EPIDEMIOLOGY/HEALTH SERVICES RESEARCH

Associations of Four Community Factors With Longitudinal Change in Hemoglobin A_{1c} Levels in Patients With Type 2 Diabetes

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OBJECTIVE

To evaluate associations of community factors with glycated hemoglobin (HbA_{1c}).

RESEARCH DESIGN AND METHODS

We identified patients with type 2 diabetes who had an HbA_{1c} ≥7.5% (58 mmol/mol) and subsequent HbA_{1c} testing within 90–270 days. We used mixed-effect models to assess whether treatment intensification (TI) and community domains (community socioeconomic deprivation [CSD], food availability, fitness assets, and utilitarian physical activity favorability [quartiled]) were associated with HbA_{1c} change over 6 and 24 months, controlling for demographics, HbA_{1c}, BMI, and time with evidence of type 2 diabetes. We evaluated whether community domains modified associations of TI with HbA_{1c} change using cross product terms.

RESULTS

There were 15,308 patients with 69,818 elevated HbA_{1c} measures. The average reduction in HbA_{1c} over 6 months was 0.07% less in townships with a high level of CSD (third quartile versus the first). Reductions were 0.10% greater for HbA_{1c} in townships with the best food availability (versus worst). HbA_{1c} reductions were 0.17–0.19% greater in census tracts in the second and third quartiles of utilitarian physical activity favorability versus the first. The association of TI with 6-month HbA_{1c} change was weaker in townships and boroughs with the worst CSD (versus best) and in boroughs with the best fitness assets (versus worst). The association of TI with 24-month HbA_{1c} change was weaker in census tracts with the worst CSD (versus third quartile) and strongest in census tracts most favorable for utilitarian physical activity (versus worst).

CONCLUSIONS

Community domains were associated with HbA_{1c} change and blunted TI effectiveness.

Control of glycated hemoglobin (HbA_{1c}) is a primary therapeutic target in type 2 diabetes (1,2). While HbA_{1c} control among persons with diabetes has improved in the U.S. over the past two decades, >40% of persons with type 2 diabetes have HbA_{1c} values >7.0% (53 mmol/mol) (3), the target recommended by treatment guidelines (4). Prior work has examined associations between clinic-, physician-, and patient-level factors and HbA_{1c} control (5). However, very little is known about whether where a person lives is associated with HbA_{1c} control.

Patients with type 2 diabetes are particularly vulnerable to the influence of community-level factors because of the importance of self-management that takes place largely

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outside of the clinical setting. Prior ecological studies have reported that the community poverty rate, unemployment rate, population density, and other characteristics have been found to explain variation in type 2 diabetes prevalence across counties (6,7); however no study, to our knowledge, has examined how these factors impact HbA_{1c} control at the individual level. A recent study reported that supermarket presence in communities was associated with HbA_{1c} trajectories among patients with type 2 diabetes (8). However, to date no one has evaluated how physical activity opportunities and food availability beyond supermarkets (e.g., fast food outlets) impact HbA_{1c} levels over time among individuals with type 2 diabetes.

We conducted a study of >15,000 patients with type 2 diabetes living in 734 communities in Pennsylvania to assess whether the food environment, physical activity environment, or community socioeconomic deprivation (CSD) were associated with HbA_{1c} levels over time. We also examined whether these factors modified associations between medical care and changes in HbA_{1c}. This question is fundamentally important to identifying barriers and facilitators of successful patient outcomes.

RESEARCH DESIGN AND METHODS

We conducted a retrospective cohort study of primary care patients from the Geisinger with type 2 diabetes. We used data from 2001–2015 from the Geisinger electronic health record (EHR) and community measures to evaluate *1*) association of type 2 diabetes treatment intensification (TI) with change in HbA_{1c} levels, *2*) associations of community factors with change in HbA_{1c} levels, and *3*) whether associations of TI with change in HbA_{1c} levels were modified by key community factors. Community features under study included CSD, food availability, fitness and recreational assets, and utilitarian physical activity favorability.

Study Population and Subject Selection

Geisinger is an integrated health system that serves >500,000 primary care patients across Pennsylvania and New Jersey. The primary care population is representative of the general population in the region (8). We classified patients as having type 2 diabetes using a validated EHR-based algorithm (9): at least two clinical encounters associated with a type 2 diabetes diagnosis (ICD-9: 250.00–250.90, with 5th digit either 0 or 2) on two separate dates, a type 2 diabetes medication order *and* at least two elevated laboratory tests (random glucose ≥200 mg/dL, fasting glucose ≥126 mg/dL, or HbA_{1c} ≥6.5% [53 mmol/mol]), a type 2 diabetes encounter diagnosis *and* a type 2 diabetes medication order, or a type 2 diabetes encounter diagnosis *and* an elevated HbA_{1c} value.

Of 249,123 primary care patients between 18 and 75 years of age, 35,260 patients met the criteria for type 2 diabetes. Of these patients, 2,220 were excluded if they had the following evidence of type 1 diabetes including: more than one type 1 diabetes diagnosis (ICD-9: 250.01–250.91, with 5th digit either 1 or 3) associated with a clinical encounter, a type 1 encounter diagnosis after the last recorded type 2 encounter diagnosis, or type 1 and type 2 diagnoses recorded on the same day. We then removed patients with <365 days between first and last encounters in the EHR (*n* = 4,942), patients without outpatient visits (*n* = 23), and patients without an HbA_{1c} value ≥7.5% (58 mmol/mol) (*n* = 10,172). Among the remaining 17,903 patients, there were 125,335 elevated HbA_{1c} values; for these, there was not a follow-up for 22,009 within 90–270 days, insulin was prescribed for an additional 32,356 prior to the HbA_{1c} measure, and 1,152 occurred within 30 days of each other. After removal of these HbA_{1c} measures, the final analytical data set consisted of 15,308 patients with a total of 69,818 HbA_{1c} measures.

Study Variables

HbA_{1c} Outcome

The dependent variable for this analysis was change in HbA_{1c} level over time. We first identified elevated HbA_{1c} levels for patients as values ≥7.5% (58 mmol/mol). We then searched for subsequent HbA_{1c} values measured between 90 and 270 days after the elevated value. We calculated the change in HbA_{1c} as the difference between the elevated measure and the subsequent measure closest to 6 months after baseline (follow-up HbA_{1c} – baseline HbA_{1c} = HbA_{1c} change); a negative value for change in HbA_{1c} indicated an improvement in HbA_{1c} levels. Six-month HbA_{1c} values could also qualify as baseline HbA_{1c} values if they were still elevated.

TI

TI measures monitor how providers respond to information about control of risk factors. For type 2 diabetes, we defined TI as a change in medication regimen in response to an elevated HbA_{1c} level meeting one of the following criteria: *1*) an increase in the number of medication classes ordered, *2*) an increased dose of a medication, or *3*) a switch to a medication in a different therapeutic class (10,11). We excluded HbA_{1c} values from analysis if a patient had an insulin order prior to the date of the elevated HbA_{1c} level, as day-to-day adjustments in insulin cannot be identified in the EHR.

To operationalize the TI measure, we determined baseline medication use by diabetes medication orders prior to the date of the elevated HbA_{1c}. Next, we classified an occurrence of any of the following as TI if the change occurred on or within 30 days after the date of the baseline HbA_{1c}: *1*) initiation of insulin, *2*) addition of a diabetes medication in a subclass not on the patient's baseline list, or *3*) increase of dose (dose/pill × pills/day) of a baseline medication.

Medication dose was only available in a free-text field in the EHR. Natural language processing was applied to identify common dose entries (i.e., entries found in at least 35 medication orders). These common entries were then manually classified as TI or no TI. Entries found for <35 medication orders were classified as "unknown TI" as manual review of the large number of unique free-text entries was not feasible.

Community Measures

Using previously described methods, we geocoded study subjects to their residential address in the EHR (12). Each home address was assigned to 1 of 734 communities using two sets of U.S. census-defined boundaries: minor civil divisions and census tracts. Minor civil divisions include townships, which range from rural to suburban; boroughs, which are generally walkable small- to medium-sized towns; and cities, which are large and heterogeneous geographies. We used a mixed definition in identifying communities, assigning patients to townships, boroughs, and census tracts in cities, as previously reported (8,12).

We conducted a confirmatory factor analysis (CFA) to develop a theory-based, formal model for measuring latent constructs that characterized obesity-related environments. Based on prior literature, we selected an initial pool of >150 candidate indicators (e.g., density, diversity, and accessibility measures) from archival data from the Geisinger service area. We estimated the CFA model using progressive model refinement to achieve an acceptable fit. Once the optimal model was identified, we generated factor scores for each of four constructs: *1*) *CSD* (proportion of population in poverty, unemployed, or on public assistance, with less than a high school education, and not in labor force), *2*) *food availability* (food service establishments per population; convenience stores, including in gasoline service stations, per area; grocery stores per area; snack food stores per area; other food retail stores per area; bars and taverns per population; fast food chain restaurants per area; and diversity of types of food establishments), *3*) *fitness and recreational assets* (indoor fitness clubs per area, indoor/outdoor recreational clubs per area, diversity of recreational and fitness establishments, and count of outdoor public parks), and *4*) *utilitarian physical activity favorability* (households per area, vehicle miles traveled per population, average block size [square miles], and street connectivity [percentage of road intersections that are connected]). Density measures for food and fitness assets were computed as the number of establishments per square mile. Diversity measures were based on 13 categories of food establishments (e.g., fast food chain, bars, taverns) and 9 categories of physical activity establishments (e.g., bowling, golf courses). For each community, the number of categories with one or more facilities was counted.

CSD was derived from U.S. Census data; food and physical activity establishment data were based on InfoUSA and Dun & Bradstreet data; and utilitarian physical activity favorability data were based on data from the Pennsylvania Department of Transportation. While the original CFA used data from these sources from the year 2000, for this study we used 2010 data (most recently available data), *z*-transforming and summing the same indicators to create updated factor scores. Each of the four pairs of 2000 and 2010 factor scores were moderately to highly correlated (Spearman values ranged from 0.6458 to 0.8075).

Statistical Analysis

The goals of the analysis were to identify the main effect of TI on HbA_{1c} change, identify the main effects of community domains on HbA_{1c} change, and evaluate moderation of TI main effect by community domains. First, we created a linear regression model to evaluate the association of TI on change in HbA_{1c}, controlling for baseline HbA_{1c} (continuous, centered, linear, and quadratic); sex; age (continuous, centered, linear, and quadratic); race/ethnicity (non-Hispanic white vs. all others); BMI (continuous); duration of type 2 diabetes in the EHR, defined as the time between the date of first type 2 diabetes diagnosis code, diabetes medication, or elevated HbA_{1c} and the date of the elevated baseline HbA_{1c} (years as continuous, centered, linear, and quadratic); and Medical Assistance (MA) (ever vs. never received) status for health insurance as a surrogate for family socioeconomic status (SES) (13,14). Comorbid diseases (e.g., hypertension, coronary artery disease, and fatty liver disease) were evaluated for confounding and were not retained in the final models. We included a random intercept for person to account for multiple HbA_{1c} change measures per person. Next, we created four mixed-effect linear regression models to evaluate associations of each of the four community domains (in quartiles) with HbA_{1c} change. These models also included a random intercept for person and controlled for the same covariates described above, as well as TI status. Finally, we added a cross product term between TI and each community factor to each model to assess effect modification. For examination of the durability of the associations observed at 6 months, the analysis was repeated for HbA_{1c} change over 24 months.

We stratified all analysis by community type (i.e., township, borough, and city census tract), since distributions of environmental measures differed by geography, leading to regression extrapolation. We did not include a random intercept for community, as the intraclass correlation coefficients for the models were very low (0.005–0.006). All analysis was performed with SAS software, version 9.2, of the SAS Institute.

RESULTS

Description of Study Population

There were 15,308 eligible patients who had at least one elevated HbA_{1c} and a follow-up HbA_{1c} value within the specified time period (Table 1). The mean age of patients was 57.8 years of age, 45.8% of patients were female, and the majority of patients were white. MA was used by

Table 1—Characteristics of patients with type 2 diabetes with elevated HbA_{1c} and a follow-up HbA_{1c} within 90–270 days and characteristics of HbA_{1c} values

Characteristics	Patients (n = 15,308)[a]
Age, years	57.8 ± 11.9
Female, *n* (%)	7,006 (45.8)
Race/ethnicity, *n* (%)	
Non-Hispanic white	14,761 (96.4)
All others	517 (3.4)
MA, *n* (%)	1,964 (12.8)
Elevated HbA_{1c} with follow-up value in specific window, number per person	3.0 (1.0–6.0)
Community type, *n* (%)	
Township	9,063 (59.2)
Borough	4,342 (28.4)
Census tract in city	1,590 (10.4)
Elevated HbA_{1c} values (n = 69,818)	
Initial elevated HbA_{1c} value, %	8.2 (7.7–9.1)
Duration between elevated HbA_{1c} and follow-up value in specific time window, days	174.60 ± 42.95
Change in HbA_{1c} in specified time window	−0.6 ± 1.5
TI, *n* (%)	
Yes	24,396 (34.9)
No	38,274 (54.8)
Unknown[b]	7,148 (10.2)

Data are mean ± SD or median (interquartile range) unless otherwise indicated. [a]Totals may not add to 15,308 patients owing to missing/unknown values. [b]Medication regimens (e.g., dose and schedule) are entered as free-text in the EHR. We applied natural language processing to identify and classify TI status for commonly used text patterns. Unknown patterns included single-use test strings that could not be used to determine TI status without manual chart review.

12.8% of patients at some point while under care by Geisinger. The median number of eligible elevated HbA_{1c} measures per person was three for a total of 69,818 elevated measures. The mean time between the HbA_{1c} measures in each pair (i.e., elevated and follow-up) was 174.6 days. TI occurred for slightly more than one-third of elevated HbA_{1c} values.

Description of Communities

Patients resided in 734 communities (Table 2), with the majority in townships (9,063 patients in 439 townships), followed by boroughs (4,342 patients in 205 boroughs) and city census tracts (1,590 patients in 90 census tracts). Community domains varied within and across community types. CSD was generally highest in census tracts and lowest in townships. Similarly, food availability, fitness and recreational assets, and utilitarian physical activity favorability scores were generally highest in census tracts and lowest in townships.

Multilevel Regression Modeling of HbA_{1c} Change

Initial elevated HbA_{1c} values had a median of 8.2% (66 mmol/mol) followed by an absolute average decline of 0.6%. In our tabulated model results, coefficients indicate the absolute difference in HbA_{1c} change between the variable level (e.g., TI) and the reference group (no TI), such that negative coefficients represent a larger decline in HbA_{1c} over time than the reference group and positive coefficients represent a smaller decline in HbA_{1c} over time than the reference group. In each community type, on average, TI (versus no TI) was associated with a larger adjusted absolute decline in HbA_{1c} over both 6 and 24 months, though the magnitude of the decline was smaller at 24 months (Table 3). Unknown TI (versus not) was associated with larger adjusted absolute decline in HbA_{1c} but only over 6 months.

The four community factors were then added to the TI models one at a time. Adding community factors to the TI models did not alter TI associations. In townships, CSD was associated with absolute change in HbA_{1c} in townships. On average, HbA_{1c} reductions over time were 0.07% smaller for HbA_{1c} measures of patients living in communities with bad CSD (third quartile) compared with the best CSD (first quartile) ($P < 0.05$). CSD was not associated with HbA_{1c} change in boroughs and cities. Adding MA to the models did not substantially change CSD associations. This association was not significant at 24 months.

Community food availability was associated with change in HbA_{1c} in townships only, with average absolute declines that were 0.1% larger for patients with the best versus the worst food availability. This same finding was observed at 24 months. Utilitarian physical activity was associated with change in HbA_{1c} in census tracts only, with average absolute declines over 6 months that were 0.17–0.19% larger for patients in communities at the second or third quartile (versus first). At 24 months, the average absolute decline was 0.25% larger for patients in census tracts at the third quartile (versus first.) The was no evidence that fitness assets were associated with change in HbA_{1c} at 6 months, but at 24 months townships with more physical activity opportunities had HbA_{1c} reductions that were 0.11% smaller than in townships with fewer opportunities (second quartile vs. first).

Effect Modification by Community Factor

There was evidence that TI was associated with smaller improvements in HbA_{1c} over 6 months in boroughs and townships with the worst CSD (fourth vs. first quartile)

Table 2—2010[a] indicators used to derive community domain factors by community type

Factors and indicators	Township (*n* = 439)	Borough (*n* = 205)	Census tract (*n* = 90)
CSD	−1.03 (−6.27, 8.82)	−0.05 (−5.26, 12.09)	3.21 (−2.91, 18.24)
Population in poverty (%, *z* score)	−0.44 (−1.44, 4.91)	0.08 (−1.49, 4.44)	0.87 (−0.96, 6.48)
Civilian unemployment rate (%, *z* score)	−0.27 (−1.92, 3.40)	−0.02 (−1.92, 4.48)	0.29 (−1.63, 3.49)
Public assistance (%, *z* score)	−0.41 (−1.01, 3.71)	−0.08 (−1.01, 5.59)	0.73 (−1.01, 6.65)
<High school education (%, *z* score)	−0.20 (−2.13, 5.36)	−0.21 (−1.85, 3.11)	0.59 (−1.25, 3.87)
Not in labor force (%, *z* score)	−0.22 (−2.03, 5.81)	−0.06 (−1.89, 4.86)	0.04 (−1.08, 4.24)
Community food availability	−2.59 (−4.71, 17.40)	0.64 (−4.81, 13.69)	4.85 (−3.92, 56.17)
Food service per 1,000 persons	0.44 (0.00, 11.82)	2.11 (0.00, 6.71)	2.29 (0.00, 17.03)
Convenience/gas station per square mile	0.00 (0.00, 2.03)	0.66 (0.00, 11.40)	2.45 (0.00, 22.43)
Grocery store area per square mile	0.00 (0.00, 2.37)	0.53 (0.00, 10.18)	2.21 (0.00, 50.72)
Snack food stores per square mile	0.00 (0.00, 3.38)	0.00 (0.00, 11.27)	0.95 (0.00, 24.99)
Other food retail per square mile	0.00 (0.00, 4.06)	0.40 (0.00, 9.50)	2.70 (0.00, 24.99)
Bar and tavern population per square mile	0.00 (0.00, 5.46)	0.00 (0.00, 2.47)	0.56 (0.00, 4.39)
Fast food chain restaurant per square mile	0.00 (0.00, 2.03)	0.00 (0.00, 3.03)	0.00 (0.00, 6.09)
Diversity of types of food establishments	2.00 (0.00, 13.00)	4.00 (0.00, 11.00)	6.00 (1.00, 11.00)
Fitness and recreational assets	−2.05 (−3.2, 15.55)	−0.55 (−3.26, 14.92)	3.76 (−2.65, 31.98)
Indoor fitness clubs per square mile	0.00 (0.00, 1.35)	0.00 (0.00, 14.37)	0.67 (0.00, 17.95)
Outdoor recreational clubs per square mile	0.00 (0.00, 1.01)	0.00 (0.00, 4.53)	0.00 (0.00, 11.66)
Indoor recreational clubs per square mile	0.00 (0.00, 0.63)	0.00 (0.00, 7.18)	0.00 (0.00, 13.88)
Diversity of fitness/recreational places	2.00 (0.00, 9.00)	2.00 (0.00, 9.00)	3.00 (0.00, 8.00)
Count of outdoor public parks/recreational spaces	0.00 (0.00, 5.00)	0.00 (0.00, 2.00)	0.00 (0.00, 2.00)
Utilitarian physical activity favorability	−0.46 (−16.11, 2.98)	0.85 (−2.23, 3.59)	1.95 (−1.68, 8.71)
Households per square mile	27.33 (0.39, 860.92)	644.55 (27.60, 4,134.04)	2,188.52 (188.17, 9,159.5)
Vehicle miles traveled per person per square mile	23.64 (3.63, 433.27)	9.16 (0.10, 105.49)	6.13 (0.67, 63.77)
Average block size (square miles)	0.41 (0.02, 3.56)	0.02 (0.00, 0.73)	0.01 (0.00, 0.11)
Street connectivity: number of 3+ intersections/m^2	0.09 (0.00, 0.23)	0.05 (0.00, 0.19)	0.02 (0.00, 0.11)

Data are median (range) unless stated otherwise. [a]U.S. census data, InfoUSA and Dun & Bradstreet, and the Pennsylvania Department of Transportation.

Table 3—Associations of TI and community factors for change in HbA$_{1c}$ in 6-month[a] window after an elevated HbA$_{1c}$ measure, by community type[b]

	Township, estimate (95% CI)	Borough, estimate (95% CI)	Census tract, estimate (95% CI)
TI in model without any community factors			
Yes vs. no	−0.34 (−0.36, −0.31)[c]	−0.34 (−0.36, −0.29)[c]	−0.42 (−0.48, −0.35)[c]
Unknown vs. no	−0.08 (−0.11, −0.04)[c]	−0.11 (–0.16, −0.05)[c]	−0.11 (−0.21, −0.011)[c]
Main effect of community factors: in models one at a time (quartile by place)			
CSD			
Quartile 2	0.04 (−0.02, 0.09)	0.01 (−0.08, 0.10)	0.03 (−0.13, 0.19)
Quartile 3	0.07 (0.01, 0.13)[c]	0.05 (−0.03, 0.14)	0.07 (−0.08, 0.23)
Quartile 4	0.06 (−0.002, 0.11)	0.04 (−0.04, 0.13)	0.06 (−0.11, 0.23)
Utilitarian PA favorability			
Quartile 2	0.04 (−0.03, 0.10)	0.01 (−0.10, 0.11)	−0.19 (−0.35, −0.03)[c]
Quartile 3	0.03 (−0.04, 0.09)	−0.01 (−0.11, 0.09)	−0.17 (−0.34, −0.004)[c]
Quartile 4	0.02 (−0.04, 0.07)	0.04 (−0.06, 0.14)	0.03 (−0.13, 0.20)
Community food availability			
Quartile 2	−0.0004 (−0.07, 0.07)	−0.03 (−0.15, 0.08)	−0.04 (−0.10, 0.21)
Quartile 3	−0.05 (−0.12, 0.02)	0.02 (−0.08, 0.13)	0.05 (−0.10, 0.21)
Quartile 4	−0.10 (−0.16, −0.03)[c]	−0.03 (−0.13, 0.07)	0.12 (−0.02, 0.26)
Fitness and recreational assets			
Quartile 2	0.06 (−0.02, 0.13)	−0.08 (−0.21, 0.06)	−0.05 (−0.21, 0.10)
Quartile 3	−0.03 (−0.10, 0.04)	−0.04 (−0.16, 0.09)	−0.002 (−0.16, 0.15)
Quartile 4	−0.05 (−0.11, 0.02)	−0.08 (−0.20, 0.04)	0.10 (−0.06, 0.26)
Effect modification on TI by community factors: in models one at a time (quartile by place)[d]			
CSD quartile 2 × TI yes	0.02 (−0.04, 0.09)	0.03 (−0.08, 0.14)	−0.07 (−0.27, 0.14)
CSD quartile 3 × TI yes	0.04 (−0.02, 0.11)	−0.09 (−0.02, 0.19)	−0.03 (−0.22, 0.17)
CSD quartile 4 × TI yes	0.11 (0.05, 0.18)[c]	0.11 (0.007, 0.21)[c]	−0.06 (−0.28, 0.16)
Fitness quartile 2 × TI yes	0.05 (−0.04, 0.13)	0.18 (0.01, 0.35)[c]	0.05 (−0.15, 0.24)
Fitness quartile 3 × TI yes	−0.02 (−0.06, 0.10)	0.11 (−0.05, 0.27)	−0.08 (−0.27, 0.11)
Fitness quartile 4 × TI yes	−0.009 (−0.08, 0.06)	0.16 (0.007, 0.31)[c]	0.05 (−0.15, 0.24)

PA, physical activity. [a]HbA$_{1c}$ value closest to 6 months after baseline HbA$_{1c}$. [b]Mixed-effect linear regression models with a random intercept for patient, adjusted for race/ethnicity and MA, age centered (linear and quadratic), baseline HbA$_{1c}$ (linear and quadratric), sex, BMI centered, and time from diabetes diagnosis to baseline HbA$_{1c}$ (linear and quadratic); change in HbA$_{1c}$ was calculated as follow-up HbA$_{1c}$ minus initial elevated HbA$_{1c}$. Reference group for community measures was quartile 1. Reference group for TI was "no TI." [c]$P < 0.05$. [d]Cross product of community factors and TI added to linear regression models one at a time. Results presented for community factors with at least one significant ($P < 0.05$) community × TI yes interaction term.

(Table 4). This same pattern was observed at 24 months but only in census tracts (third vs. first quartile) (Table 4). TI was also associated with smaller improvements in HbA$_{1c}$ in boroughs with the highest level of fitness assets (fourth quartile vs. first quartile) (Table 3). Notably, TI was associated with greater improvements in HbA$_{1c}$ over 24 months in census tracts that had the highest level of utilitarian physical activity opportunities (second and fourth quartile vs. first quartile) (Table 4).

CONCLUSIONS

This is the first study, to our knowledge, to evaluate the association between community characteristics and control of HbA$_{1c}$ over time and how these characteristics modify HbA$_{1c}$ response to care. We found that in certain community types, CSD, food availability, and utilitarian physical activity favorability were associated with HbA$_{1c}$ trajectories. Moreover, community factors blunted the associations of TI with HbA$_{1c}$ levels. The results suggest that factors outside of the clinical setting may be important to HbA$_{1c}$ control and point to opportunities for more targeted secondary prevention strategies that take community into account.

To date, most studies of community and type 2 diabetes have focused on risk of onset. Living in communities with greater resources to support physical activity and healthy diets has been associated with lower incidence of type 2 diabetes (15–17). Only two other studies to our knowledge have evaluated community characteristics and HbA$_{1c}$ control over time in patients with type 2 diabetes. These studies found that loss of supermarket presence in communities and higher levels of chronic environmental contamination were associated with worse HbA$_{1c}$ trajectories (7,8,18).

This study demonstrated that other aspects of the community, including opportunities for utilitarian physical activity, the food environment, and CSD, were associated with HbA$_{1c}$ trajectories, independent of treatment, in some community types. These associations are biologically plausible through a number of pathways. Communities with high levels of CSD, for example, create a context for higher psychosocial stress; stress has been linked to physiological changes associated with type 2 diabetes onset and higher HbA$_{1c}$ (19–21). An obesity pathway may also explain our observed associations. Obesity is a strong risk factor for poor type 2 diabetes control, and weight loss in type 2 diabetes is associated with improvements in glycemic control (22,23). Community domains, including CSD and opportunities for physical activity, have been associated with obesity (13,24,25).

A decrease of 1% in HbA$_{1c}$ has been associated with a 15–20% decrease in major cardiovascular events and a 37% decrease in microvascular complications

Table 4—Associations of TI and community factors for change in HbA_{1c} in 24-month[a] window after an elevated HbA_{1c} measure, by community type[b]

	Township, estimate (95% CI)	Borough, estimate (95% CI)	Census tract, estimate (95% CI)
TI in model without any community factors			
Yes vs. no	−0.13 (−0.15, −0.10)[c]	−0.12 (−0.15, −0.08)[c]	−0.13 (−0.19, −0.07)[c]
Unknown vs. no	−0.01 (−0.05, 0.02)	−0.02 (−0.08, 0.03)	−0.05 (−0.15, 0.04)
Community factors: in models one at a time (quartile by place)			
CSD			
Quartile 2	0.03 (−0.04, 0.10)	0.002 (−0.11, 0.12)	−0.03 (−0.23, 0.18)
Quartile 3	−0.07 (−0.01, 0.14)	0.06 (−0.05, 0.17)	−0.01 (−0.21, 0.18)
Quartile 4	0.06 (−0.01, 0.13)	0.04 (−0.07, 0.15)	−00.18 (−0.40, 0.04)
Utilitarian PA favorability			
Quartile 2	0.001 (−0.07, 0.09)	−0.01 (−0.14, 0.12)	−0.20 (−0.41, 0.01)
Quartile 3	−0.03 (−0.11, 0.06)	0.01 (−0.12, 0.14)	−0.25 (−0.46, −0.03)[c]
Quartile 4	−0.02 (−0.09, 0.06)	0.07 (−0.06, 0.19)	−0.08 (−0.29, 0.13)
Community food availability			
Quartile 2	0.02 (−0.07, 0.10)	−0.04 (−0.19, 0.11)	−0.10 (−0.28, 0.07)
Quartile 3	−0.07 (−0.15, 0.02)	−0.02 (−0.16, 0.12)	0.02 (−0.18, 0.22)
Quartile 4	−0.10 (−0.19, −0.02)[c]	−0.04 (−0.17, 0.08)	−0.03 (−0.22, 0.15)
Fitness and recreational assets			
Quartile 2	0.11 (0.01, 0.20)[c]	−0.12 (−0.30, 0.05)	0.03 (−0.18, 0.23)
Quartile 3	0.03 (−0.06, 0.11)	−0.05 (−0.21, 0.10)	0.03 (−0.17, 0.23)
Quartile 4	−0.04 (−0.12, 0.04)	−0.09 (−0.25, 0.05)	0.04 (−0.16, 0.25)
Effect modification on TI by community factors: in models one at a time (quartile by place)[d]			
CSD quartile 2 × TI yes	−0.002 (−0.07, 0.06)	−0.05 (−0.16, 0.06)	−0.16 (−0.36, 0.04)
CSD quartile 3 × TI yes	−0.03 (−0.09, 0.04)	−0.03 (−0.14, 0.07)	−0.20 (−0.39, −0.005)[c]
CSD quartile 4 × TI yes	0.009 (−0.05, 0.07)	−0.03 (−0.13, 0.07)	−0.10 (−0.31, 0.12)
Utilitarian PA quartile 2 × TI yes	0.05 (−0.02, 0.12)	0.004 (−0.12, 0.13)	−0.30 (−0.50, −0.09)[c]
Utilitarian PA quartile 3 × TI yes	−0.006 (−0.08, 0.07)	−0.01 (−0.14, 0.11)	−0.15 (−0.36, −0.06)
Utilitarian PA quartile 4 × TI yes	0.02 (−0.05, 0.08)	−0.02 (−0.14, 0.10)	−0.29 (−0.49, −0.09)[c]

PA, physical activity. [a]HbA_{1c} value closest to 24 months after baseline HbA_{1c}. [b]Mixed-effect linear regression models with a random intercept for patient, adjusted for race/ethnicity and MA, age centered (linear and quadratic), baseline HbA_{1c} (linear and quadratric), sex, BMI centered, and time from diabetes diagnosis to baseline HbA_{1c} (linear and quadratic); change in HbA_{1c} was calculated as follow-up HbA_{1c} minus initial elevated HbA_{1c}. Reference group for community measures was quartile 1. Reference group for TI was "no TI." [c]$P < 0.05$. [d]Cross product of community factors and TI added to linear regression models one at a time. Results presented for community factors with at least one significant ($P < 0.05$) community × TI yes interaction term.

(26). We observed that TI was associated with an absolute additional decline in HbA_{1c} of 0.35– 0.44% over 6 months, thus potentially resulting in up to an additional 8.8% decrease in major cardiovascular events. On average, the HbA_{1c} levels of patients living in census tracts favorable to utilitarian physical activity (quartile 3) dropped an average of 0.25% more than those in the communities least favorable to utilitarian physical activity over 24 months, a reduction that might be expected to produce a 4–5% reduction in cardiovascular disease and a 9% reduction in risk of microvascular complications.

The food and utilitarian physical activity environments, like TI, had durable associations with HbA_{1c} reductions. The magnitude of the association between TI and HbA_{1c} change was lower with longer durations between HbA_{1c} values; in contrast, the magnitude of associations with the food environment remained the same and strengthened for utilitarian physical activity. The difference in durability may reflect the stability of environmental measures over these durations, providing for a more persistent role, while the impact of TI at a single clinical encounter, based on our findings, appears to weaken over time.

Consistent with prior studies, we demonstrated that TI was associated with improvements in HbA_{1c} over time (11,27). Sidorenkov et al. (28) reported that TI (versus none) was associated with a decline in HbA_{1c} of 0.21% after 21–120 days. Selby et al. (11) demonstrated that facility-level improvements in TI rates were associated with improvement in facility-level HbA_{1c} control rates. We also observed that unknown TI status resulted in greater HbA_{1c} reductions compared with patients known not to have had TI. We suspect that the unknown group included patients who actually received TI. To our knowledge, no study has evaluated how characteristics of where patients live modify the relation between TI and outcomes. We observed that CSD and opportunities for physical activity modified the effectiveness of diabetes care in some community types.

The mechanism for the observed effect modification is not clear. Worse CSD and neighborhood safety both have been associated with worse medication adherence rates and delays in filling prescriptions in type 2 diabetes (29,30). It may be that high CSD in townships and boroughs presents barriers to adherence, thus resulting in a weaker association between TI, as defined by medication orders, and HbA_{1c}. Regarding fitness assets, aerobic exercise has been shown to interact with a number of medications that are used to treat type 2 diabetes, influencing changes in insulin sensitivity, insulin secretion, or glycemic control (31).

While all four community domains that we studied were associated with HbA_{1c} or modified TI and HbA_{1c} associations, none of our observed associations between community and HbA_{1c} existed in all three of our community types. There was very little overlap in the distribution of scores for the community domains across the three community types, with census tracts generally scoring the worst for CSD but best for food availability, fitness, and utilitarian physical activity—and townships the opposite extreme. It is possible that community factors have nonlinear relations with HbA_{1c} change, including threshold exposure effects, as has been observed for population density (32). Residents may only begin to use active transport (i.e., walking) above population densities of 3,500 persons per square mile. We evaluated associations by quartiling by community type; therefore, it may be that our highest quartiles of some community factors in some community types did not exceed thresholds needed to change behaviors. It is notable that there were instances when there was a statistically and clinically significant association at the 2nd or 3rd quartile of some community domains, but there was not a statistically significant association at the 4th quartile. It may be that there are unmeasured community factors that occur at the highest quartiles that counteract the benefits of HbA_{1c} reduction.

Less than 12% of HbA_{1c} variation among patients with diabetes can be attributed to physician- or clinical-level factors (5). Our findings demonstrated that while TI improved HbA_{1c} control, factors outside of the clinic were associated with HbA_{1c} control. Furthermore, we found that the association between TI and HbA_{1c} reduction was blunted by community characteristics. This finding suggests that community features may act like genetic differences; both community and genetic differences may modify the individual response to therapy, as has already been demonstrated in pharmacogenetic research (33). This finding is relevant to the growing precision medicine movement, an approach to medicine that selects treatments specific to the genes, environment, and lifestyle of each patient. Our results raise the possibility that medical treatments may need to be tailored to community characteristics to be effectively optimized (34).

The study used a unique combination of longitudinal treatment data, HbA_{1c} from laboratory measurements, and community-level variables on $>$15,000 individuals across 734 communities. These data sources enabled us to evaluate associations between community factors and changes in HbA_{1c} levels while controlling for potential confounding variables. We also used multidimensional community measures from a CFA model, rather than single indicators in each domain, overcoming limitations of most prior research (35–38), which has generally relied on single indicators, ignoring the spatial co-occurrence of multiple features in each community domain.

The study had several limitations. First, we cannot conclude that our associations are generalizable outside of the region we studied. Second, self-selection may bias our results such that factors that motivate individuals to live in certain communities may be confounding our findings. However, we controlled for a number of variables known to be associated with diabetes status, including race/ethnicity, age, sex, and family SES. Third, we assessed community factors using geographic information systems but did not measure patient perceptions of their communities. Christine et al. (15) observed that geographic information system–based measures were less strongly associated with type 2 diabetes than measures of the perception of the availability of food and physical activity establishments. Finally, health care providers generally do not record health behaviors in the EHR, so we were unable to evaluate whether changes in health-related behaviors could have accounted for the results.

Despite improvements in type 2 diabetes care and treatment options, HbA_{1c} levels remain poorly controlled for many individuals with this disease. Our findings are a novel contribution to understanding correlates of type 2 diabetes control beyond clinical care. Our observed associations between community and HbA_{1c} levels, particularly that community factors may modify the influence of medical care, provide evidence to support the study of disease-management strategies that take community factors into consideration.

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