalence	% below FPL	Experiment	4.5 k	USA	2011	[24]
	Prevalence	6 clusters based on 12 indicators	Cohort	2.2 K	USA	2017	[25]
	Prevalence	IRSD (17 variables)	Survey	11 K	Australia	2016	[26]
	Prevalence	PCA (6 variables)	Cohort	1.8 K	USA	2015	[27]
	Prevalence	Unemployment	Survey	9 K	Germany	2013	[28]
	Prevalence	Unemployment, Income	Survey	1.3 K	Germany	2012	[29]
	Prevalence	Z-score (6 variables)	Cohort	384	USA	2014	[30]

SE Sweden, *DE* Germany, *US* United States, *AU* Australia, *UK* United Kingdom, *IL* Israel, *CA* Canada, *IRSD* Index of Relative Socioeconomic Disadvantage, *SIMD* Scottish Index of Multiple Deprivation, *PCA* principal component analysis. For the sample size (*N*), K are thousands, and M are millions

unemployment and lower income [28, 29], increased poverty concentration [23], and multi-indicator measures of deprivation [26, 27, 30]. Last, other studies have looked at the association of deprivation and rates of control, finding that people with diabetes living in areas with higher deprivation are less likely to achieve diabetes control, as measured by HbA1c levels [17, 18, 30]. Other studies have also found associations between lower neighborhood socioeconomic status (or higher neighborhood deprivation) and complications among persons with diabetes, such as cardiovascular disease [13, 14], diabetes-related eye disease [15], and foot ulcer [16].

This association between neighborhood socioeconomic status and diabetes has also been found in experimental studies. In an analysis of the Moving To Opportunity study, where families were randomized to either receive a housing voucher to move to a low poverty area, a housing voucher to move freely, or no voucher, diabetes prevalence was lower in people who were assigned to the voucher to move to a low poverty area [24]. In an analysis of a natural experiment in Sweden, investigators followed refugees that were relocated to different areas of the country, finding that those that were relocated to areas with higher neighborhood deprivation had a higher incidence of diabetes [21]. Given that refugees had no control over where they were being relocated, this analysis is similar to a randomized experiment (see the "Methodological Challenges" section below).

Built and Physical Environment

Food Environment

The association between healthier food environments and diabetes risk and control has been examined using numerous measures and study designs (Table 2). Food environments have been typically operationalized as favorable for diet/health (e.g., access to healthier foods at farmers markets and supermarkets) or unfavorable for diet/health (access and density of fast food and convenience stores). Favorable or unfavorable has been operationalized either as single items or combined into a composite index. Results in this area have been somewhat mixed. A recent meta-analysis that included studies up to June 2017 concluded that there was weak to null evidence that a greater availability of grocery stores or supermarkets was associated with lower diabetes risk [59].

A few studies published since then reported on change in environment and change in diabetes risk or control have also found mixed results. Two studies looking at change in the presence of supermarkets found lower diabetes prevalence [32] and marginally improved diabetes control [31] in people living in areas where new supermarkets had opened. However, these changes were small in magnitude. Other studies have found no changes in diabetes incidence in

Table 2 Studies looking at the association between built and physical environment characteristics and diabetes risk or control (sorted by exposure)

Exposure	Outcome	Source	N	Setting	Year	Ref.
Supermarket presence (change)	Control	EHR	434 K	USA	2017	[31]
Supermarket presence (change)	Prevalence	Survey	831	USA	2017	[32]
Fast-food venues	Incidence	Survey	7 K	Canada	2016	[33]
Fast-food venues	Prevalence	Cohort	10 K	UK	2015	[34]
Health-harming food outlets (change)	Incidence	EHR	4.7 M	Sweden	2016	[35]
Food stores, PA resources	Incidence	Cohort	3.7 K	USA	2017	[36]
Food stores, PA resources	Incidence	Cohort	5.1 K	USA	2015	[37]
Food Outlets, land use mix, parks	Control	EHR	183 K	USA	2018	[38]
Walkability	Incidence	EHR	2.9 M	Canada	2016	[39]
Walkability	Incidence	EHR	1.2 M	Canada	2013	[40]
Walkability	Incidence	EHR	512 K	Sweden	2015	[41]
Walkability	Prevalence	EHR	78 K	Canada	2017	[42]
Walkability	Prevalence	Survey	5.9 K	Australia	2013	[43]
Walkability, open spaces	Incidence	Cohort	3.2 K	Australia	2014	[44]
Green space	Prevalence	Cohort	267 K	Australia	2014	[45]
Green space	Prevalence	Cohort	10 K	UK	2014	[46]
Green space	Incidence	Cohort	24 K	UK	2016	[47]
Particulate matter	Incidence	Cohort	3.6 K	Germany	2015	[48]
Particulate matter	Diabetes mortality	Census	2.1 M	Canada	2013	[49]
Particulate matter, NO_2, OP	Prevalence	Survey	289 K	Netherlands	2017	[50]
Particulate matter, NO_2	Prevalence	Survey	4 K	USA	2017	[51]
NO_2	Prevalence, incidence	Cohort	61 K	Hong Kong	2018	[52]
NO_2, traffic intensity	Diabetes mortality	Cohort	52 K	Denmark	2013	[53]
Traffic intensity	Prevalence	Survey	3.6 K	Germany	2014	[54]
Noise	Incidence	Cohort	380 K	Canada	2017	[55]
Noise	Incidence	Cohort	57 K	Denmark	2013	[56]
Neighborhood slope	Prevalence, control	Survey	8.9 K	Japan	2017	[57]
Burden of AML	Control	EHR	28 K	USA	2013	[58]

OP oxidative potential of particulate matter, *NO_2* nitrogen dioxide, *AML* coal abandoned mile lands. For the sample size (*N*), K are thousands, and M are millions. All studies using "Control" as the outcome were conducted in people with diabetes

people living in areas with a higher density of healthier food establishments; however, incidence was lower in people living in areas with higher perceived healthy food availability [37].

Studies of the unfavorable food environment and diabetes have been somewhat more promising. Diabetes incidence and prevalence have been found to be higher in people who stay or move into areas with more health-harming food outlets (convenience stores and fast-food outlets) [35], or who live in areas with more fast-food outlets [33, 34]. However, a study conducted in the USA found that diabetes incidence was also higher in adults living both in areas with greater density of unfavorable stores (defined as convenience and fast food outlets) and in areas with higher density of favorable ("healthy") food stores (although confidence intervals included the null) [36].

Physical Activity Environment

Physical activity environments appear to be somewhat more consistently associated with diabetes risk (Table 2) [59]. Walkability has been measured and used in several studies of the built environment and diabetes. Walkability is determined by higher population density, greater mix of land use (commercial, residential, parks), and greater street connectivity. In several studies, walkability of the environment has been associated with lower diabetes prevalence [42] and incidence [39–41]. Recent studies have found that the incidence of diabetes is lower in more walkable areas [39], and that this association was stronger in immigrants and people living in lower neighborhood socioeconomic status areas [40], but this association may be partially explained by individual-level factors [41]. Green and open spaces have also been associated with a lower diabetes prevalence and incidence. Two studies in the UK and two in Australia have found associations between higher availability of green or open spaces and lower diabetes prevalence [45, 46] and incidence [44, 47].

Other Physical Environment Characteristics

Other built environment factors also seem to be associated with diabetes risk (Table 2). Higher exposure to particulate matter, nitrous oxide, and traffic intensity have been associated with higher diabetes prevalence [50–52, 54] and incidence [48, 52], poorer diabetes control [51], and higher diabetes-related mortality [49, 53], though the magnitude of these associations has typically been small. A hypothesized general pathway in these studies is air pollution's effects on inflammation and oxidative stress and subsequent increased insulin resistance [60].

Recent studies have also found an association between diabetes markers and novel built environment measures such as traffic-related noise [55], the burden of abandoned coal mine lands [58], and even the average slope (steepness of the streets in the neighborhood) of neighborhoods [57]. Some of these factors may operate directly (by increasing inflammation, as with air pollution), or through more indirect mechanisms (such as effects on physical activity levels).

Methodological Challenges

The literature studying the link between residential environments and diabetes is subject to similar methodological challenges as other epidemiologic studies of neighborhoods and neighborhood-level exposures. One of the main challenges is the limited ability to address confounding by neighborhood selection. The issue of neighborhood selection arises when individual characteristics determine residential location, through either segregation or individual preferences [11]. If the same characteristics that lead to segregation are also associated with diabetes risk (for example, individual socioeconomic status), the association between residential environments and diabetes may be confounded and be partially or fully explained by other factors. There are two main ways of correcting for this type of bias. One approach is via randomization or pseudo-randomization. These methods have been employed by studies such as the Moving To Opportunity study [24] and natural experiments [21]. The key idea in these settings is that individuals have no control regarding their neighborhood assignment, thus removing the effect of potential confounders that would be related to neighborhood selection. However, randomization may not be able to properly account for exposures occurring before randomization that may carry over to the new neighborhoods [61]. Alternatively, there are standard statistical methods to adjust for or match based on factors leading to neighborhood selection. However, these types of studies can be challenging if important factors are unknown or unmeasured, or if there is no overlap between the residential environments where individuals of, lower and higher SES live [11]. Alternatively, the use of within-person effects (exploiting changes to exposures due to mobility to a new area) can help control for this type of confounding. Some studies have found that a large portion of the association between environmental factors and cardiometabolic factors may be due to neighborhood selection [62, 63]. However, as with randomized experiments of mobility, some exposures may have long-term effects that are not washed out with mobility [61].

Future Research

Here, we outline five potential paths forward in the study of the links between residential environments and diabetes risk: (1) increased attention to the issue of scale, (2) consideration of the consequences of neighborhood dynamics, (3) possible use of neighborhood variables to improve risk prediction or treatment decisions, (4) new research to understand the contributions of neighborhoods to the emergence of health inequalities, and (5) increased leveraging of natural experiments and evaluation of policy interventions.

The Issue of Scale

The first path forward for future research is to gain an understanding of whether neighborhoods are the most appropriate or relevant spatial context for explaining diabetes risk. For example, previous research has shown that dietary patterns may not vary as much between neighborhoods as they do between nations [64]. It is likely that we should consider multiple levels of analysis simultaneously (individual, neighborhood, city, region, or country).

Recommendation Adequate theorization about the construct of interest (e.g., the food system/environment) should guide data collection. If the neighborhood construct of interest has a strong city- or nation-wide component, studies in multiple cities or countries would be warranted. Cross-national comparisons of neighborhood or city characteristics and health are becoming more common and should be encouraged.

Neighborhood Dynamics and Change

A second path forward for future research is to conceptualize and measure neighborhoods as dynamic environments that change over time [65]. A static characterization of neighborhoods, where the exposure is assessed only once, limits inferences on the dynamic links between the environment and diabetes. First, it ignores the changes that may occur from the measurement point to when diabetes occurs, potentially resulting in misclassification of the exposure. Second, studies of neighborhood characteristics measured at a single time point are especially subject to the issue of neighborhood selection: are the observed health patterns because of contextual characteristics or are they just the reflection of differential neighborhood selection patterns?

Further, care must be paid to avoid the assumption that neighborhood mobility is akin to neighborhood change. Many studies of neighborhood change operationalize the change in the exposure as neighborhood mobility. While this is a useful device to be able to study longitudinal changes in the exposure side, it comes with its own challenges derived from (a) who moves and why, in the case of non-randomized studies, and (b) whether neighborhood mobility can be translated into feasible or helpful policy intervention. Some reanalyses of the Moving To Opportunity study have showed how, while the intervention may have been beneficial for diabetes and obesity [24], it may have been harmful for other health outcomes [66]. This may reflect unintended consequences and/or neighborhood stickiness (carry-over effects) [61], as the effects of the study intervention on some outcomes were differential by age (stronger and more positive effects in people that moved earlier in life [67]).

Recommendation Future studies of neighborhood characteristics and diabetes should explicitly measure and evaluate changes in neighborhood characteristics. Longitudinal data sources for neighborhood characteristics should be leveraged to understand the consequences of neighborhood change, not just residential mobility. In the case of residential mobility studies, care must be paid to the issue of stickiness and whether neighborhood exposures before a certain age may have long-term consequences.

Neighborhood-Level Factors to Improve Risk Prediction and Clinical Practice

A third path forward for future research is to evaluate the utility of neighborhood measures in diabetes risk prediction or clinical practice. Recent research has shown that risk prediction models for diabetes underestimate risk for people living in lower neighborhood socioeconomic status areas and overestimated risk for people living in higher neighborhood socioeconomic status areas [68], while adding SES or neighborhood socioeconomic status to risk prediction models did not significantly improve prediction [68]. However, a systematic examination of diabetes control in electronic health records can help identify neighborhoods where community-level interventions for improved diabetes treatment are in need [69], or be used as a systematic tool for surveillance [70]. Moreover, electronic health records can be a powerful tool to improve diabetes control and quality of care [71].

Recommendation Future studies should assess whether diabetes control is improved by incorporating measures of the environment into electronic health records to better guide treatments. An Institute of Medicine report from 2014 [72] recommends collecting neighborhood-level median household income and geocoded residential address, that can then be used to derive measures of the built environment [72]. These measures can then help in identifying access to resources and potential hazards, leading to improved quality of care and subsequent improved diabetes control.

Other techniques, such as asset mapping, allow for patients to develop a systematic exploration of resources available in their community [73]. These techniques, if implemented in health systems, could help patients understand the resources available to improve diabetes prevention and/or control [73].

Contribution of Neighborhoods to Health Inequalities

A fourth path forward for future research is to better understand the interactions between individual characteristics and contextual characteristics, and how neighborhoods contribute to inequalities by individual social factors such as race or SES. Recent research has shown that part of the inequality in cardiovascular disease by SES is explained by differential exposure to lower neighborhood socioeconomic status neighborhoods and increased prevalence of diabetes and hypertension in lower SES individuals [74]. Moreover, research in Canada has shown that the association between walkability and diabetes is stronger in new residents (immigrants) as compared to long-term residents, and that this association was even stronger in recent immigrants living in high poverty areas [40]. A potential mechanism mediating these disparities may be inflammation, that has been found to account for at least a third of the increased risk of diabetes in people of lower SES [75].

Recommendation Future studies should try to decompose the inequalities in diabetes by social factors (including SES and race) and understand the contribution of neighborhood characteristics to the widening of these inequalities. Understanding the contribution of neighborhood characteristics to inequalities in diabetes can also provide policy-actionable results.

Leveraging Natural Experiments and Evaluating Policy

A final potential path forward for future research is for the field to better leverage natural experiments and policy evaluation. As mentioned before in this review, the Moving To Opportunity study evaluated the effects of moving to a lower poverty neighborhood, finding lower HbA1c in people (with and without diabetes) that were randomized to this intervention [24], while refugee relocation in Sweden to wealthier areas reduced the incidence of diabetes [21]. Other natural experiments at higher scales than the neighborhood have found decreased rates of diabetes incidence and mortality after the Special Period of Cuba [76], and increased rates of diabetes in those exposed in-utero to the Ukrainian famine in the 1930s [77] and other famines [78]. While the intensity of neighborhood exposures tends to be of lower magnitude than the upstream political changes described above, some actually represent large-scale relocation events. For example, the relocation of hurricane Katrina survivors to areas with higher sprawl was associated with body weight gain [79].

Recommendation Surveillance and formal evaluation of policy changes [80] and other type of macrosocial exposures [81] can offer opportunities to study the effects of neighborhoods on health. Examples on the impact of policies on the built environment and obesity-related outcomes are available [82], but they should be expanded to diabetes risk and control.

Limitations

This review is narrative in nature, and therefore there exists the possibility that we have missed some relevant studies (see the study by den Braver et al. for a comprehensive review that also includes county-level studies [59]). We could not find any studies of the association between local alcohol and tobacco availability and diabetes risk and control. We also did not review the association between social environment characteristics and diabetes, as these have been recently reviewed [6, 83–85]. It is important to note that distinction between the social and the built environment can be fuzzy, as both influence each other. A good example of a factor that may be simultaneously considered a feature of the built and social environments is foreclosure, a topic that has received recent attention in relation to diabetes [86, 87]. We have also not reviewed neighborhood determinants of obesity, the main risk factor for diabetes, as this literature has been reviewed elsewhere [84, 88, 89].

Conclusion

In this review, we summarized the evidence regarding the overall association between neighborhood socioeconomic status and diabetes risk and control, as well as the specific associations between built environment characteristics and diabetes risk and control. To address the methodological shortcomings of previous studies, future research should also consider looking at more upstream levels of inference, understanding the role of neighborhood change in generating diabetes risk, further explore the potential for the use of neighborhood characteristics in diabetes risk prediction and treatment decisions, examine the contributions of neighborhood factors to health inequalities, and leverage natural experiments and policy evaluation to better understand how neighborhoods contribute to diabetes risk and poor control.

Compliance with Ethical Standards

Conflict of Interest Usama Bilal, Amy H. Auchincloss, and Ana V. Diez-Roux declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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