Original Investigation

Association of Neighborhood Walkability With Change in Overweight, Obesity, and Diabetes

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IMPORTANCE Rates of obesity and diabetes have increased substantially in recent decades; however, the potential role of the built environment in mitigating these trends is unclear.

OBJECTIVE To examine whether walkable urban neighborhoods are associated with a slower increase in overweight, obesity, and diabetes than less walkable ones.

DESIGN, SETTING, AND PARTICIPANTS Time-series analysis (2001-2012) using annual provincial health care (N ≈ 3 million per year) and biennial Canadian Community Health Survey (N ≈ 5500 per cycle) data for adults (30-64 years) living in Southern Ontario cities.

EXPOSURES Neighborhood walkability derived from a validated index, with standardized scores ranging from 0 to 100, with higher scores indicating more walkability. Neighborhoods were ranked and classified into quintiles from lowest (quintile 1) to highest (quintile 5) walkability.

MAIN OUTCOMES AND MEASURES Annual prevalence of overweight, obesity, and diabetes incidence, adjusted for age, sex, area income, and ethnicity.

RESULTS Among the 8777 neighborhoods included in this study, the median walkability index was 16.8, ranging from 10.1 in quintile 1 to 35.2 in quintile 5. Resident characteristics were generally similar across neighborhoods; however, poverty rates were higher in high- vs low-walkability areas. In 2001, the adjusted prevalence of overweight and obesity was lower in quintile 5 vs quintile 1 (43.3% vs 53.5%; $P < .001$). Between 2001 and 2012, the prevalence increased in less walkable neighborhoods (absolute change, 5.4% [95% CI, 2.1%-8.8%] in quintile 1, 6.7% [95% CI, 2.3%-11.1%] in quintile 2, and 9.2% [95% CI, 6.2%-12.1%] in quintile 3). The prevalence of overweight and obesity did not significantly change in areas of higher walkability (2.8% [95% CI, −1.4% to 7.0%] in quintile 4 and 2.1% [95% CI, −1.4% to 5.5%] in quintile 5). In 2001, the adjusted diabetes incidence was lower in quintile 5 than other quintiles and declined by 2012 from 7.7 to 6.2 per 1000 persons in quintile 5 (absolute change, −1.5 [95% CI, −2.6 to −0.4]) and 8.7 to 7.6 in quintile 4 (absolute change, −1.1 [95% CI, −2.2 to −0.05]). In contrast, diabetes incidence did not change significantly in less walkable areas (change, −0.65 in quintile 1 [95% CI, −1.65 to 0.39], −0.5 in quintile 2 [95% CI, −1.5 to 0.5], and −0.9 in quintile 3 [95% CI, −1.9 to 0.02]). Rates of walking or cycling and public transit use were significantly higher and that of car use lower in quintile 5 vs quintile 1 at each time point, although daily walking and cycling frequencies increased only modestly from 2001 to 2011 in highly walkable areas. Leisure-time physical activity, diet, and smoking patterns did not vary by walkability ($P > .05$ for quintile 1 vs quintile 5 for each outcome) and were relatively stable over time.

CONCLUSIONS AND RELEVANCE In Ontario, Canada, higher neighborhood walkability was associated with decreased prevalence of overweight and obesity and decreased incidence of diabetes between 2001 and 2012. However, the ecologic nature of these findings and the lack of evidence that more walkable urban neighborhood design was associated with increased physical activity suggest that further research is necessary to assess whether the observed associations are causal.

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Editorial page 2175

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The global increase in obesity is a major contemporary health problem. The National Health and Nutrition Examination Survey estimated that 69% of US adults were overweight or obese in 2011-2012, whereas 35% met the definition of obesity, an increase in obesity prevalence from 15% in the late 1970s.[1,2] A parallel increase in diabetes prevalence among adults occurred during the latter half of this period, from less than 4% in 1990 to 8.3% in 2012.[3,4] Similar trends have been observed in Canada and other nations worldwide.[5,6]

Despite public health efforts to reduce obesity through diet and exercise, rates of overweight, obesity, and diabetes remain high, prompting a search for population-wide strategies to help curb these dual epidemics. One approach that is gaining interest among public health professionals and urban planners is to redesign the built environment to offer more opportunities for physical activity and healthy eating. Urban design preferences during the past 40 years have shifted toward sprawling, car-oriented communities that discourage walking and increase reliance on motorized transportation. In contrast, neighborhoods that favor pedestrian activities—those with high population density, high numbers of destinations within walking distance of residential areas, and well-connected streets—are characterized by higher rates of walking and bicycling for transportation and lower rates of car use.[7,8] In turn, research has linked residence in these more walkable areas to lower levels of obesity and diabetes.[9-13]

To our knowledge, no prospective studies have examined the capacity for walkable neighborhoods to mitigate the increase in obesity-related diseases on a population scale. The primary objective of this study was to examine whether urban neighborhoods that are more walkable are associated with a slower increase in overweight, obesity, and diabetes than less walkable neighborhoods and, if so, whether these patterns correspond to transportation choices within neighborhoods.

Methods

Context and Setting

A time-series analysis was conducted to compare rates of overweight, obesity, and diabetes incidence during a 12-year period across urban neighborhoods with various levels of walkability. This study was conducted in metropolitan areas within Southern Ontario, a region that is highly urbanized and undergoing rapid growth and development. The study area included 15 municipalities with a combined population of more than 7 million residents (London, Ottawa, Hamilton, Toronto, and surrounding communities), representing approximately one-fifth of the Canadian population. Data collected from administrative health care databases and national surveys were used to derive population-level estimates for overweight, obesity, and diabetes for the population living in this area. To do so, health information for local residents was linked to neighborhood-level data on walkability, using their postal code of residence. The sample in this study included the adult population aged 30 to 64 years, a group that has experienced a rapid increase in obesity-related conditions, including diabetes.[5]

This protocol received ethical approval from the institutional review boards at St Michael's Hospital and Sunnybrook Health Sciences Centre in Toronto and from the Institute for Clinical Evaluative Sciences, where the data are held. Participant informed consent was not required by any of these research institutes in accordance with Ontario's privacy legislation because all data were maintained in a deidentified form.

Neighborhood Walkability

Baseline walkability scores were calculated for residential units (known as dissemination areas) within the study region. Dissemination areas are the smallest geographic unit for which Canadian census data are available and are relatively uniform in terms of population size (approximately 400-700 persons). Dissemination areas are generally composed of several adjacent city blocks and have several postal codes within their boundary (median = 13). Only residential areas that were developed before 2001 and classified by Statistics Canada as urban areas (which includes suburban areas) were included in this study. Fringe areas on the outskirts of a city that were largely rural or undeveloped were excluded.

Neighborhood walkability was derived for each dissemination area with a validated composite walkability index.[10,11] The index includes 4 equally weighted components: population density (number of persons per square kilometer), residential density (number of occupied residential dwellings per square kilometer), walkable destinations (number of retail stores, services [eg, libraries, banks, community centers], and schools within a 10-minute walk), and street connectivity (number of intersections with at least 3 converging roads or pathways).

In a validation study, index scores derived from equally weighting these components were highly correlated with those in which weights were based on factor scores from principal components analysis ($R>0.99$).[10] The index was created with ArcGIS version 10.2 and data from the 2001 Canadian Census and 2003 DMTI Spatial Inc (Enhanced Points of Interest file), supplemented with data on locations of public recreational facilities from local municipalities and schools from the Ontario government's Ministry of Education. Residential areas were then ordered by increasing walkability scores and divided into quintiles, from the least (quintile 1) to the most walkable quintile (quintile 5). For descriptive purposes, scores were standardized to a scale from 0 to 100. To assess the stability of walkability quintiles over time, walkability scores were recreated for each neighborhood with data from the 2006 Canadian Census and 2009 DMTI Spatial Inc.

Other Neighborhood Variables

A number of additional variables were measured, including factors that could contribute to the association between walkability and study outcomes or that could be potential confounders. Because neighborhood gentrification (the influx of wealthier persons into neighborhoods, displacing poorer residents) may have occurred in highly walkable areas during the follow-up, a number of socioeconomic and retail measures were compared at the start and end of this period that reflected the underlying wealth of neighborhoods in each walkability quintile. This included socioeconomic indicators—the level of poverty, education, and unemployment; the number of dwellings requiring major repairs; and the percentage of the population who did not speak English or French—based on the 2001 Canadian Census and the 2011 National Household Survey (which replaced the long form of the 2011 Canadian Census); retail indicators, including the availability of private gyms or fitness clubs (number per capita) and the availability of a particular specialty coffee house (number per capita) vs a particular coffee and doughnut shop (number per capita); and the ratio of specialty coffee houses to coffee and doughnut shops (based on these same measures), derived from Enhanced Points of Interest data from DMTI Spatial Inc (2003 and 2012).[14,15] Access to local parks was assessed by calculating the distance to the nearest park (in meters) for each dissemination area. Parkland was captured with several measures from DMTI Spatial Inc (2003 and 2009); very small parks (<20 000 m^2) were excluded. In addition, access to health care services was examined across neighborhoods by measuring the number of primary care visits per year among local residents according to fee-for-service physicians' services claims.

Outcomes

Overweight/Obesity

The prevalence of overweight and obesity was estimated for each quintile of neighborhood walkability with self-reported data from the Canadian Community Health Survey, which is a series of cross-sectional nationally representative health surveys of Canadians aged 12 years and older and is conducted by Statistics Canada. Details on the survey design and sampling frame have been published elsewhere.[16] To evaluate patterns over time, data from 6 consecutive cycles, released approximately every 2 years from 2001 to 2011/2012, were analyzed; the prevalence between years was derived through interpolation.

Prevalence of overweight and obesity was derived for each cycle with data from all respondents aged 30 to 64 years who were living in the study area when the survey was conducted, excluding women who were pregnant or breastfeeding. Body mass index was calculated with self-reported weight and height measurements according to a standard formula (weight in kilograms divided by height in meters squared). Because certain ethnic groups have an elevated diabetes risk at lower BMI levels,[17-19] ethnic-specific BMI thresholds were used to define overweight or obesity based on self-reported ethnicity derived from predefined racial or cultural group categories created by Statistics Canada, using a threshold of 23 or higher for South Asian and Chinese respondents and 25 or greater for all others.

Diabetes Incidence

Administrative health data collected from April 1, 2001, to March 31, 2013, were used to calculate the annual incidence of diabetes within each quintile of neighborhood walkability. Because of Canada's universal health care system, administrative health care databases include anonymized health information on virtually all permanent residents. Yearly denominators were derived from the electronic health care registry that captures demographic, residential, and vital statistics data. Numerators were based on new diabetes cases identified from the Ontario Diabetes Database. The database uses a validated algorithm based on hospitalization records and physicians' services claims to identify persons with diagnosed diabetes, with a high level of sensitivity (86%) and specificity (97%).[20] The database is unable to distinguish cases of type 1 from type 2 diabetes; however, the majority of new cases in the study would be expected to be type 2, given the minimum age criterion of 30 years.

Yearly diabetes incidence rates were calculated among adults aged 30 to 64 years who were living in the study area and were free of diabetes at the start of each fiscal year. Only individuals who were eligible for health care coverage for a minimum of 3 years before each fiscal year were included to ensure that new entries into the database were truly incident cases. Individuals living in long-term care institutions were also excluded.

Transportation and Health Behaviors

Self-reported transportation behaviors were examined by neighborhood walkability, with data collected from a randomly selected sample of households that were participating in one of 3 cycles (2001, 2006, and 2011) of the Transportation Tomorrow Survey, a comprehensive telephone-based household survey (switched to online in 2011) conducted in the Greater Toronto and Hamilton Area every census year, with an average annual sample size of 128 420.[21] The contact and refusal rates across the 3 cycles ranged from 60% to 81% and 21% to 26%, respectively, resulting in an overall completion rate of 64.1% in 2001, 45.7% in 2006, and 48.9% in 2011. Validation studies suggest that survey participants were highly representative of the census population living in the same areas.[21-23] Furthermore, there was a high level of agreement between daily transit and driving trip volumes from self-reported data collected in the Transportation Tomorrow Survey and counts derived from regional transit authorities and cordon count programs (direct observation of traffic), with overall counts within 3%.[22,23] Transportation patterns were examined among all eligible respondents living in the study area at the time of the survey, according to their walkability quintile. These data were reported as the weighted mean number of daily trips per 100 persons by walking or bicycling, public transit, and automobile.

Data from the Canadian Community Health Survey were used to examine self-reported health behaviors during the same period by neighborhood walkability, including the proportion of the eligible population who were inactive in their leisure time (not including transportation-related activities according to an energy expenditure <1.5 kcal/kg per day), consumed fewer than 5 servings of fruits and vegetables daily, or were current smokers. These data were available for 4 consecutive survey cycles (spanning 2003 to

2009/2010), with interpolated values derived for years in between cycles.

Analysis

Stability of Walkability Measure Over Time

In the main analysis, walkability was considered to be relatively stable over time and was not treated as a time-dependent variable. To test this assumption, a weighted κ statistic was used to examine the agreement between neighborhood-level walkability scores at baseline (2001-2003) and later during follow-up (2006-2009).

Temporal Patterns of Overweight and Obesity

Annual rates of overweight and obesity (using ethnic-specific cut-offs as described above) were estimated for each walkability quintile and were age and sex standardized, incorporating survey sampling weights and using the 1991 Canadian population as the referent population. The Proc LOESS procedure in SAS, a nonparametric method that allows fitting of nonlinear curves, was used to smooth the plotted curves demonstrating the relationship between overweight and obesity prevalence and time. Poisson regression was used to adjust for area-level poverty. It was also used to test for differences in slopes of the modeled rates of overweight and obesity over time within a given walkability quintile, as well as differences between quintile 5 (highest walkability) and quintile 1 (lowest walkability) at the start and end of the observation period. These models were created with individuals as the unit of analysis. Individuals living in dissemination areas that had missing census data on neighborhood income or ethnicity were excluded from the analysis, as were those with missing BMI.

Temporal Patterns of Diabetes Incidence

Modeling was performed with the residential area as the unit of analysis. Random-effects Poisson models were used to derive diabetes incidence rates after adjusting for age, sex, area-level income, and ethnicity and to account for the clustered nature of the data. Poisson regression was then used to evaluate modeled diabetes incidence rates over time, with the population at risk as an offset. Plotted incidence rates were smoothed with the same method described above. Interaction terms were used to detect any differences in slope (change in diabetes incidence over time) within and across walkability quintiles, comparing quintiles 1 and 5 at the start and end of the observation period. Areas with missing census variables were excluded from the analysis.

As a sensitivity analysis, the relationship between walkability and diabetes incidence was examined across neighborhoods with different levels of poverty. To do so, Poisson regression was used to examine the association between standardized walkability scores and diabetes incidence in 2012, adjusting for age, sex, and area ethnicity and stratifying into 3 groups on the basis of poverty (tertiles of the percentage of residents living below the low-income cutoff). Models accounted for potential underdispersion and overdispersion of data and were rerun with and without accounting for the clustering of residents in the same neighborhoods. The intraclass correlation coefficient derived from the model was used to assess the within- and between-neighborhood variance.

Temporal Patterns in Transportation- and Health-Related Behaviors

Similar approaches were used to examine temporal patterns in transportation- and health-related behaviors by neighborhood walkability. These models were created with individuals as the unit of analysis.

All analyses were performed with SAS version 9.4. All statistical tests were 2-sided, with a threshold for significance of $P < .05$.

Results

Neighborhood Characteristics

Overall, there were 8793 residential neighborhoods in the study area. Sixteen were excluded because of missing census data; however, this represented less than 0.1% of the eligible study population. Compared with residents living in the least walkable neighborhoods, those in the most walkable areas were somewhat younger and more likely to be nonwhite or to have immigrated to Canada in the preceding 10 years (**Table 1**). Poverty rates were higher in high-walkability (quintile 5) vs low-walkability (quintile 1) neighborhoods, but decreased to a small extent in quintile 4 (−2.5%) and quintile 5 (−4.3%) during the study (eTable 1 in the Supplement). Levels of education and unemployment were similar in quintiles 1 and 5 at the start and end of the period despite small increases in both during follow-up. The retail environment remained relatively stable during the study, although quintile 5 had a greater concentration of specialty coffee houses, with fewer coffee and doughnut shops at baseline and a greater increase in both during this period of the study. Access to commercial gyms and fitness clubs was greater in both low- and high-walkability areas but by 2012 had decreased in quintile 5; however, access to parks was similar across all neighborhood types.

Neighborhood walkability scores ranged from 0 to 100 (median, 16.8), with a fairly skewed distribution (median of 10.1 in quintile 1 and 35.2 in quintile 5). During the follow-up period, most neighborhoods remained in the same quintile (78% overall, 95% in quintile 5) and 99% remained within 1 quintile of their baseline assignment (weighted κ for agreement = 0.85). In addition, the area population and residential density, street connectivity, and number of retail outlets and services in each quintile were fairly stable (eTable 2 in the Supplement).

Prevalence of Overweight and Obesity

Overall, there were 32 767 individuals who participated in the Canadian Community Health Survey between 2001 and 2012 (≈5500 per cycle) and met the inclusion criteria for this study; the sample size by cycle ranged from 4878 to 6165 and was similar across quintiles (7686 in quintile 1 and 5576 in quintile 5). Overall, the proportion of individuals in the sample (N = 1293; 3.9%) who had missing BMI data was similar across quintiles.

The most walkable neighborhoods (quintile 5) had a lower adjusted prevalence of overweight and obesity at all points

Table 1. Baseline 2001-2003 Neighborhood Characteristics, by Walkability Quintile[a]

	Walkability Quintiles				
	1 (Least Walkable)	2	3	4	5 (Most Walkable)
No. of neighborhoods	1757	1757	1757	1759	1747
Population per neighborhood, median (IQR)	551 (420-644)	561 (441-747)	533 (435-728)	513 (451-701)	521 (457-677)
Demographic Characteristics[b]					
Age, %					
30-49	65.1	65.4	65.8	66.6	70.5
50-64	34.9	34.6	34.2	33.4	29.5
Sex, %					
Male	49.2	48.8	48.5	48.1	48.9
Female	50.8	51.2	51.5	51.9	51.1
Nonwhite ethnicity, %	23.9	27.8	31.0	30.6	26.3
Immigrated in last 10 y, %					
No	91.4	89.0	86.4	85.9	86.7
Yes	8.6	11.0	13.6	14.1	13.3
Unable to speak English or French, %					
No	97.8	97.2	96.7	96.4	95.0
Yes	2.2	2.8	3.3	3.6	5.0
Socioeconomic indicators, %[b]					
Poverty (population living below the low-income cutoff), %[c]	11.2	13.9	17.1	21.3	25.1
Population aged ≥20 y with high school education or less, %	32.7	35.2	38.6	39.7	33.8
Dwellings requiring major repair, %	4.7	5.6	6.6	8.2	9.9
Unemployment, %	5.3	5.9	6.3	6.9	6.9
Retail indicators, %[d]					
No. specialty coffee shops per 100 000	0.7	0.6	0.9	0.5	3.1
No. coffee/doughnut shops per 100 000	10.5	6.4	5.3	5.7	5.0
Ratio of specialty coffee shops to coffee/doughnut shops	0.06	0.09	0.18	0.09	0.63
Commercial fitness club/gyms, No. per 100 000 population	25.1	12.2	12.2	11.3	21.0
Built Environment Characteristics					
Walkability score, median (range)	10.1 (0-12.04)	13.7 (12.05-15.22)	16.8 (15.23-18.60)	20.9 (18.61-25.49)	35.2 (25.50-100)
Mean distance to nearest park, m[e]	3224	3207	3182	3169	3186

Abbreviation: IQR, interquartile range.

[a] Study area included London, Ottawa, Hamilton, Toronto, and surrounding communities.

[b] Demographic characteristics and socioeconomic indicators were based on 2001 Canada Census data for 8777 dissemination areas. Data presented are weighted means and percentages for the dissemination areas included in each walkability quintile.

[c] An established and widely used indicator of income adequacy in Canada.

[d] Retail indicators were derived with DMTI Spatial Inc Enhanced Points of Interest (2003).

[e] Access to parks was derived from a composite of 3 measures from DMTI Spatial Inc (2003 and 2009).

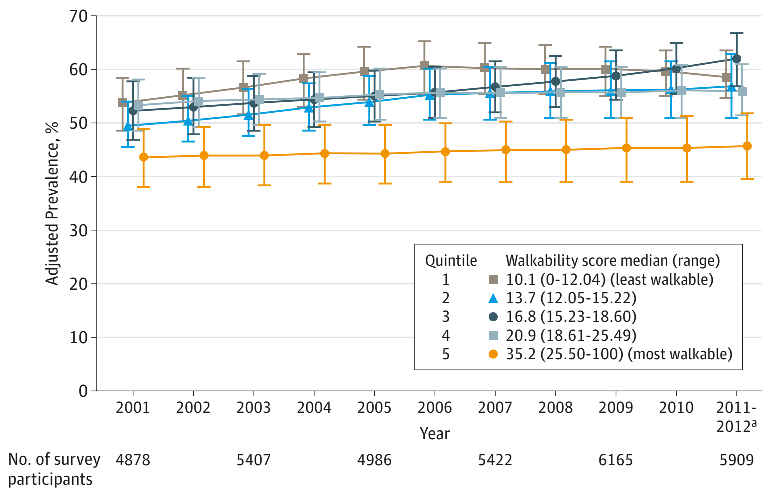
during the observation window (**Figure 1**) after accounting for differences in age, sex, income, and ethnicity (43.3% vs 53.5% in quintile 1 vs quintile 5; absolute difference, −10.2% [95% CI, −13.5% to −6.8%; *P* < .001]). The prevalence increased significantly in the lower 3 categories of walkability between 2001 and 2012 (change in prevalence, 5.4% [95% CI, 2.1% to 8.8%; *P* = .002], 6.7% [95% CI, 2.3% to 11.1%; *P* = .003], and 9.2% [95% CI, 6.2% to 12.1%; *P* < .001] in quintiles 1, 2, and 3, respectively). In contrast, there was no significant change in rates of overweight and obesity in neighborhoods within the top 2 quintiles of walkability (2.8% in quintile 4 [95% CI, −1.4% to 7.0%; *P* = .20] and 2.1% in quintile 5 [95% CI, −1.4% to 5.5%; *P* = .20]). By 2012, the difference in prevalence between the highest- and lowest-walkability quintile had increased (45.4% vs 58.9%; absolute difference, −13.5% [95% CI, −16.9% to −10.2%]; *P* < .001).

Diabetes Incidence

This analysis included nearly 3 million persons per year (ranging from 2 775 781 in fiscal year 2001 to 2 906 539 in 2012). The population size was similar across quintiles: 553 144 in quintile 1 and 568 646 in quintile 5 in fiscal year 2001, increasing to 658 267 and 586 996, respectively, by 2012.

Temporal patterns in diabetes incidence were similar to those observed for overweight and obesity. After adjusting for area differences in age, sex, income, and ethnicity, the incidence of diabetes was lowest in the highest-walkability neighborhoods compared with less walkable areas throughout the 12-year period (**Figure 2**). The adjusted annual incidence of diabetes decreased significantly in the highest 2 walkability quintiles, from 8.7 to 7.6 per 1000 persons in quintile 4 (absolute change, −1.1 [95% CI, −2.2 to −0.05]) and 7.7 to 6.2 per 1000 persons in quintile 5 (absolute

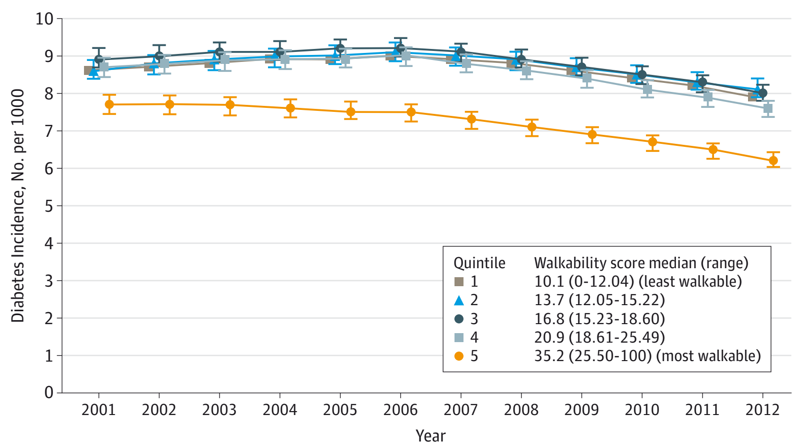
Figure 1. Adjusted Prevalence of Overweight and Obesity Among Adults Aged 30 to 64 Years and Living in Urban Areas, by Walkability Quintile, 2001-2012



Data sources: consecutive Canadian Community Health Survey cycles; 2001 and 2006 Canada Census. Interpolated values for 2002, 2004, 2006, 2008, and 2010. Study areas include London, Ottawa, Toronto, Hamilton, and surrounding communities. Rates represent the adjusted prevalence among all eligible Canadian Community Health Survey participants in a given quintile. Error bars indicate 95% CIs around prevalence. Estimates were generated with ethnic-specific BMI cut-offs, age and sex standardized (incorporating survey sampling weights) and adjusted for area-level income. Lines were smoothed with the SAS Proc LOESS method.

[a] Data from combined 2011 and 2012 surveys.

Figure 2. Adjusted Neighborhood-Level Diabetes Incidence Among an Urban Population Aged 30 to 64 Years, by Walkability Quintile, Fiscal Year 2001-2012

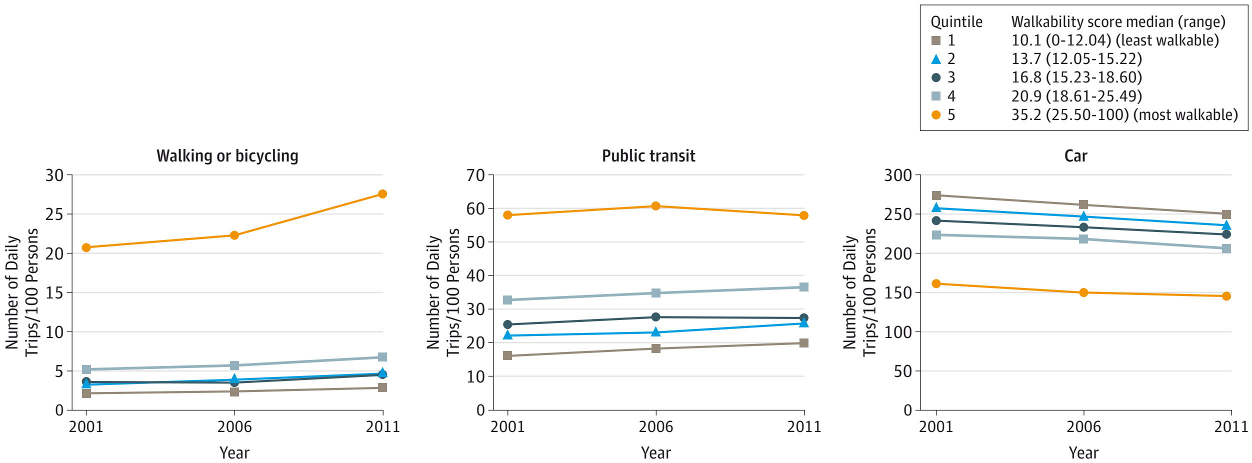


Data sources: Ontario Diabetes Database and Registered Persons Database. Study areas include London, Ottawa, Toronto, Hamilton, and surrounding communities. N = 2 775 781 in 2001 and 2 906 539 in 2012; yearly median (range): quintile 1, 641 307 (553 144-670 082); quintile 2, 573 943 (555 943-596 845); quintile 3, 537 596 (529 913-560 935); quintile 4, 556 765 (539 137-575 020); and quintile 5, 585 166 (568 646-615 810). Median neighborhood population (IQR): quintile 1, 551 (420-644); quintile 2, 561 (441-747); quintile 3, 533 (435-728); quintile 4, 513 (451-701); and quintile 5, 521 (457-677). Rates represent modeled diabetes incidence by neighborhood, based on all dissemination areas in a given quintile. Error bars indicate 95% CIs around incidence. Disseminated area-level models were adjusted for age, sex, area-level income, and area-level ethnicity. Lines were smoothed with the SAS Proc LOESS method. Fiscal year runs from April 1 to March 31 of the next year.

change, −1.5 [95% CI, −2.6 to −0.4]). In less walkable areas, diabetes incidence was not significantly different in 2012 compared with baseline (change, −0.65 in quintile 1 [95% CI, −1.65 to 0.39; *P* = .20], −0.5 in quintile 2 [95% CI, −1.5 to 0.5; *P* = .30], and −0.9 in quintile 3 [95% CI, −1.9 to 0.02; *P* = .06]). By 2012, the adjusted diabetes incidence was 1.7 per 1000 persons lower in the highest- vs lowest-walkability neighborhoods (6.2 vs 7.9 per 1000; absolute difference, −1.7 [95% CI, −2.8 to −0.7]; *P* = .001).

In the sensitivity analysis, walkability was inversely related to diabetes incidence in neighborhoods of various income levels. For every 5-point increase in neighborhood walkability score (treated as a continuous variable), the relative risk of diabetes was 0.96 (95% CI, 0.96-0.96), 0.95 (95% CI, 0.94-0.96), and 0.96 (95% CI, 0.95-0.97) in areas with lower, middle, and higher levels of poverty, respectively, in 2012. The intraclass correlation coefficient was close to zero; however, rerunning the model while accounting for clustering led to similar results (relative risk for every 5-point increase in neighborhood walkability: 0.96 [95% CI, 0.94-0.98], 0.95 [95% CI, 0.94-0.96], and 0.96 [95% CI, 0.96-0.97] for lower, middle, and higher levels of poverty, respectively).

Figure 3. Mode of Transportation Among Adults Aged 30 to 64 Years and Living in Urban Areas, by Walkability Quintile, 2001-2011



Data sources include Transportation Tomorrow Survey (TTS) conducted in 2001, 2006, and 2011 (n ≈ 128 420 households per cycle) in Toronto, Hamilton, and surrounding communities. Age-group-specific rates were based on all eligible TTS participants in a given quintile and weighted with TTS survey weights. Tests of trends over time; $P < .001$ for increases in walking or cycling (quintiles 1, 2, 4, and 5) and public transit (quintiles 1, 2, and 4); $P < .001$ for decreases in driving in all quintiles. Quintile 5 vs quintile 1 difference in walking or cycling: 19 per 100 persons (95% CI, 17-20) in 2001 and 25 per 100 (95% CI, 24-26) in 2011.

Table 2. Age- and Sex-Adjusted Prevalence of Health Behaviors Among Individual Adults Aged 30-64 Years and Living in the Study Area[a]

Health Behavior and Walkability Quintile[b]	Age- and Sex-Adjusted Prevalence by Cycle, %[e] 2003	2005	2007-2008	2009-2010
Physically inactive in leisure time[c,g]				
1 (Least walkable)	51.3	50.6	55.2	53.6
2	55.8	53.8	59.5	59.9
3	54.7	56.2	58.4	56.6
4	59.3	57.3	60.8	59.5
5 (Most walkable)	50.1	48.6	52.1	52.3
Inadequate fruit and vegetable intake[d,g]				
1 (Least walkable)	56.1	58.9	55.9	57.9
2	58.2	57.4	63.6	58.6
3	59.0	62.0	57.7	55.9
4	61.7	57.8	59.5	56.6
5 (Most walkable)	56.4	53.6	58.7	60.5
Current smoker[f,g]				
1 (Least walkable)	18.1	15.2	16.2	16.1
2	21.2	20.8	15.5	17.9
3	25.3	24.8	22.6	18.5
4	24.8	20.9	22.0	18.9
5 (Most walkable)	24.0	24.4	23.2	20.6

Data source: Canadian Community Health Survey.

[a] London, Ottawa, Hamilton, Toronto, and surrounding communities.

[b] Median walkability score (range): quintile 1, 10.1 (0-12.04), quintile 2, 13.7 (12.05-15.22), quintile 3, 16.8 (15.23-18.60), quintile 4, 20.9 (18.61-25.49), and quintile 5, 35.2 (25.50-100).

[c] Leisure-time physical activity index of <1.5 cal/kg per day.

[d] Eats fewer than 5 servings of fruits and vegetables per day.

[e] Individual survey weights were incorporated into regression models to derive adjusted prevalence estimates. N = 5407 in 2003, N = 4986 in 2005, N = 5422 in 2007, and N = 6165 in 2009.

[f] $P < .01$ for decreases in smoking over time in quintiles 2 to 5; $P > .05$ in quintile 1.

[g] $P > .05$ for yearly comparisons of quintile 1 vs quintile 5 and all other tests of trends over time.

Transportation Behaviors

At each point, residents in the most walkable neighborhoods had higher rates of daily walking or cycling (28 vs 3 per 100 persons in 2011; difference, 25 per 100; 95% CI, 24-26; $P = <.001$) and public transit trips (58 vs 20 per 100 persons in 2011; difference, 38 per 100 persons; 95% CI, 36-40; $P < .001$) and lower rates of daily driving trips (145 vs 250 per 100 persons in 2011; difference, −105 per 100 (95% CI, −110 to −100; $P < .001$) compared with those living in the least walkable areas (**Figure 3**). During the 10-year period, there were modest increases in walking and cycling in highly walkable areas, equivalent to 7 additional daily trips per 100 persons.

Other Health Behaviors

There was little variation in rates of physical inactivity during leisure time, inadequate fruit and vegetable consumption, and smoking in the population during the study and no association between neighborhood walkability and any of these health behaviors (**Table 2**). Primary care use was similar across walkability quintiles and was stable over time (median of 2 visits in the previous year [interquartile range, 0-5] in 2001 and 2012).

Discussion

This study found that urban neighborhoods that were characterized by more walkable urban design were associated with a stable prevalence of overweight and obesity and declining diabetes incidence during a 12-year period. By 2012, rates of each of these conditions were significantly lower in these highly walkable neighborhoods compared with less walkable areas, in which levels of obesity continued to increase.

To our knowledge, this is the first prospective study to examine the association between neighborhood walkability and concomitant health outcomes (overweight/obesity and diabetes). The strengths of this study include its large sample size, its population-based nature, and the consistency of findings across outcomes ascertained by using different data sources. The relationships observed were not linear in that body weight and diabetes risk were lower only in higher-walkability neighborhoods. The consistency of the relationship between walkability and obesity-related outcomes has been borne out in other studies conducted in North American cities.[9-12] Although the majority of earlier studies on this topic were cross-sectional, there is some evidence from smaller prospective studies that individuals living in environments that support walking and other physical activities experience less weight gain and are less likely to develop insulin resistance or diabetes.[11,12,24,25] However, several of these studies measured walkability according to residents' perceptions, and none addressed the issue that residents living in walkable areas may be inherently healthier or more physically active.

In addition, the observed patterns are not easily explained by other confounders. The analysis accounted for differences in the ethnic composition and socioeconomic characteristics of each residential area. There was no indication that highly walkable areas were undergoing rapid shifts in wealth compared with less walkable neighborhoods, although there was a modest decrease in poverty in these areas, with a concomitant increase in education level. Although there is evidence that low-income neighborhoods have higher levels of obesity and diabetes, the changes in poverty observed during this period were likely too small to explain a decline in diabetes incidence of this magnitude.[26,27] Furthermore, poverty levels remained 9% higher in the most vs least walkable areas at the end of the study period, and changes in socioeconomic status were accounted for in the analysis.

Although residents living in more walkable areas may be expected to be more health conscious, they reported that they were no more likely to engage in leisure-time physical activity, nor did they report having a better-quality diet or smoking less. There were also no significant differences across quintiles with respect to access to parks, fitness clubs, or health care. Recent studies suggest that individuals who regularly engage in walking and cycling or who use public transit may be more likely to achieve the 30 or more recommended minutes of moderate to vigorous physical activity per day.[7] In contrast, driving has been linked to a higher likelihood of obesity, similar to other sedentary behaviors.[9,28] However, although the relationships observed are plausible from an etiologic perspective, rates of walking or cycling increased only modestly during the study. Thus, it is not possible to directly ascribe population-level changes in overweight, obesity, and diabetes to transportation choices. Further research is needed to understand whether the relationship between walkability and obesity-related outcomes is causal and, if so, whether transportation patterns mediate such effects.

Findings from this study revealed a continuing increase in obesity-related outcomes in less walkable areas, although rates increased less sharply than in earlier decades, with a plateauing of diabetes incidence from approximately 2006 onward. Data from the National Health and Nutrition Examination Survey and other US surveys suggest that the epidemic of obesity and diabetes has slowed in the United States.[1-4] Studies from the United Kingdom, Sweden, Switzerland, and Spain have reported a similar phenomenon, with relatively stable levels during the past decade.[29-33] During the same period, rates of walking, cycling, and public transportation use increased modestly, whereas driving rates decreased. Although this may be due in part to increasing oil prices or traffic congestion, there have been major public health efforts to promote physical activity and healthier eating through public policies, social advocacy, and media campaigns.[34,35] Simultaneously, there has been increasing awareness among clinicians and public health officials of the effectiveness of intensive lifestyle strategies for diabetes prevention after such landmark trials as the Diabetes Prevention Program.[36] Despite increased public awareness and repeated messaging, individuals may be able to act only when opportunities for physical activity exist, in the presence of a permissive and supportive environment.

There are several limitations to this study that merit discussion. Self-selection may have contributed to observed differences in outcomes across neighborhoods. However, key sociodemographic variables that are related to obesity and diabetes were controlled for in the analysis, including age, income, and ethnicity. This was not a randomized trial, and therefore it is possible that unmeasured confounders (eg, occupation) contributed to the findings. Assigning causation to neighborhood walkability requires caution because of the difficulty in disentangling its effects from that of other neighborhood exposures, such as socioeconomic status, using observational data. However, the relationship between walkability and diabetes incidence was consistent across neighborhoods of various income levels. Moreover, there may be other characteristics of highly walkable areas that relate to better health that were not measured; for instance, access to healthier food.[37] The Transportation Tomorrow Survey provided data on the frequency of walking or cycling trips, but information on the cumulative duration of such trips and overall energy expenditure devoted to transportation was lacking. Other limitations include the use of self-reported rather than measured BMI, which could have led to underestimating the true prevalence of overweight and obesity; self-report may have also led to overreporting the amount of physical activity. Validation studies have found that obesity is underestimated in the Canadian Community Health Survey by 6% to 9% in all cycles; however, this underreporting should have been consistent across neighborhood subtypes, making it unlikely to significantly influence the results.[38] In addition, undiagnosed cases of diabetes could not be captured, which may have led to lower estimates of diabetes incidence; however, the proportion of cases that are unknown is likely to be very low because of universal access to health care and high rates of both primary care use and diabetes screening in the Canadian population.[39,40]

Conclusions

In Ontario, Canada, higher neighborhood walkability was associated with decreased prevalence of overweight and obesity and decreased incidence of diabetes between 2001 and 2012. However, the ecologic nature of these findings and the lack of evidence that more walkable urban neighborhood design was associated with increased physical activity suggest that further research is necessary to assess whether the observed associations are causal.

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