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ASSOCIATION BETWEEN NEIGHBOURHOOD WALKABILITY AND METABOLIC RISK FACTORS INFLUENCED BY PHYSICAL ACTIVITY: A CROSS-SECTIONAL STUDY OF ADULTS IN TORONTO, CANADA

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TITLE

Association between neighbourhood walkability and metabolic risk factors influenced by physical activity: a cross-sectional study of adults in Toronto, Canada

ABSTRACT

Objective: To determine whether neighbourhood walkability is associated with clinical measures of obesity, hypertension, diabetes, and dyslipidemia in an urban adult population.

Design: Observational cross-sectional study

Setting: Urban primary care patients

Participants: 78,023 Toronto residents, aged 18 years and over, who received care from a primary care physician participating in the University of Toronto Practice Based Research Network (UTOPIAN), within the Canadian Primary Care Sentinel Surveillance Network (CPCSSN). Included participants must have been formally rostered, or have had at least two visits, with a CPCSSN-UTOPIAN primary care physician between 2012 and 2014.

Main outcome measures: Differences in average BMI, systolic and diastolic blood pressure, fasting blood glucose, hemoglobin A1c, total cholesterol, high-density lipoprotein, low-density lipoprotein, and triglyceride between residents in the highest quartile of neighbourhood walkability and residents in lowest quartile of walkability. Outcomes were objectively measured by primary care practitioners or through laboratory testing and were retrieved from primary care electronic medical records.

Results: Compared to those in the lowest neighbourhood walkability quartile, individuals in the highest quartile had lower mean BMI (-2.64 kg/m^2, 95% CI -2.98 to -2.30; p<0.001), systolic blood pressure (-1.35 mmHg, 95% CI -2.01 to -0.70; p<0.001), diastolic blood pressure (-0.60 mmHg, 95% CI -1.06 to -0.14; p=0.010), and hemoglobin A1c (-0.063%, 95% CI -0.11 to -0.021; p=0.003), and higher mean high-density lipoprotein (0.052 mmol/L, 95% CI 0.029 to 0.075; p<0.001).

Conclusions: There was a clinically meaningful association between living in a neighbourhood in the highest walkability quartile and having lower BMI and modestly lower blood pressure.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This neighbourhood walkability study is unique in examining a set of objectively measured metabolic risk factors, all of which are known to change with physical activity.
- We used electronic medical record data, which allowed us to control for patient-level covariates and express results in a clinically meaningful way.
- It was not possible to control for diet or the food environment with our study data.
- The cross-sectional study design could not rule out a residential selection effect in which individuals with healthier lifestyles may choose to reside in more walkable neighbourhoods.

INTRODUCTION

Increasing physical activity can significantly impact disability adjusted life years (DALYs) in developed countries. This is because many of the top risk factors associated with excess morbidity and mortality – high body mass index, high blood pressure, high glycemic levels, and high cholesterol – are all impacted by exercise [1]. Clinical practice guidelines consistently recommend physical activity, both as part of a healthy lifestyle [2-4] and as non-pharmacologic therapy for overweight and obesity [5-8], hypertension [9-11], diabetes [12-14], and dyslipidemia [15-17]. At the population level, public health professionals have advocated for the use of built environment designs that support or promote active transportation such as walking or cycling [18 19]. This latter approach advances health promotion to sectors beyond health care, toward the creation of public policies and environments that support health [20].

Multiple scales have been developed and validated to measure aspects of a neighbourhood's built environment that promote pedestrian walking [21 22]. Characteristics such as residential density, intersection density, and public transport density have been shown to influence walkability and physical activity [23]. Current evidence suggests that greater neighbourhood walkability is associated with increased physical activity, through walking for transport or "utilitarian walking" [24-29]. Studies using survey or administrative data have found associations between areas of higher walkability and population-level health outcomes such as lower prevalence of obesity, diabetes [28 30 31], [30 32] and hypertension [33]. However, there is limited information on objectively measured metabolic risk factors which are known to change with physical activity.

This study examined the association between relative residential neighbourhood walkability and objectively measured metabolic risk factors in an urban adult population.

METHODS

This was an observational cross-sectional study which used routinely collected electronic medical record (EMR) data linked with neighborhood-level characteristics.

Study Population

The study population included patients, aged 18 and above, seen by a primary care physician participating in the University of Toronto Practice Based Research Network (UTOPIAN). UTOPIAN is one of 11 Primary Care Practice Based Research Networks that are part of the Canadian Primary Care Sentinel Surveillance Network (CPCSSN). CPCSSN is a multi-disease surveillance system where primary care physicians contribute de-identified EMR data to a national database [34]. Patients who were enrolled with, or who had at least two visits with a CPCSSN-UTOPIAN primary care physician between January 1, 2012 and December 31, 2014 and who had a valid City of Toronto residential postal code were included in this study. Data were extracted as of December 31, 2014 using procedures previously described [34].

Measure of Neighbourhood Walkability

The walkability of each individual's residential neighbourhood was measured using Walk Score®, a validated index that calculates the walkability of an address based on distance to amenities and aspects of pedestrian friendliness including population density, block length, and intersection density [35]. In this walkability index, locations are scored from 0 to 100, where 100 is the most walkable [35]. Toronto has 140 neighbourhoods, each of which is an administrative area that covers several city blocks, and has a minimum population of 7,000 to 10,000 [36]. Neighbourhood-level Walk Scores® for all Toronto neighbourhoods are publicly available online [37] and represent a population-weighted aggregation of a grid of Walk Score® points for the entire area of a neighbourhood, as delineated by administrative boundaries [35]. Based on their residential postal code, participants were assigned to a Toronto neighbourhood using Toronto neighbourhood and postal code area shapefiles [38-40] with ESRI ArcGIS ArcMap V.10.1.

Health Outcome Measures

The health outcome measures in this study were body mass index (BMI), systolic and diastolic blood pressure (sBP, dBP), fasting blood glucose (FBG), hemoglobin A1c (HbA1c), total cholesterol (TC), high-density lipoprotein (HDL), low-density lipoprotein (LDL), and triglyceride (TG). If multiple values were present for the period, the most recent record was used for data analysis. Given that the study sample was derived from a primary care patient population, the collection of these health measures represented the full spectrum of clinical testing: screening of healthy and at-risk individuals, diagnosis of individuals, and monitoring of individuals with chronic conditions for disease control and therapy optimization.

Covariates

Individual and neighbourhood level covariates were measured. Individual health and socio-demographic characteristics obtained from CPCSSN-UTOPIAN data included patient age, sex, current smoking status, presence of a diagnosis of hypertension or diabetes, and presence of a prescription for a weight-loss medication, an anti-hypertensive medication, an anti-diabetic medication, or a lipid-lowering medication. Diagnoses of hypertension and diabetes were based upon validated CPCSSN case definitions and case-finding algorithms [41].

Neighbourhood rates of violent crime reported to the Toronto Police Service (i.e. assault, sexual assault, robbery, and murder) were used as an indicator of neighbourhood safety [42]. Scores reflecting material deprivation, ethnic concentration, residential instability, and dependency at the Toronto neighbourhood level were also retrieved from the Ontario Marginalization Index [43 44]. Material deprivation scores incorporated measures of unemployment, low income, low education, and low-quality housing. Ethnic concentration scores accounted for recent immigration and self-identification as a visible minority. Residential instability scores were derived from multiple indicators, including the proportion of the population who had moved in the previous five years, and the proportion of dwellings that were not owned. Dependency scores included indicators measuring the proportion of the population aged 65 and older and the proportion of the population not participating in the labour force [43 44].

Statistical Analysis

Descriptive statistics were calculated for demographic variables, health outcome measures and all covariates. Toronto neighbourhood walkability was visualized with a choropleth map. Means and 95% confidence intervals (95% CI) of all health measures were calculated for the highest and lowest neighbourhood walkability quartiles. Multivariable linear regression models were also used to compare mean health measures in the highest versus the lowest walkability quartile. All models were adjusted for covariates of age, sex, smoking status, neighbourhood rates of violent crime and neighbourhood indices of material deprivation, ethnic concentration, residential instability and dependency. Models predicting BMI were also adjusted for the presence of a weight-loss medication. Models predicting blood pressure were adjusted for BMI, the presence of a hypertension diagnosis and prescription of anti-hypertensive medication. Models predicting HbA1c and FBG were adjusted for BMI, the presence of a diabetes diagnosis and prescription of anti-diabetic medication. Models predicting cholesterol (total cholesterol, HDL, LDL, TG) were adjusted for BMI and the presence of a prescription for lipid-lowering medication. There were insufficient observations within each neighbourhood to use multilevel models. However, to ensure that the use of non-hierarchical linear regression was appropriate, intraclass correlation coefficients (ICCs) were calculated. Low ICCs for each health outcome (ICC=0.050 for BMI, ICC<0.01 for all other outcomes) revealed that very little of the total variance was accounted for by clustering within neighbourhoods, and that a non-hierarchical approach was reasonable.

Differences in health measures across walkability quartiles were examined for all ages, and in stratified analyses across three age subgroups of 18 to under 40 years, 40 to 65 years, and over 65 years. Broadly, these age categories represent segments of the population where primary versus secondary prevention strategies may be relevant in distinct ways. A younger adult population is more amenable to primary prevention of chronic disease. Both primary and secondary prevention are relevant for middle-aged adults, and notably, they undergo lipid and diabetes screening as recommended by clinical practice guidelines [15 45]. Finally, older adults may differ from younger adults due to increased medical comorbidities that affect the health markers of interest, and due to potentially decreased mobility that may affect levels of walking and physical activity.

All data were analyzed using Stata IC/ V.12.1 and mapping was carried out using ESRI ArcGIS ArcMap V.10.1. This study was reviewed and approved by the CPCSSN Research Privacy and Ethics Officer and by the London School of Hygiene and Tropical Medicine MSc Research Ethics Committee.

RESULTS

78, 023 UTOPIAN patients met the inclusion criteria. The generation of the study sample is displayed in Figure 1.

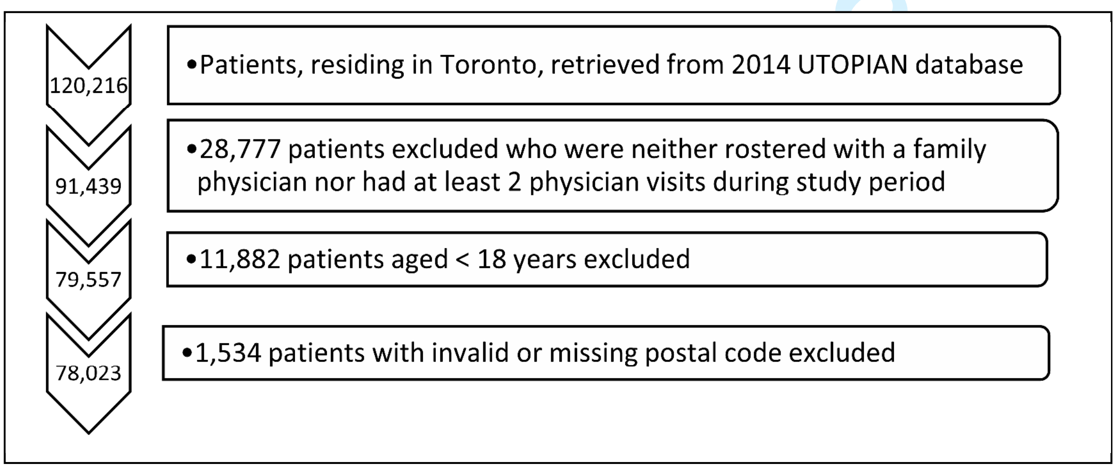

Figure 1. Sequence of steps in generation of study sample.

Characteristics of the study sample are displayed in Table 1. Residents of the lowest and highest quartiles of neighbourhood walkability were similar with respect to age, proportion of women and proportion of smokers. Neighbourhoods in the highest walkability quartile had higher violent crime rates, somewhat lower deprivation scores, but similar ethnic concentration compared to neighbourhoods in the lowest quartile. A map of Toronto's 140 neighbourhoods and their Walk Scores® is displayed in Figure 2. The most walkable neighbourhoods were concentrated in Toronto's downtown core. Neighbourhood Walk Scores® ranged from 42 to 100.

Unadjusted means and 95% CIs for all health measures in the lowest and highest quartiles of neighbourhood walkability are displayed in Table 2. In the lowest quartile of neighbourhood walkability, the unadjusted mean BMI, sBP, dBP, FBG, HbA1c, and TG of residents were all higher than in residents of the highest quartile. On the other hand, the unadjusted means for TC, HDL and LDL were lower in residents of the lowest walkability quartile, compared to residents in the highest quartile. All differences in unadjusted means were significant at the $p<0.001$ level.

Table 1. Descriptive characteristics of study participants.

	Lowest Quartile of Neighbourhood Walkability			Highest Quartile of Neighbourhood Walkability			Total Study Population		
Characteristic	**Frequency (%)**	**Mean (SD)**	**N patients with data**	**Frequency (%)**	**Mean (SD)**	**N patients with data**	**Frequency (%)**	**Mean (SD)**	**N patients with data**
Sex (female)	11,303 (62.3%)		18,137	11,399 (62.7%)		18,192	48,556 (62.2%)		78,022
Age [years]		49.2 (19.2)	18,122		48.5 (17.9)	18,180		50.0 (19.2)	77,966
18<u><</u>age<40	6,448 (35.6%)			6,895 (37.9%)			26,977 (34.6%)		
40<u><</u>age<u><</u>65	7,731 (42.7%)			7,760 (42.7%)			33,056 (42.4%)		
>65 years	3,943 (21.8%)			3,525 (19.4%)			17,933 (23.0%)		
Smoking (current smoker)	1,530 (12.0%)		12,772	1,669 (13.3%)		12,511	6,808 (12.1%)		56,093
Anthropometric indicators									
Body Mass Index (BMI) [kg/m^2]		29.6 (10.0)	9,819		26.0 (6.22)	10,920		27.2 (7.4)	46,029
Overweight or obese (BMI<u>></u>25 kg/m^2)	6,370 (64.9%)		9,819	5,505 (50.4%)		10,920	26,309 (57.2%)		46,029
Prescribed weight-loss medication	1,146 (6.3%)		18,137	523 (2.9%)		18,192	3,387 (4.3%)		78,023
Blood pressure control									
Hypertension diagnosis	4,068 (22.4%)		18,137	2,980 (16.4%)		18,192	16,241 (20.8%)		78,023
Prescribed anti-hypertensive medication	4,796 (26.4%)		18,137	3,555 (19.5%)		18,192	19,020 (24.4%)		78,023
Systolic blood pressure (sBP) [mmHg]		121.5 (16.0)	13,722		117.4 (15.5)	13,950		119.8 (16.0)	59,634
Diastolic blood pressure (dBP) [mmHg]		75.0 (10.0)	13,722		73.1 (10.0)	13,950		73.8 (10.0)	59,634
Blood glucose control									
Diabetes diagnosis	2,242 (12.4%)		18,137	1,096 (6.0%)		18,192	6,988 (9.0%)		78,023
Prescribed anti-diabetic medication	1,788 (9.9%)		18,137	786 (4.3%)		18,192	5,220 (6.7%)		78,023
Hemoglobin A1c (HbA1c) [%]		6.10 (1.10)	6,721		5.74 (0.75)	5,570		5.89 (0.88)	29,575
Fasting blood glucose (FBG) [mmol/L]		5.56 (1.70)	8,388		5.32 (1.26)	6,367		5.42 (1.46)	34,698
Lipid control									
Prescribed lipid-lowering medication	3,686 (20.3%)		18,137	2,453 (13.5%)		18,192	13,979 (17.9%)		78,023
Total cholesterol (TC) [mmol/L]		4.73 (1.08)	8,690		4.93 (1.04)	6,825		4.81 (1.06)	36,498
High density lipoprotein (HDL) [mmol/L]		1.43 (0.41)	8,844		1.58 (0.47)	7,014		1.49 (0.44)	37,295
Low density lipoprotein (LDL) [mmol/L]		2.71 (0.90)	8,770		2.78 (0.88)	6,983		2.74 (0.89)	37,097
Triglycerides (TG) [mmol/L]		1.34 (1.05)	8,883		1.26 (0.79)	7,008		1.31 (0.87)	37,417
Neighbourhood violent crime rate* [events per 10,000 residents]		95.4 (49.8)	18,137		128.2 (84.3)	18,192		91.3 (59.6)	78,023
Neighbourhood Instability Score†		-0.048 (0.48)	18,137		1.37 (0.68)	18,192		0.480 (0.71)	78,023
Neighbourhood Deprivation Score†		0.30 (0.96)	18,137		-0.53 (0.69)	18,192		-0.170 (0.77)	78,023
Neighbourhood Ethnic Concentration Score†		1.78 (0.89)	18,137		0.82 (0.89)	18,192		1.353 (1.08)	78,023
Neighbourhood Dependency Score†		-0.020 (0.36)	18,137		-0.44 (0.27)	18,192		-0.100 (0.39)	78,023

SD—standard deviation, N—number of observations in study sample

*Violent crime includes occurrences of assault, sexual assault, robbery, and murder.

†Scores of neighbourhood instability, deprivation, ethnic concentration and dependency are dimensions of the Ontario Marginalization Index [46]. Scores are population-weighted, and higher values indicate greater instability/deprivation/ethnic concentration/dependency.

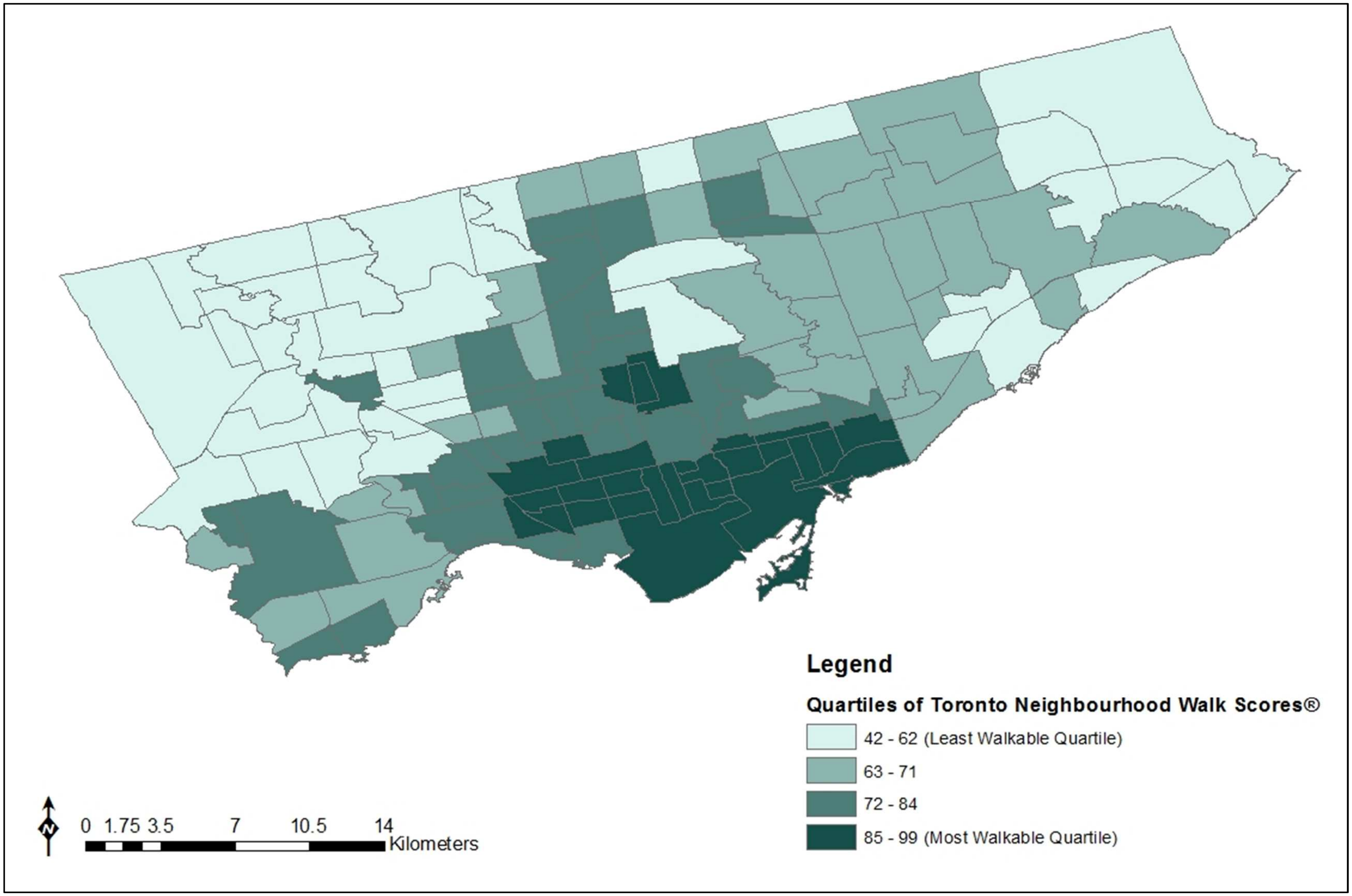

Figure 2. Map of Toronto neighbourhood walkability as measured by neighbourhood Walk Scores®. Walk Scores® for Toronto neighbourhoods (n=140) were retrieved from www.walkscore.com [37].

Table 2. **Unadjusted means and 95% confidence intervals (95% CIs) for health measures in the lowest and highest quartiles of neighbourhood walkability**.

Health measure [unit]	Mean (95% CI) in Lowest Quartile of Neighbourhood Walkability	Mean (95% CI) in Highest Quartile of Neighbourhood Walkability
BMI [kg/m^2]	29.6 (29.5—29.8)	26.0 (25.9—26.2)*
sBP [mmHg]	121.5 (121.2—121.7)	117.4 (117.2—117.7)*
dBP [mmHg]	75.0 (74.8—75.1)	73.1 (72.9—73.3)*
HbA1c [%]	6.10 (6.08—6.12)	5.74 (5.72—5.76)*
FBG [mmol/L]	5.56 (5.53—5.59)	5.32 (5.28—5.35)*
TC [mmol/L]	4.73 (4.71—4.75)	4.93 (4.91—4.96)*
HDL [mmol/L]	1.43 (1.42—1.44)	1.58 (1.57—1.59)*
LDL [mmol/L]	2.71 (2.69—2.73)	2.78 (2.76—2.80)*
TG [mmol/L]	1.34 (1.32—1.36)	1.26 (1.24—1.28)*

*Asterisks indicate a significant difference between the unadjusted mean at the highest walkability quartile, compared to the unadjusted mean in the lowest walkability quartile, at a significance level of p<0.001.

Table 3 displays the adjusted linear regression coefficients comparing differences in mean health measures between the highest and lowest quartiles of neighbourhood walkability. Data for all quartiles are reported in Supplementary Table 1. After adjusting for covariates, there were statistically significant differences in average measures of BMI, sBP, dBP, HbA1c, and HDL between participants in the lowest versus the highest walkability quartile.

Mean BMI was 2.64 kg/m^2 lower (95% CI -2.98 to -2.30, p<0.001) among individuals in the highest neighbourhood walkability quartile, compared to those in the lowest quartile. In the stratified analyses, this difference was greatest in those aged 18 to under 40, where mean BMI was -4.44 kg/m^2 lower (95% CI -5.09 to -3.79, p<0.001), and smallest in those over age 65, where mean BMI was 0.87 kg/m^2 lower (95% CI -1.48 to -0.26, p=0.005), comparing the highest to lowest neighbourhood walkability quartiles.

When comparing average blood pressure measurements of individuals in the highest quartile of neighbourhood walkability to those in the lowest quartile, mean sBP was 1.35 mmHg lower (95% CI -2.01 to -0.70, p<0.001) and mean dBP was 0.60 mmHg lower (95% CI -1.06 to -0.14, p=0.010). When stratifying by age categories, significant differences in mean sBP and dBP were observed only in those aged 40 to 65.

With respect to blood glucose control, mean HbA1c was 0.063% lower (95% CI -0.11 to -0.021, p=0.003) in those within the highest neighbourhood walkability quartile compared to those in the lowest quartile. Across the age subgroups, a significant difference in mean HbA1c was observed only in those aged 18 to under 40. No evidence of differences in mean FBG was observed between the highest and the lowest quartiles of neighbourhood walkability.

In terms of cholesterol parameters, mean HDL was 0.052 mmol/L higher (95% CI 0.029 to 0.075, p<0.001) in those in the highest versus the lowest neighbourhood walkability quartile. Across the age subgroups, a difference in mean HDL was present in the two older age categories, but absent in those aged 18 to under 40. The difference observed in mean TC was of borderline statistical significance (0.061 mmol/L, 95% CI 0.00025 to 0.12; p=0.049), and in the stratified analyses, was only significant in those aged 40 to 65. No strong evidence of differences in other cholesterol parameters was apparent when comparing the highest to the lowest quartiles of neighbourhood walkability.

Table 3. Adjusted linear regression coefficients comparing differences in mean health measures between the highest and lowest quartiles of neighbourhood walkability. Results are presented for all ages and for each age sub-category. Regression coefficients represent differences in the mean health measure, adjusting for covariates of age, sex, current smoking status, BMI (except in the model where BMI is the health outcome measure) relevant medications and medical diagnoses, neighbourhood violent crime rates, and neighbourhood indices of material deprivation, ethnic concentration, dependency, and residential instability.

Health measure [unit]	Regression coefficient (95% CI)	p-value
BMI [kg/m^2] – all ages ≥ 18	-2.64 (-2.98 to -2.30)	<0.001
18 ≤ age < 40	-4.44 (-5.09 to -3.79)	<0.001
40 ≤ age ≤ 65	-2.74 (-3.24 to -2.23)	<0.001
age > 65	-0.87 (-1.48 to -0.26)	0.005
sBP [mmHg] – all ages ≥ 18	-1.35 (-2.01 to -0.70)	<0.001
18 ≤ age < 40	-0.64 (-1.68 to 0.41)	0.23
40 ≤ age ≤ 65	-1.97 (-2.91 to -1.03)	<0.001
age > 65	-0.64 (-2.14 to 0.85)	0.40
dBP [mmHg] – all ages ≥ 18	-0.60 (-1.06 to -0.14)	0.010
18 ≤ age < 40	0.12 (-0.68 to 0.93)	0.76
40 ≤ age ≤ 65	-1.30 (-1.94 to -0.66)	<0.001
age > 65	-0.19 (-1.13 to 0.75)	0.69
HbA1c [%] – all ages ≥ 18	-0.063 (-0.11 to -0.021)	0.003
18 ≤ age < 40	-0.12 (-0.23 to -0.019)	0.021
40 ≤ age ≤ 65	-0.059 (-0.12 to 0.0026)	0.060
age > 65	-0.013 (-0.078 to 0.051)	0.69
FBG [mmol/L] – all ages ≥ 18	0.030 (-0.038 to 0.099)	0.39
18 ≤ age < 40	-0.086 (-0.24 to 0.073)	0.29
40 ≤ age ≤ 65	0.028 (-0.068 to 0.12)	0.57
age > 65	0.083 (-0.036 to 0.20)	0.17
TC [mmol/L] – all ages ≥ 18	0.061 (0.00025 to 0.12)	0.049
18 ≤ age < 40	-0.023 (-0.18 to 0.13)	0.77
40 ≤ age ≤ 65	0.11 (0.024 to 0.19)	0.012
age > 65	-0.023 (-0.13 to 0.078)	0.65
HDL [mmol/L] – all ages ≥ 18	0.052 (0.029 to 0.075)	<0.001
18 ≤ age < 40	0.022 (0.038 to 0.081)	0.47
40 ≤ age ≤ 65	0.052 (0.020 to 0.084)	0.001
age > 65	0.060 (0.019 to 0.10)	0.004
LDL [mmol/L] – all ages ≥ 18	0.010 (-0.041 to 0.062)	0.69
18 ≤ age < 40	-0.0088 (-0.14 to 0.12)	0.89
40 ≤ age ≤ 65	0.026 (-0.044 to 0.096)	0.47
age > 65	-0.036 (-0.12 to 0.049)	0.41
triglyceride [mmol/L] – all ages ≥ 18	-0.0031 (-0.053 to 0.047)	0.90
18 ≤ age < 40	-0.14 (-0.33 to 0.047)	0.14
40 ≤ age ≤ 65	0.038 (-0.029 to 0.11)	0.27
age > 65	-0.041 (-0.11 to 0.033)	0.28

DISCUSSION

Key findings: Neighbourhood Walkability and Metabolic Risk Factors

We observed an association between higher neighborhood walkability and objectively measured metabolic risk factors. This was most pronounced for BMI, especially for younger adults. The differences observed for BMI and blood pressure were clinically significant and relevant for population health.

Strengths and Limitations

The main strength of this study is that it used EMR data to examine a set of clinical measures known to change with physical activity, all of which were objectively measured through physical examination or laboratory testing. The study controlled for both individual clinical attributes, as well as neighbourhood-level covariates that could have confounded the relationship between neighbourhood walkability and the metabolic risk factors of interest [26 32 47 48].

Overall, the study population included a large and diverse sample of adults of all ages, with and without chronic disease. However, the application of the study findings to other adult populations in a developed, urban setting should also consider that these were primary care patients. In particular, this population did not include children or adolescents, was older and had a greater proportion of women than the general population of Toronto [49].

The main limitation of this study is its cross-sectional nature, which precludes the establishment of temporality in the association between neighbourhood walkability and health outcomes. Importantly, it is not possible to rule out a residential selection effect, in which healthier individuals who choose to engage in more health-promoting behaviours, such as physical activity, may also choose to live in more walkable areas to facilitate their preferred lifestyle. Similarly, individuals with obesity or diabetes may have poorer mobility and decreased exercise capacity, and may elect to reside in areas that facilitate automobile transportation rather than utilitarian walking. Thus, the magnitude of the observed differences in health measures in this study, and the extent to which they may be attributable to neighbourhood walkability must be interpreted with care. The study is also limited in that it did not control for diet, which could not be captured in a valid manner using electronic medical record (EMR) data. It is possible that dietary habits, particularly as linked to the food environment, may differ between neighbourhoods of high versus low walkability but the extent to which this may have affected estimates in this study is unclear. Similarly, this study did not control for major disabilities or mobility limitations which may have precluded engagement in utilitarian walking in affected participants. This may have contributed to the attenuation of differences in mean BMI observed in older adults.

Relation to Other Studies

The BMI findings are consistent with several recent studies which demonstrated lower prevalence of obesity in high walkability neighbourhoods compared to low walkability neighbourhoods [27 28 30 31]. Importantly, this study quantified the magnitude of the mean difference in BMI that was observed (2.64 kg/m^2), and found that this clinically meaningful difference varied across three age categories. In one previous longitudinal study of 701 participants, residential relocation involving a 10-point increase in street address Walk Score® was associated with an average within-individual BMI reduction of 0.06 kg/m^2 [50]. The magnitude of this effect was smaller than the 2.64 kg/m^2 difference in mean BMI that was observed in this study, between the highest and lowest neighbourhood walkability quartiles (a difference of about 20-60 points in aggregate neighbourhood Walk Score®). Importantly, the scale at which walkability was measured in the present study was at the larger neighbourhood level, rather than at the level of each resident's individual address. This has interesting implications for determining the spatial scale at which a built environment might exert positive health effects mediated by walkability and utilitarian physical activity.

With respect to blood pressure, one previous study that measured walkability and fast-food outlet density reported an association with blood pressure decreases in older adults [51], while another study found no association between walkability and self-reported hypertension [31]. Based on a systematic review and meta-analysis, the effect size of aerobic exercise on blood pressure reduction has been reported as -3.84 mmHg for sBP and -2.58 mmHg for dBP [52]. In the context of previous findings, it is plausible that the small differences in mean sBP and dBP in the current study may be attributable to differences in levels of physical activity, such as utilitarian walking.

Although previous studies have found an association between neighbourhood walkability and both the prevalence and incidence of diabetes [28 30 32], associations between neighbourhood walkability and HbA1c have not been reported. In a systematic review and meta-analysis of 23 RCTs, structured aerobic exercise durations of 150 minutes or less per week were found to be associated with HbA1c reductions of 0.36% [53]. The observed difference in mean HbA1c in this study was considerably smaller. This suggests that the level of physical activity potentially promoted by a more walkable neighbourhood may not be strongly associated with clinically significant changes to HbA1c. Another possibility is that the observed relationship between neighbourhood walkability and mean HbA1c may have been confounded by variations in individual diet as well as in the larger food environment. Furthermore, given that neighbourhood walkability is associated with BMI and obesity prevalence, both of which influence the risk of diabetes, this may explain the finding of higher incidence and prevalence of diabetes in higher walkability neighbourhoods, rather than simply an independent effect of walkability on diabetes.

An association between neighbourhood walkability and objective cholesterol parameters has not been previously reported in the peer-reviewed literature. One previous study reported a lack of an association between walkability and self-reported hypercholesterolemia [31]. In a Cochrane review of exercise effects on overweight or obesity, an HDL improvement of 0.06 mmol/L was found among those who engaged in moderate aerobic exercise compared to controls with no treatment [54]. This suggests that, in the current study, the observed difference in mean HDL between the highest and lowest neighbourhood walkability quartiles is of a magnitude that could be plausibly attributed to a physical activity effect. The lack of consistent differences in other cholesterol parameters between the highest and lowest walkability quartiles is not incompatible with the literature. Indeed, a review of 51 studies, including 28 RCTs, of the effect of aerobic exercise training on blood lipids found that an increase in HDL was the most frequently observed outcome, and reductions in total cholesterol, LDL, and triglyceride were less commonly seen [55]. Again, the current study did not control for dietary factors, which are known to influence cholesterol parameters [56], and the observed associations should be interpreted with this in mind.

Implications of Findings for Population Health

From a clinical perspective, recognizing the relative walkability of a patient's residential neighbourhood may aid health providers in making context-appropriate physical activity recommendations for health maintenance and chronic disease management. More importantly, the implications for walkable environments as a public health intervention are significant if the health associations for walkability presented in this and other studies represent a truly causal relationship. In other words, a highly walkable neighbourhood could represent a population-wide intervention capable of conferring multiple benefits related to obesity prevention, blood pressure control, and potentially even blood glucose and lipid control. At the population level, even small changes in average BMI or blood pressure have the potential to "shift the curve" with respect to the population distribution of disease risk. By lowering the average level of risk factors, such a population strategy targets the determinants of disease incidence and may have the capacity to prevent a considerable fraction of obesity, hypertension, diabetes, and cardiovascular disease that is attributed to physical inactivity [57 58].

One final issue of relevance for policy makers is that of equity. This study demonstrated that across 140 neighbourhoods within a single city, variations in health existed based on walkability characteristics of the built environment. Addressing the determinants of health and health equity at the population level should therefore include consideration of the built environment.

CONCLUSIONS

There is a clinically meaningful association between living in a neighbourhood in the highest walkability quartile and having lower BMI and modestly lower blood pressure. This study demonstrates that EMR data can be a source of objective clinical measures for population health research. Further longitudinal studies on walkable environments are needed to provide a realistic estimate of the magnitude and distribution of their health effects on the population, and to clarify the spatial scale at which neighbourhood walkability realizes these effects. Further research is also needed to examine the broader health and non-health impacts of walkable neighbourhoods, particularly if they are implemented as a built environment intervention at the population level.

Details of Contributors

CKJL conceptualized the study. CKJL and DL designed the analyses in consultation with MG and BA. CKJL cleaned and analyzed the data, and drafted the manuscript. All authors contributed to revising the paper.

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Competing Interests

"Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work."

Ethics Approval

This study was reviewed and approved by the Canadian Primary Care Sentinel Surveillance Network (CPCSSN) Research, Privacy and Ethics Officer and by the London School of Hygiene and Tropical Medicine MSc Research Ethics Committee.

Data Sharing

No additional data available.

References

1. Institute for Health Metrics and Evaluation. Global Burden of Disease. GBD Compare | Viz Hub, 2013.
2. Tremblay MS, Warburton DER, Janssen I, et al. New Canadian Physical Activity Guidelines. Applied Physiology, Nutrition, and Metabolism 2011;**36**(1):36-46 doi: 10.1139/H11-009[published Online First: Epub Date]|.
3. Department of Health. UK Physical Activity Guidelines, 2011.
4. US Department of Health and Human Services. 2008 Physical Activity Guidelines for Americans, 2008.
5. Brauer P, Connor Gorber S, Shaw E, et al. Recommendations for prevention of weight gain and use of behavioural and pharmacologic interventions to manage overweight and obesity in adults in primary care. Canadian Medical Association Journal 2015 doi: 10.1503/cmaj.140887[published Online First: Epub Date]|.
6. *Obesity: Identification, Assessment and Management of Overweight and Obesity in Children, Young People and Adults: Partial Update of CG43*. London: National Clinical Guideline Centre, 2014., 2014.
7. Jensen MD, Ryan DH, Apovian CM, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and The Obesity Society. Circulation 2014;**129**(25 Suppl 2):S102-38 doi: 10.1161/01.cir.0000437739.71477.ee[published Online First: Epub Date]|.
8. Moyer VA. Screening for and management of obesity in adults: U.S. Preventive Services Task Force recommendation statement. Annals of internal medicine 2012;**157**(5):373-8 doi: 10.7326/0003-4819-157-5-201209040-00475[published Online First: Epub Date]|.
9. Daskalopoulou SS, Rabi DM, Zarnke KB, et al. The 2015 Canadian Hypertension Education Program recommendations for blood pressure measurement, diagnosis, assessment of risk, prevention, and treatment of hypertension. Canadian Journal of Cardiology 2015;**31**(5):549-68
10. James PA, Oparil S, Carter BL, et al. 2014 evidence-based guideline for the management of high blood pressure in adults: Report from the panel members appointed to the eighth joint national committee (jnc 8). JAMA 2014;**311**(5):507-20 doi: 10.1001/jama.2013.284427[published Online First: Epub Date]|.
11. McCormack T, Krause T, O'Flynn N. Management of hypertension in adults in primary care: NICE guideline. The British Journal of General Practice 2012;**62**(596):163-64 doi: 10.3399/bjgp12X630232[published Online First: Epub Date]|.
12. Canadian Diabetes Association Clinical Practice Guidelines Expert Committee. Canadian Diabetes Association 2013 clinical practice guidelines for the prevention and management of diabetes in Canada. Canadian Journal of Diabetes 2013;**37**(suppl 1)
13. National Institute for Health and Care Excellence (NICE). Type 2 diabetes in adults: management: National Institute for Health and Care Excellence, 2015.
14. Association AD. 4. Foundations of care: education, nutrition, physical activity, smoking cessation, psychosocial care, and immunization. Diabetes Care 2015;**38**(Supplement 1):S20-S30
15. Anderson TJ, Grégoire J, Hegele RA, et al. 2012 update of the Canadian Cardiovascular Society guidelines for the diagnosis and treatment of dyslipidemia for the prevention of cardiovascular disease in the adult. Canadian journal of cardiology 2013;**29**(2):151-67
16. Stone NJ, Robinson JG, Lichtenstein AH, et al. 2013 ACC/AHA Guideline on the Treatment of Blood Cholesterol to Reduce Atherosclerotic Cardiovascular Risk in AdultsA Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Journal of the American College of Cardiology 2014;**63**(25_PA):2889-934 doi: 10.1016/j.jacc.2013.11.002[published Online First: Epub Date]|.

17. National Institute for Health and Care Excellence (NICE). Cardiovascular disease: risk assessment and reduction, including lipid modification: National Institute for Health and Care Excellence, 2014.
18. National Institute for Health and Care Excellence (NICE). Physical activity and the environment. Public health guideline: National Institute for Health and Care Excellence, 2008.
19. Mowat D, Gardner C, McKeown D, Tran N, Moloughney B, Bursey G. Improving health by design in the Greater Toronto-Hamilton Area. A Report of Medical Officers of Health in the GTHA 2014.
20. The Ottawa Charter for Health Promotion. First International Conference on Health Promotion; 1986 November 21, 1986; Ottawa.
21. Duncan DT, Aldstadt J, Whalen J, Melly SJ, Gortmaker SL. Validation of Walk Score® for Estimating Neighborhood Walkability: An Analysis of Four US Metropolitan Areas. International Journal of Environmental Research and Public Health 2011;**8**(11):4160-79
22. Glazier RH, Weyman JT, Creatore MI, et al. Development and validation of an urban walkability index for Toronto, Canada. Toronto Community Health Profiles Partnership, 2012.
23. Sallis JF, Cerin E, Conway TL, et al. Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. The Lancet 2016;**387**(10034):2207-17
24. Freeman L, Neckerman K, Schwartz-Soicher O, et al. Neighborhood walkability and active travel (walking and cycling) in New York City. Journal of Urban Health 2013;**90**(4):575-85
25. Thielman J, Rosella L, Copes R, Lebenbaum M, Manson H. Neighborhood walkability: Differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. Preventive medicine 2015;**77**:174-80 doi: http://dx.doi.org/10.1016/j.ypmed.2015.05.011[published Online First: Epub Date]|.
26. Arvidsson D, Eriksson U, Lonn SL, Sundquist K. Neighborhood Walkability, Income, and Hour-by-Hour Physical Activity Patterns. Medicine & Sciece in Sports & Exercise 2013;**45**(4):698-705
27. Chiu M, Shah BR, Maclagan LC, Rezai M-R, Austin PC, Tu JV. Walk Score and the prevalence of utilitarian walking and obesity among Ontario adults: a cross-sectional study. Statistics Canada Catalogue no.82-003-X Health Reports 2015;**26**(7):3-10
28. Glazier RH, Creatore MI, Weyman JT, et al. Density, Destinations or Both? A Comparison of Measures of Walkability in Relation to Transportation Behaviors, Obesity and Diabetes in Toronto, Canada. PLoS ONE 2014;**9**(1):e85295 doi: 10.1371/journal.pone.0085295[published Online First: Epub Date]|.
29. Hajna S, Ross NA, Joseph L, Harper S, Dasgupta K. Neighbourhood walkability, daily steps and utilitarian walking in Canadian adults. BMJ Open 2015;**5**(11) doi: 10.1136/bmjopen-2015-008964[published Online First: Epub Date]|.
30. Creatore MI, Glazier RH, Moineddin R, et al. Association of Neighborhood Walkability With Change in Overweight, Obesity, and Diabetes. JAMA 2016;**315**(20):2211-20 doi: 10.1001/jama.2016.5898[published Online First: Epub Date]|.
31. Müller-Riemenschneider F, Pereira G, Villanueva K, et al. Neighborhood walkability and cardiometabolic risk factors in australian adults: an observational study. BMC Public Health 2013;**13**(1):1-9 doi: 10.1186/1471-2458-13-755[published Online First: Epub Date]|.
32. Booth GL, Creatore MI, Moineddin R, et al. Unwalkable neighborhoods, poverty, and the risk of diabetes among recent immigrants to Canada compared with long-term residents. Diabetes Care 2013;**36**(2):302-08
33. Chiu M, Rezai M-R, Maclagan LC, et al. Moving to a Highly Walkable Neighborhood and Incidence of Hypertension: A Propensity-Score Matched Cohort Study. Environ Health Perspect 2015
34. Birtwhistle R, Keshavjee K, Lambert-Lanning A, et al. Building a pan-Canadian primary care sentinel surveillance network: initial development and moving forward. The Journal of the American Board of Family Medicine 2009;**22**(4):412-22

35. Walk Score. Walk Score Methodology. Secondary Walk Score Methodology 2015. https://www.walkscore.com/methodology.shtml.
36. City of Toronto. Neighbourhood Profiles. Secondary Neighbourhood Profiles 2015. http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=ae17962c8c3f0410VgnVCM10000071d60f89RCRD&vgnextchannel=1e68f40f9aae0410VgnVCM10000071d60f89RCRD.
37. Walk Score. Living in Toronto: Toronto Neighborhoods. Secondary Living in Toronto: Toronto Neighborhoods 2015. https://www.walkscore.com/CA-ON/Toronto.
38. Social Development Finance & Administration, City of Toronto. Boundaries of City of Toronto Neighbourhoods. Secondary Boundaries of City of Toronto Neighbourhoods 2014. http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=04b489fe9c18b210VgnVCM1000003dd60f89RCRD&vgnextchannel=75d6e03bb8d1e310VgnVCM10000071d60f89RCRD.
39. Statistics Canada. Postal Code Conversion File (PCCF) Reference Guide: June 2013 postal codes. Catalogue no. 92-154-G: Statistics Canada, 2013.
40. Statistics Canada. Forward Sortation Area Boundary File, Reference Guide: Census year 2011. Catalogue no. 92-179-G: Statistics Canada, 2011.
41. Williamson T, Green ME, Birtwhistle R, et al. Validating the 8 CPCSSN Case Definitions for Chronic Disease Surveillance in a Primary Care Database of Electronic Health Records. Annals of Family Medicine 2014;**12**(4):367-72 doi: 10.1370/afm.1644[published Online First: Epub Date]|.
42. Friesen D, Rajagopalan P, Strashin J. Toronto Crime by Neighbourhood. Secondary Toronto Crime by Neighbourhood April 15, 2015 2011. http://www.cbc.ca/toronto/features/crimemap/.
43. Toronto Community Health Profiles Partnership. DA & CT ON-Marg Data, 2006., 2006.
44. Toronto Community Health Profiles Partnership. Ontario Marginalization Index (ON-Marg). Secondary Ontario Marginalization Index (ON-Marg) 2015. http://www.torontohealthprofiles.ca/onmarg.php.
45. Ekoé J-M, Punthakee Z, Ransom T, Prebtani APH, Goldenberg R. Screening for Type 1 and Type 2 Diabetes. Canadian Journal of Diabetes 2013;**37**(Supplement):S12-S15
46. Matheson FI, Dunn J, Smith KLW, Moineddin R, Glazier RH. Ontario Marginalization Index User Guide Version 1.0. Toronto: Centre for Research on Inner City Health, 2012.
47. Manaugh K, El-Geneidy A. Validating walkability indices: How do different households respond to the walkability of their neighborhood? Transportation research part D: transport and environment 2011;**16**(4):309-15
48. Carr LJ, Dunsiger SI, Marcus BH. Walk score™ as a global estimate of neighborhood walkability. American Journal of Preventive Medicine 2010;**39**(5):460-63
49. City of Toronto, City Planning Social Policy Analysis & Research. 2011 Census: Age and Sex Counts. Toronto: City of Toronto, 2012.
50. Hirsch JA, Diez Roux AV, Moore KA, Evenson KR, Rodriguez DA. Change in walking and body mass index following residential relocation: the multi-ethnic study of atherosclerosis. American Journal of Public Health 2014;**104**(3):e49-e56
51. Li F, Harmer P, Cardinal BJ, Vongjaturapat N. Built environment and changes in blood pressure in middle aged and older adults. Preventive medicine 2009;**48**(3):237-41
52. Whelton SP, Chin A, Xin X, He J. Effect of aerobic exercise on blood pressure: a meta-analysis of randomized, controlled trials. Annals of internal medicine 2002;**136**(7):493-503
53. Umpierre D, Ribeiro PA, Kramer CK, et al. Physical activity advice only or structured exercise training and association with HbA1c levels in type 2 diabetes: a systematic review and meta-analysis. JAMA 2011;**305**(17):1790-99
54. Shaw K, Gennat H, O'Rourke P, Del Mar C. Exercise for overweight or obesity. The Cochrane database of systematic reviews 2006(4):CD003817 doi: 10.1002/14651858.CD003817.pub3[published Online First: Epub Date]|.

55. Leon AS, Sanchez OA. Response of blood lipids to exercise training alone or combined with dietary intervention. Medicine and science in sports and exercise 2001;**33**(6; SUPP):S502-S15
56. Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. Circulation 2002;**106**(25):3143-421
57. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Impact of Physical Inactivity on the World's Major Non-Communicable Diseases. Lancet (London, England) 2012;**380**(9838):219-29 doi: 10.1016/S0140-6736(12)61031-9[published Online First: Epub Date]|.
58. Rose G. Sick individuals and sick populations. International journal of epidemiology 2001;**30**(3):427-32

Supplementary Table 1. Adjusted linear regression coefficients comparing differences in mean health measures between the highest three quartiles (Q2-Q4) of neighbourhood walkability and the lowest quartile (Q1). Results are presented for all ages and for each age category. Regression coefficients represent differences in the mean health measure, adjusting for covariates of age, sex, BMI (except in the model where BMI is the health outcome measure) current smoking status, relevant medications and medical diagnoses, neighbourhood violent crime rates, and neighbourhood indices of material deprivation, ethnic concentration, dependency, and residential instability.

Health measure [unit]	Q2-Q1 regression coefficient (95% CI)	p-value	Q3-Q1 regression coefficient (95% CI)	p-value	Q4-Q1 regression coefficient (95% CI)	p-value
BMI [kg/m^2] – all ages ≥ 18	-2.00 (-2.22 to -1.78)	<0.001	-2.02 (-2.25 to -1.79)	<0.001	-2.64 (-2.98 to -2.30)	<0.001
18 ≤ age < 40	-3.54 (-4.00 to -3.08)	<0.001	-3.51 (-3.99 to -3.03)	<0.001	-4.44 (-5.09 to -3.79)	<0.001
40 ≤ age ≤ 65	-1.83 (-2.16 to -1.50)	<0.001	-1.92 (-2.27 to -1.57)	<0.001	-2.74 (-3.24 to -2.23)	<0.001
age > 65	-0.79 (-1.14 to -0.43)	<0.001	-0.91 (-1.30 to -0.52)	<0.001	-0.87 (-1.48 to -0.26)	0.005
sBP [mmHg] – all ages ≥ 18	0.14 (-0.29 to 0.56)	0.52	-0.95 (-1.40 to -0.50)	<0.001	-1.35 (-2.01 to -0.70)	<0.001
18 ≤ age < 40	0.30 (-0.44 to 1.04)	0.43	-0.75 (-1.52 to 0.018)	0.056	-0.64 (-1.68 to 0.41)	0.23
40 ≤ age ≤ 65	0.21 (-0.40 to 0.83)	0.49	-0.74 (-1.39 to -0.095)	0.025	-1.97 (-2.91 to -1.03)	<0.001
age > 65	0.012 (-0.86 to 0.88)	0.98	-1.22 (-2.17 to -0.26)	0.012	-0.64 (-2.14 to 0.85)	0.40
dBP [mmHg] – all ages ≥ 18	-0.42 (-0.72 to -0.13)	0.005	-0.33 (-0.64 to -0.012)	0.042	-0.60 (-1.06 to -0.14)	0.010
18 ≤ age < 40	-0.47 (-1.04 to 0.10)	0.11	-0.29 (-0.89 to 0.30)	0.33	0.12 (-0.68 to 0.93)	0.76
40 ≤ age ≤ 65	-0.26 (-0.68 to 0.16)	0.23	-0.31 (-0.75 to 0.13)	0.16	-1.30 (-1.94 to -0.66)	<0.001
age > 65	-0.69 (-1.24 to -0.14)	0.014	-0.57 (-1.18 to 0.030)	0.063	-0.19 (-1.13 to 0.75)	0.69
HbA1c [%] – all ages ≥ 18	-0.035 (-0.060 to -0.0093)	0.007	-0.041 (-0.068 to -0.014)	0.003	-0.063 (-0.11 to -0.021)	0.003
18 ≤ age < 40	-0.027 (-0.10 to 0.047)	0.47	-0.051 (-0.13 to 0.027)	0.20	-0.12 (-0.23 to -0.019)	0.021
40 ≤ age ≤ 65	-0.037 (-0.075 to 0.00049)	0.053	-0.046 (-0.086 to -0.0055)	0.026	-0.059 (-0.12 to 0.0026)	0.060
age > 65	-0.018 (-0.054 to 0.018)	0.34	-0.015 (-0.055 to 0.018)	0.46	-0.013 (-0.078 to 0.051)	0.69
FBG [mmol/L] – all ages ≥ 18	0.0098 (-0.031 to 0.051)	0.64	0.0041 (-0.041 to 0.049)	0.86	0.030 (-0.038 to 0.099)	0.39
18 ≤ age < 40	-0.020 (-0.12 to 0.081)	0.69	-0.072 (-0.18 to 0.039)	0.20	-0.086 (-0.24 to 0.073)	0.29
40 ≤ age ≤ 65	0.0060 (-0.052 to 0.064)	0.84	0.00032 (-0.062 to 0.063)	0.99	0.028 (-0.068 to 0.12)	0.57
age > 65	0.018 (-0.050 to 0.085)	0.60	0.032 (-0.043 to 0.11)	0.40	0.083 (-0.036 to 0.20)	0.17
total cholesterol [mmol/L] – all ages ≥ 18	0.038 (0.00077 to 0.074)	0.045	0.020 (-0.019 to 0.060)	0.31	0.061 (0.00025 to 0.12)	0.049
18 ≤ age < 40	-0.029 (-0.13 to 0.074)	0.58	-0.047 (-0.16 to 0.063)	0.40	-0.023 (-0.18 to 0.13)	0.77
40 ≤ age ≤ 65	0.066 (0.016 to 0.12)	0.010	0.041 (-0.013 to 0.095)	0.13	0.11 (0.024 to 0.19)	0.012
age > 65	0.039 (-0.019 to 0.096)	0.19	-0.012 (-0.075 to 0.051)	0.72	-0.023 (-0.13 to 0.078)	0.65
HDL [mmol/L] – all ages ≥ 18	0.0046 (-0.0093 to 0.019)	0.52	0.0018 (-0.013 to 0.017)	0.82	0.052 (0.029 to 0.075)	<0.001
18 ≤ age < 40	-0.039 (-0.078 to 0.00044)	0.053	-0.054 (-0.096 to -0.012)	0.012	0.022 (0.038 to 0.081)	0.47
40 ≤ age ≤ 65	-0.00062 (-0.020 to 0.019)	0.95	0.0014 (-0.019 to 0.022)	0.90	0.052 (0.020 to 0.084)	0.001
age > 65	0.028 (0.0044 to 0.051)	0.020	0.021 (-0.0043 to 0.047)	0.10	0.060 (0.019 to 0.10)	0.004
LDL [mmol/L] – all ages ≥ 18	0.016 (-0.015 to 0.047)	0.31	0.0084 (-0.025 to 0.042)	0.62	0.010 (-0.041 to 0.062)	0.69
18 ≤ age < 40	-0.014 (-0.10 to 0.071)	0.74	0.0014 (-0.090 to 0.093)	0.98	-0.0088 (-0.14 to 0.12)	0.89
40 ≤ age ≤ 65	0.033 (-0.010 to 0.077)	0.13	0.016 (-0.030 to 0.062)	0.49	0.026 (-0.044 to 0.096)	0.47
age > 65	0.019 (-0.029 to 0.067)	0.44	-0.015 (-0.068 to 0.038)	0.59	-0.036 (-0.12 to 0.049)	0.41
triglyceride [mmol/L] – all ages ≥ 18	0.031 (0.00050 to 0.061)	0.046	0.019 (-0.013 to 0.052)	0.24	-0.0031 (-0.053 to 0.047)	0.90
18 ≤ age < 40	0.0079 (-0.12 to 0.13)	0.90	-0.051 (-0.18 to 0.082)	0.46	-0.14 (-0.33 to 0.047)	0.14
40 ≤ age ≤ 65	0.056 (0.014 to 0.097)	0.009	0.035 (-0.010 to 0.079)	0.13	0.038 (-0.029 to 0.11)	0.27
age > 65	0.00043 (-0.041 to 0.042)	0.98	-0.0032 (-0.049 to 0.042)	0.89	-0.041 (-0.11 to 0.033)	0.28

RESEARCH CHECKLIST

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (p. 2)
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found (p.2)
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported (p. 4)
Objectives	3	State specific objectives, including any prespecified hypotheses (p. 4)
Methods		
Study design	4	Present key elements of study design early in the paper (p. 4)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection (p.4-5)
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants (p. 4-5)
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable (p.4-6)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group (p. 4-5)
Bias	9	Describe any efforts to address potential sources of bias (p. 4-6)
Study size	10	Explain how the study size was arrived at (p.6)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why (p. 5-6)
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (p. 5-6)
		(*b*) Describe any methods used to examine subgroups and interactions (p. 6)
		(*c*) Explain how missing data were addressed – data from EMR; N indicated for each variable of interest (p. 4-6, 8)
		(*d*) If applicable, describe analytical methods taking account of sampling strategy – N/A
		(*e*) Describe any sensitivity analyses – N/A
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (p. 6)
		(b) Give reasons for non-participation at each stage (p. 6)
		(c) Consider use of a flow diagram (p. 6)
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (p. 7-8)
		(b) Indicate number of participants with missing data for each variable of interest – data from EMR; N indicated for each variable of interest (p. 8)
Outcome data	15*	Report numbers of outcome events or summary measures (p. 8)

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (p. 10-11)
		(*b*) Report category boundaries when continuous variables were categorized (p. 8-11)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period – N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses (p. 6, 11)
Discussion		
Key results	18	Summarise key results with reference to study objectives (p. 11)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias (p. 12)
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence (p. 11-14)
Generalisability	21	Discuss the generalisability (external validity) of the study results (p. 12)
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based – N/A

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Association between neighbourhood walkability and metabolic risk factors influenced by physical activity: a cross-sectional study of adults in Toronto, Canada

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ASSOCIATION BETWEEN NEIGHBOURHOOD WALKABILITY AND METABOLIC RISK FACTORS INFLUENCED BY PHYSICAL ACTIVITY: A CROSS-SECTIONAL STUDY OF ADULTS IN TORONTO, CANADA

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TITLE

Association between neighbourhood walkability and metabolic risk factors influenced by physical activity: a cross-sectional study of adults in Toronto, Canada

ABSTRACT

Objective: To determine whether neighbourhood walkability is associated with clinical measures of obesity, hypertension, diabetes, and dyslipidemia in an urban adult population.

Design: Observational cross-sectional study

Setting: Urban primary care patients

Participants: 78,023 Toronto residents, aged 18 years and over, who were formally rostered or had at least two visits between 2012-2014 with a primary care physician participating in the University of Toronto Practice Based Research Network (UTOPIAN), within the Canadian Primary Care Sentinel Surveillance Network (CPCSSN).

Main outcome measures: Differences in average body mass index (BMI), systolic and diastolic blood pressure, fasting blood glucose, hemoglobin A1c, total cholesterol, high-density lipoprotein, low-density lipoprotein, and triglyceride between residents in the highest versus the lowest quartile of neighbourhood walkability, as estimated using multivariable linear regression models and stratified by age. Outcomes were objectively measured and were retrieved from primary care electronic medical records. Models adjusted for age, sex, smoking, medications, medical comorbidities and indices of neighbourhood safety and marginalization.

Results: Compared to those in the lowest walkability quartile, individuals in the highest quartile had lower mean BMI (-2.64 kg/m^2, 95% CI -2.98 to -2.30; p<0.001), systolic blood pressure (-1.35 mmHg, 95% CI -2.01 to -0.70; p<0.001), diastolic blood pressure (-0.60 mmHg, 95% CI -1.06 to -0.14; p=0.010), and hemoglobin A1c (-0.063%, 95% CI -0.11 to -0.021; p=0.003), and higher mean high-density lipoprotein (0.052 mmol/L, 95% CI 0.029 to 0.075; p<0.001). In age-stratified analyses, differences in mean BMI were consistently observed for adults aged 18 to under 40 (-4.44 kg/m^2, 95% CI -5.09 to -3.79; p<0.001), adults aged 40-65 (-2.74 kg/m^2, 95% CI -3.24 to -2.23; p<0.001), and adults aged over 65 (-0.87 kg/m^2, 95% CI -1.48 to -0.26; p=0.005).

Conclusions: There was a clinically meaningful association between living in the most walkable neighbourhoods and having lower BMI in adults of all ages.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This neighbourhood walkability study is unique in examining a set of objectively measured metabolic risk factors, all of which are known to change with physical activity.
- We used electronic medical record data, which allowed us to control for patient-level covariates and express results in a clinically meaningful way.
- It was not possible to control for diet or the food environment with our study data.
- The cross-sectional study design could not rule out a residential selection effect in which individuals with healthier lifestyles may choose to reside in more walkable neighbourhoods.

INTRODUCTION

Increasing physical activity can significantly impact disability adjusted life years (DALYs) in developed countries. This is because many of the top risk factors associated with excess morbidity and mortality – high body mass index, high blood pressure, high glycemic levels, and high cholesterol – are all impacted by exercise [1]. Clinical practice guidelines consistently recommend physical activity, both as part of a healthy lifestyle [2-4] and as non-pharmacologic therapy for overweight and obesity [5-8], hypertension [9-11], diabetes [12-14], and dyslipidemia [15-17].

At the population level, public health professionals have advocated for the use of built environment designs that support or promote active transportation such as utilitarian walking or cycling [18 19]. Utilitarian walking describes non-recreational walking that is used as a mode of transportation, commonly in the course of conducting errands, or traveling to and from school or work [20 21]. By recognizing neighbourhood design as a way to influence health behaviours and "build in" physical activity into daily living, this population health approach advances health promotion to sectors beyond health care, toward the creation of public policies and environments that support health [22].

Multiple scales have been developed and validated to measure aspects of a neighbourhood's built environment that promote pedestrian walking [23 24]. Characteristics such as residential density, intersection density, and public transport density have been shown to influence walkability and physical activity [25]. Current evidence suggests that greater neighbourhood walkability is associated with increased physical activity, through walking for transport or utilitarian walking [26-31]. Studies using survey or administrative data have found associations between areas of higher walkability and population-level health outcomes such as lower prevalence and incidence of obesity and diabetes [30 32-34], and lower incidence of hypertension [35]. However, there is limited information on objectively measured metabolic risk factors which are known to change with physical activity.

This study examined the association between relative residential neighbourhood walkability and objectively measured metabolic risk factors in an urban adult population.

METHODS

This study used an observational cross-sectional design and linked routinely collected electronic medical record (EMR) data with neighborhood-level characteristics.

Study Population

The study population included patients, aged 18 and above, seen by a primary care physician participating in the University of Toronto Practice Based Research Network (UTOPIAN). UTOPIAN is one of 11 Primary Care Practice Based Research Networks that are part of the Canadian Primary Care Sentinel Surveillance Network (CPCSSN). CPCSSN is a multi-disease surveillance system where primary care physicians contribute de-identified EMR data to a national database [36]. In Canada, universal access to primary care services is publicly funded, and in the province of Ontario, where Toronto is situated, 94% of residents have a primary care provider [37]. Patients who were enrolled with, or who had at least two visits with a CPCSSN-UTOPIAN primary care physician between January 1, 2012 and December 31, 2014 and who had a valid City of Toronto residential postal code were included in this study. Data were extracted as of December 31, 2014 using procedures previously described [36].

Measure of Neighbourhood Walkability

The walkability of each individual's residential neighbourhood was measured using Walk Score®, a validated index that calculates the walkability of an address based on distance to amenities and aspects of pedestrian friendliness including population density, block length, and intersection density [38]. Increasing Walk Score® has been linked to increased utilitarian walking and decreased obesity prevalence in Ontario, Canada [29]. In this walkability index, locations are scored from 0 to 100, where 100 is the most walkable [38]. Toronto has 140 neighbourhoods, each of which is an administrative area that covers several city blocks, and has a minimum population of 7,000 to 10,000 [39]. Neighbourhood-level Walk Scores® for all Toronto neighbourhoods are publicly available online [40] and represent a population-weighted aggregation of a grid of Walk Score® points for the entire area of a neighbourhood, as delineated by administrative boundaries [38]. The Walk Scores current as of 2014 were retrieved [40]. Based on their residential postal code, participants were assigned to a Toronto neighbourhood using Toronto neighbourhood and postal code area shapefiles [41-43] with ESRI ArcGIS ArcMap V.10.1.

Health Outcome Measures

The health outcome measures in this study were body mass index (BMI), systolic and diastolic blood pressure (sBP, dBP), fasting blood glucose (FBG), hemoglobin A1c (HbA1c), total cholesterol (TC), high-density lipoprotein (HDL), low-density lipoprotein (LDL), and triglyceride (TG). These measures were selected because they represent widely accepted indicators of obesity, hypertension, glycemic control, and dyslipidemia, for which target ranges are well-established in clinical practice guidelines [5-17]. If multiple values were present between 2012-2014, the most recent record was used for data analysis. Given that the study sample was derived from a primary care patient population, the collection of these health measures represented the full spectrum of clinical testing: screening of healthy and at-risk individuals, diagnosis of individuals, and monitoring of individuals with chronic conditions for disease control and therapy optimization.

Covariates

Individual and neighbourhood level covariates were measured. Individual health and socio-demographic characteristics obtained from CPCSSN-UTOPIAN data included key variables that can influence the clinical outcome measures of interest: patient age, sex, current smoking status, presence of a diagnosis of hypertension or diabetes, and presence of a prescription for a weight-loss medication, an anti-hypertensive medication, an anti-diabetic medication, or a lipid-lowering medication. Diagnoses of hypertension and diabetes were based upon validated CPCSSN case definitions and case-finding algorithms [44].

Neighbourhood rates of violent crime reported to the Toronto Police Service (i.e. assault, sexual assault, robbery, and murder) were used as an indicator of neighbourhood safety [45], given the possibility that neighbourhood crime and perception of safety may influence utilitarian walking [21]. Due to the link between marginalization and health, the Ontario Marginalization Index scores of Toronto neighbourhoods were also included as covariates [46 47]. This index uses census data and assigns scores across four specific dimensions that contribute to the process of marginalization. Material deprivation scores incorporated measures of unemployment, low income, low education, and low-quality housing. Ethnic concentration scores accounted for recent immigration and self-identification as a visible minority. Residential instability scores were derived from multiple indicators, including the proportion of the population who had moved in the previous five years, and the proportion of dwellings that were not owned. Dependency scores included indicators measuring the proportion of the population aged 65 and older and the proportion of the population not participating in the labour force [46 47].

Statistical Analyses

Descriptive statistics were calculated for demographic variables, health outcome measures and all covariates. Toronto neighbourhood walkability was visualized with a choropleth map. Means and 95% confidence intervals (95% CI) of all health measures were calculated for the highest and lowest neighbourhood walkability quartiles and significance testing was performed on the unadjusted means using t-tests assuming equal variances. Multivariable linear regression models were also used to compare mean health measures in the highest versus the lowest walkability quartile. All models were adjusted for covariates of age, sex, smoking status, neighbourhood rates of violent crime and neighbourhood indices of material deprivation, ethnic concentration, residential instability and dependency from the Ontario Marginalization Index. Models predicting BMI were also adjusted for the presence of a weight-loss medication. Models predicting blood pressure were adjusted for BMI, the presence of a hypertension diagnosis and prescription of anti-hypertensive medication. Models predicting HbA1c and FBG were adjusted for BMI, the presence of a diabetes diagnosis and prescription of anti-diabetic medication. Models predicting cholesterol (total cholesterol, HDL, LDL, TG) were adjusted for BMI and the presence of a prescription for lipid-lowering medication. There were insufficient observations within each neighbourhood to use multilevel models. However, to ensure that the use of non-hierarchical linear regression was appropriate, intraclass correlation coefficients (ICCs) were calculated. Low ICCs for each health outcome (ICC=0.050 for BMI, ICC<0.01 for all other outcomes) revealed that very little of the total variance was accounted for by clustering within neighbourhoods, and that a non-hierarchical approach was reasonable.

Differences in health measures across walkability quartiles were examined for all ages, and in stratified analyses across three age subgroups of 18 to under 40 years, 40 to 65 years, and over 65 years. Broadly, these age categories represent segments of the population where primary versus secondary prevention strategies may be relevant in distinct ways. A younger adult population is more amenable to primary prevention of chronic disease. Both primary and secondary prevention are relevant for middle-aged adults, and notably, they undergo lipid and diabetes screening as recommended by clinical practice guidelines [15 48]. Finally, older adults may differ from younger adults due to increased medical comorbidities that affect the health markers of interest, and due to potentially decreased mobility that may affect levels of walking and physical activity.

All data were analyzed using Stata IC/ V.12.1 and mapping was carried out using ESRI ArcGIS ArcMap V.10.1. This study was reviewed and approved by the CPCSSN Research Privacy and Ethics Officer and by the London School of Hygiene and Tropical Medicine MSc Research Ethics Committee.

RESULTS

78, 023 UTOPIAN patients met the inclusion criteria. The generation of the study sample is displayed in Figure 1.

Figure 1. Sequence of steps in generation of study sample.

Characteristics of the study sample are displayed in Table 1. Residents of the lowest and highest quartiles of neighbourhood walkability were similar with respect to age, proportion of women and proportion of smokers. Neighbourhoods in the highest walkability quartile had higher violent crime rates, somewhat lower deprivation scores, but similar ethnic concentration compared to neighbourhoods in the lowest quartile. A map of Toronto's 140 neighbourhoods and their Walk Scores® is displayed in Figure 2. The most walkable neighbourhoods were concentrated in Toronto's downtown core. Neighbourhood Walk Scores® ranged from 42 to 99.

Unadjusted means and 95% CIs for all health measures in the lowest and highest quartiles of neighbourhood walkability are displayed in Table 2. All differences in unadjusted means were significant at the p<0.001 level.

Table 1. Descriptive characteristics of study participants.

	Lowest Quartile of Neighbourhood Walkability			Highest Quartile of Neighbourhood Walkability			Total Study Population		
Characteristic	**Frequency (%)**	**Mean (SD)**	**N patients with data**	**Frequency (%)**	**Mean (SD)**	**N patients with data**	**Frequency (%)**	**Mean (SD)**	**N patients with data**
Sex (female)	11,303 (62.3%)		18,137	11,399 (62.7%)		18,192	48,556 (62.2%)		78,022
Age [years]		49.2 (19.2)	18,122		48.5 (17.9)	18,180		50.0 (19.2)	77,966
18≤age<40	6,448 (35.6%)			6,895 (37.9%)			26,977 (34.6%)		
40≤age≤65	7,731 (42.7%)			7,760 (42.7%)			33,056 (42.4%)		
>65 years	3,943 (21.8%)			3,525 (19.4%)			17,933 (23.0%)		
Smoking (current smoker)	1,530 (12.0%)		12,772	1,669 (13.3%)		12,511	6,808 (12.1%)		56,093
Anthropometric indicators									
Body Mass Index (BMI) [kg/m^2]		29.6 (10.0)	9,819		26.0 (6.22)	10,920		27.2 (7.4)	46,029
Overweight or obese (BMI≥25 kg/m^2)	6,370 (64.9%)		9,819	5,505 (50.4%)		10,920	26,309 (57.2%)		46,029
Prescribed weight-loss medication	1,146 (6.3%)		18,137	523 (2.9%)		18,192	3,387 (4.3%)		78,023
Blood pressure control									
Hypertension diagnosis	4,068 (22.4%)		18,137	2,980 (16.4%)		18,192	16,241 (20.8%)		78,023
Prescribed anti-hypertensive medication	4,796 (26.4%)		18,137	3,555 (19.5%)		18,192	19,020 (24.4%)		78,023
Systolic blood pressure (sBP) [mmHg]		121.5 (16.0)	13,722		117.4 (15.5)	13,950		119.8 (16.0)	59,634
Diastolic blood pressure (dBP) [mmHg]		75.0 (10.0)	13,722		73.1 (10.0)	13,950		73.8 (10.0)	59,634
Blood glucose control									
Diabetes diagnosis	2,242 (12.4%)		18,137	1,096 (6.0%)		18,192	6,988 (9.0%)		78,023
Prescribed anti-diabetic medication	1,788 (9.9%)		18,137	786 (4.3%)		18,192	5,220 (6.7%)		78,023
Hemoglobin A1c (HbA1c) [%]		6.10 (1.10)	6,721		5.74 (0.75)	5,570		5.89 (0.88)	29,575
Fasting blood glucose (FBG) [mmol/L]		5.56 (1.70)	8,388		5.32 (1.26)	6,367		5.42 (1.46)	34,698
Lipid control									
Prescribed lipid-lowering medication	3,686 (20.3%)		18,137	2,453 (13.5%)		18,192	13,979 (17.9%)		78,023
Total cholesterol (TC) [mmol/L]		4.73 (1.08)	8,690		4.93 (1.04)	6,825		4.81 (1.06)	36,498
High density lipoprotein (HDL) [mmol/L]		1.43 (0.41)	8,844		1.58 (0.47)	7,014		1.49 (0.44)	37,295
Low density lipoprotein (LDL) [mmol/L]		2.71 (0.90)	8,770		2.78 (0.88)	6,983		2.74 (0.89)	37,097
Triglycerides (TG) [mmol/L]		1.34 (1.05)	8,883		1.26 (0.79)	7,008		1.31 (0.87)	37,417
Neighbourhood violent crime rate* [events per 10,000 residents]		95.4 (49.8)	18,137		128.2 (84.3)	18,192		91.3 (59.6)	78,023
Neighbourhood Instability Score†		-0.048 (0.48)	18,137		1.37 (0.68)	18,192		0.480 (0.71)	78,023
Neighbourhood Deprivation Score†		0.30 (0.96)	18,137		-0.53 (0.69)	18,192		-0.170 (0.77)	78,023
Neighbourhood Ethnic Concentration Score†		1.78 (0.89)	18,137		0.82 (0.89)	18,192		1.353 (1.08)	78,023
Neighbourhood Dependency Score†		-0.020 (0.36)	18,137		-0.44 (0.27)	18,192		-0.100 (0.39)	78,023

SD—standard deviation, N—number of observations in study sample

*Violent crime includes occurrences of assault, sexual assault, robbery, and murder.

†Scores of neighbourhood instability, deprivation, ethnic concentration and dependency are dimensions of the Ontario Marginalization Index [49]. Scores are population-weighted, and higher values indicate greater instability/deprivation/ethnic concentration/dependency.

Figure 2. Map of Toronto neighbourhood walkability as measured by neighbourhood Walk Scores®. Walk Scores® for Toronto neighbourhoods (n=140) were retrieved from the City of Toronto Open Data Catalogue [40].

Table 2. Unadjusted means and 95% confidence intervals (95% CIs) for health measures in the lowest and highest quartiles of neighbourhood walkability.

Health measure [unit]	Mean (95% CI) in Lowest Quartile of Neighbourhood Walkability	Mean (95% CI) in Highest Quartile of Neighbourhood Walkability
Body Mass Index (BMI) [kg/m²]	29.6 (29.5—29.8)	26.0 (25.9—26.2)*
Systolic blood pressure (sBP) [mmHg]	121.5 (121.2—121.7)	117.4 (117.2—117.7)*
Diastolic blood pressure (dBP) [mmHg]	75.0 (74.8—75.1)	73.1 (72.9—73.3)*
Hemoglobin A1c (HbA1c) [%]	6.10 (6.08—6.12)	5.74 (5.72—5.76)*
Fasting blood glucose (FBG) [mmol/L]	5.56 (5.53—5.59)	5.32 (5.28—5.35)*
Total cholesterol (TC) [mmol/L]	4.73 (4.71—4.75)	4.93 (4.91—4.96)*
High density lipoprotein (HDL) [mmol/L]	1.43 (1.42—1.44)	1.58 (1.57—1.59)*
Low density lipoprotein (LDL) [mmol/L]	2.71 (2.69—2.73)	2.78 (2.76—2.80)*
Triglycerides (TG) [mmol/L]	1.34 (1.32—1.36)	1.26 (1.24—1.28)*

*Asterisks indicate a significant difference between the unadjusted means at the highest versus the lowest walkability quartile, using t-tests at a significance level of p<0.001.

Table 3 displays the adjusted linear regression coefficients comparing differences in mean health measures between the highest and lowest quartiles of neighbourhood walkability. Data for all quartiles are reported in Supplementary Table 1. After adjusting for covariates, there were statistically significant differences in average measures of BMI, sBP, dBP, HbA1c, and HDL between participants in the highest versus the lowest walkability quartile.

Mean BMI was 2.64 kg/m^2 lower (95% CI -2.98 to -2.30, p<0.001) among individuals in the highest versus the lowest neighbourhood walkability quartile. In the stratified analyses, this difference was greatest in those aged 18 to under 40, where mean BMI was -4.44 kg/m^2 lower (95% CI -5.09 to -3.79, p<0.001), and smallest in those over age 65, where mean BMI was 0.87 kg/m^2 lower (95% CI -1.48 to -0.26, p=0.005).

When comparing average blood pressure measurements of individuals in the highest versus the lowest walkability quartile, mean sBP was 1.35 mmHg lower (95% CI -2.01 to -0.70, p<0.001) and mean dBP was 0.60 mmHg lower (95% CI -1.06 to -0.14, p=0.010). When stratifying by age categories, significant differences in mean sBP and dBP were observed only in those aged 40 to 65.

With respect to blood glucose control, mean HbA1c was 0.063% lower (95% CI -0.11 to -0.021, p=0.003) in those within the highest neighbourhood walkability quartile compared to those in the lowest quartile. After age stratification, a statistically significant difference was only present in those aged 18 to under 40. No evidence of differences in mean FBG was observed between the highest and the lowest quartiles of neighbourhood walkability.

In terms of cholesterol parameters, mean HDL was 0.052 mmol/L higher (95% CI 0.029 to 0.075, p<0.001) in those in the highest versus the lowest neighbourhood walkability quartile. Across the age subgroups, a significant difference in mean HDL was present only in the two older age categories. The difference observed in mean TC was of borderline statistical significance, and in the stratified analyses, was only significant in those aged 40 to 65. No strong evidence of differences in other cholesterol parameters was apparent.

Table 3. Adjusted linear regression coefficients comparing differences in mean health measures between the highest and lowest quartiles of neighbourhood walkability. Results are presented for all ages and for each age sub-category. Regression coefficients represent differences in the mean health measure, adjusting for covariates of age, sex, current smoking status, BMI (except in the model where BMI is the health outcome measure) relevant medications and medical diagnoses, neighbourhood violent crime rates, and neighbourhood indices of material deprivation, ethnic concentration, dependency, and residential instability.

Health measure [unit]	Regression coefficient (95% CI)	p-value
BMI [kg/m²] – all ages ≥ 18	-2.64 (-2.98 to -2.30)	<0.001
18 ≤ age < 40	-4.44 (-5.09 to -3.79)	<0.001
40 ≤ age ≤ 65	-2.74 (-3.24 to -2.23)	<0.001
age > 65	-0.87 (-1.48 to -0.26)	0.005
sBP [mmHg] – all ages ≥ 18	-1.35 (-2.01 to -0.70)	<0.001
18 ≤ age < 40	-0.64 (-1.68 to 0.41)	0.23
40 ≤ age ≤ 65	-1.97 (-2.91 to -1.03)	<0.001
age > 65	-0.64 (-2.14 to 0.85)	0.40
dBP [mmHg] – all ages ≥ 18	-0.60 (-1.06 to -0.14)	0.010
18 ≤ age < 40	0.12 (-0.68 to 0.93)	0.76
40 ≤ age ≤ 65	-1.30 (-1.94 to -0.66)	<0.001
age > 65	-0.19 (-1.13 to 0.75)	0.69
HbA1c [%] – all ages ≥ 18	-0.063 (-0.11 to -0.021)	0.003
18 ≤ age < 40	-0.12 (-0.23 to -0.019)	0.021
40 ≤ age ≤ 65	-0.059 (-0.12 to 0.0026)	0.060
age > 65	-0.013 (-0.078 to 0.051)	0.69
FBG [mmol/L] – all ages ≥ 18	0.030 (-0.038 to 0.099)	0.39
18 ≤ age < 40	-0.086 (-0.24 to 0.073)	0.29
40 ≤ age ≤ 65	0.028 (-0.068 to 0.12)	0.57
age > 65	0.083 (-0.036 to 0.20)	0.17
TC [mmol/L] – all ages ≥ 18	0.061 (0.00025 to 0.12)	0.049
18 ≤ age < 40	-0.023 (-0.18 to 0.13)	0.77
40 ≤ age ≤ 65	0.11 (0.024 to 0.19)	0.012
age > 65	-0.023 (-0.13 to 0.078)	0.65
HDL [mmol/L] – all ages ≥ 18	0.052 (0.029 to 0.075)	<0.001
18 ≤ age < 40	0.022 (0.038 to 0.081)	0.47
40 ≤ age ≤ 65	0.052 (0.020 to 0.084)	0.001
age > 65	0.060 (0.019 to 0.10)	0.004
LDL [mmol/L] – all ages ≥ 18	0.010 (-0.041 to 0.062)	0.69
18 ≤ age < 40	-0.0088 (-0.14 to 0.12)	0.89
40 ≤ age ≤ 65	0.026 (-0.044 to 0.096)	0.47
age > 65	-0.036 (-0.12 to 0.049)	0.41
triglyceride [mmol/L] – all ages ≥ 18	-0.0031 (-0.053 to 0.047)	0.90
18 ≤ age < 40	-0.14 (-0.33 to 0.047)	0.14
40 ≤ age ≤ 65	0.038 (-0.029 to 0.11)	0.27
age > 65	-0.041 (-0.11 to 0.033)	0.28

DISCUSSION

Key findings: Neighbourhood Walkability and Metabolic Risk Factors

We observed an association between higher neighborhood walkability and objectively measured metabolic risk factors. The magnitude of differences observed for BMI across all age groups, and for blood pressure in middle-aged adults were clinically significant and relevant for population health.

Strengths and Limitations

The main strength of this study is that it used EMR data to examine a set of clinical measures known to change with physical activity, all of which were objectively measured through physical examination or laboratory testing. The study controlled for both individual clinical attributes, as well as neighbourhood-level covariates that could have confounded the relationship between neighbourhood walkability and the metabolic risk factors of interest [28 32 50 51].

Overall, the study population included a large and diverse sample of adults of all ages, with and without chronic disease. However, the application of the study findings to other adult populations in a developed, urban setting should also consider that these were primary care patients. In particular, the study population did not include children or adolescents, had more older adults, and had a greater proportion of women than the general population of Toronto [52]. With respect to major comorbidities, the prevalence of hypertension and diabetes in the study sample (20.8% and 9.0%, respectively) were comparable to the prevalence of these diseases in the general population of Toronto (22.7% and 10.4% respectively) [53 54]. The study sample had a higher prevalence of overweight or obesity of 57.2% compared to the published Toronto prevalence of 45.8% [53]. This may be related to the fact that the latter value is from self-reported population survey data, which is prone to underreporting of BMI [55]. National estimates that use directly measured BMI yield an overweight or obesity prevalence of 62% [56]. Given that CPCSSN is the first multi-disease, EMR-based surveillance system in Canada, further work would be of interest to characterize the sociodemographic and health attributes of participating patient populations, especially in relation to the general population.

The main limitation of this study is its cross-sectional nature, which precludes the establishment of temporality in the association between neighbourhood walkability and health outcomes. Importantly, it is not possible to rule out a residential selection effect, in which healthier individuals who choose to engage in more health-promoting behaviours, such as physical activity, may also choose to live in more walkable areas to facilitate their preferred lifestyle. In other studies that either controlled for neighbourhood self-selection, or were longitudinal in design, significant associations were still observed between neighbourhood walkability and levels of overweight or obesity [57 58]. This study did not control for leisure physical activity, which may also influence the measured clinical outcomes, but—unlike utilitarian walking—is not thought to be a key mediator of the putative health benefits of walkable built environments [20 21 29 59]. Based on a recent study in Ontario, Canada, which found that differences in leisure physical activity were not significant between individuals from areas of varying walkability [29], any significant confounding by leisure physical activity would have biased results toward the null and led to underestimation of effects in the present study. Dietary information could not be captured in a valid manner using electronic medical record (EMR) data in this study. It is possible that dietary habits, particularly as linked to the food environment, may differ between neighbourhoods of high versus low walkability [60 61] but the extent to which this may have affected estimates in this study is unclear. Similarly, this study did not control for major disabilities or mobility limitations which may have precluded engagement in utilitarian walking in affected participants. This may have contributed to the attenuation of differences in mean BMI observed in older adults. Future work that controls for mobility limitations would be of interest to better explore the effects of neighbourhood walkability in older populations, particularly given that an association between walkability and physical activity has been previously reported in adults aged 65 and older [62].

Findings in Relation to Other Studies

The BMI findings are consistent with several recent studies which demonstrated lower prevalence of obesity in high walkability neighbourhoods compared to low walkability neighbourhoods [29 30 33 34]. Importantly, this study quantified the magnitude of the mean difference in BMI that was observed (2.64 kg/m^2), and found that this clinically meaningful difference varied across three age categories. In one previous longitudinal study of 701 participants, residential relocation involving a 10-point increase in street address Walk Score® was associated with an average within-individual BMI reduction of 0.06 kg/m^2 [57]. The magnitude of this effect was smaller than the 2.64 kg/m^2 difference in mean BMI that was observed in this study, between the highest and lowest neighbourhood walkability quartiles (a difference of about 20-60 points in aggregate neighbourhood Walk Score®). Importantly, the scale at which walkability was measured in the present study was at the larger neighbourhood level, rather than at the level of each resident's individual address. This has interesting implications for determining the spatial scale at which a built environment might exert positive health effects mediated by walkability and utilitarian physical activity.

With respect to blood pressure, one previous study that measured walkability and fast-food outlet density reported an association with blood pressure decreases in older adults [60], while another study found no association between walkability and self-reported hypertension [34]. The effect size of aerobic exercise on blood pressure reduction has been reported as -3.84 mmHg for sBP and -2.58 mmHg for dBP [63]. Thus, it is plausible that the small differences in mean sBP and dBP in the current study may be attributable to differences in levels of utilitarian walking. In the age-stratified analyses, only adults aged 40-65 demonstrated a significant difference in mean sBP and dBP. In Canada, the age-specific prevalence of hypertension follows an S-shaped curve, with a prevalence of 5.7% in adults aged 35-39, which rises steadily from 9.3% in adults aged 40-44 to 53.6% in adults aged 65-69 [64]. The lack of association in younger adults may be related to insufficient power in this study to detect blood pressure differences where hypertension prevalence is low. Alternatively, an association between walkable neighbourhoods and blood pressure may not exist or be relevant in younger adults, for which the incidence and risk of hypertension is already quite low (less than 1% incidence in Canadians under 40 years of age) [64]. In older adults, potential explanations for a lack of an association include decreased mobility and ability to engage in utilitarian walking, or the possibility that physical activity effects on blood pressure become relatively insignificant in the context of multiple medications and comorbidities in this age group.

Although previous studies have found an association between neighbourhood walkability and both the prevalence and incidence of diabetes [30 32 33], associations between neighbourhood walkability and HbA1c have not been reported. In a systematic review and meta-analysis of 23 RCTs, structured aerobic exercise durations of 150 minutes or less per week were found to be associated with HbA1c reductions of 0.36% [65]. The observed difference in mean HbA1c in this study was considerably smaller. This suggests that the level of physical activity potentially promoted by a more walkable neighbourhood may not be strongly associated with clinically significant changes to HbA1c. Another possibility is that the observed relationship between neighbourhood walkability and mean HbA1c may have been confounded by variations in individual diet as well as in the larger food environment. Furthermore, given that neighbourhood walkability is associated with BMI and obesity prevalence, both of which influence the risk of diabetes, this may explain the finding of higher incidence and prevalence of diabetes in higher walkability neighbourhoods, rather than simply an independent effect of walkability on diabetes.

An association between neighbourhood walkability and objective cholesterol parameters has not been previously reported in the peer-reviewed literature. One previous study reported a lack of an association between walkability and self-reported hypercholesterolemia [34]. In a

Cochrane review of exercise effects on overweight or obesity, an HDL improvement of 0.06 mmol/L was found among those who engaged in moderate aerobic exercise compared to controls with no treatment [66]. This suggests that, in the current study, the observed difference in mean HDL between the highest and lowest neighbourhood walkability quartiles is of a magnitude that could be plausibly attributed to a physical activity effect. The lack of consistent differences in other cholesterol parameters between the highest and lowest walkability quartiles is not incompatible with the literature. Indeed, a review of 51 studies, including 28 RCTs, of the effect of aerobic exercise training on blood lipids found that an increase in HDL was the most frequently observed outcome, and reductions in total cholesterol, LDL, and triglyceride were less commonly seen [67]. Again, the current study did not control for dietary factors, which are known to influence cholesterol parameters [68], and the observed associations should be interpreted with this in mind.

Implications of Findings for Population Health

From a clinical perspective, recognizing the relative walkability of a patient's residential neighbourhood may aid health providers in making context-appropriate physical activity recommendations for health maintenance and chronic disease management. More importantly, the implications for walkable environments as a public health intervention are significant if the health associations for walkability presented in this and other studies represent a truly causal relationship. In other words, a highly walkable neighbourhood could represent a population-wide intervention capable of conferring multiple benefits related to obesity prevention, blood pressure control, and potentially even blood glucose and lipid control. At the population level, even small changes in average BMI or blood pressure have the potential to "shift the curve" with respect to the population distribution of disease risk. By lowering the average level of risk factors, such a population strategy targets the determinants of disease incidence and may have the capacity to prevent a considerable fraction of obesity, hypertension, diabetes, and cardiovascular disease that is attributed to physical inactivity [69 70].

One final issue of relevance for policy makers is that of equity. This study demonstrated that across 140 neighbourhoods within a single city, variations in health existed based on walkability characteristics of the built environment. Addressing the determinants of health and health equity at the population level should therefore include built environment considerations, such as access to public transportation and safe pedestrian infrastructure.

CONCLUSIONS

There is a clinically meaningful association between living in a neighbourhood in the highest walkability quartile and having lower BMI and modestly lower blood pressure. This study demonstrates that EMR data can be a source of objective clinical measures for population health research. Further longitudinal studies on walkable environments are needed to provide a realistic estimate of the magnitude and distribution of their health effects on the population, and to clarify the spatial scale at which neighbourhood walkability realizes these effects. Further research is also needed to examine the broader health and non-health impacts of walkable neighbourhoods, particularly if they are implemented as a built environment intervention at the population level.

Details of Contributors

CKJL conceptualized the study. CKJL and DL designed the analyses in consultation with MG and BA. CKJL cleaned and analyzed the data, and drafted the manuscript. All authors contributed to revising the paper.

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Competing Interests
"Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work."

Ethics Approval
This study was reviewed and approved by the Canadian Primary Care Sentinel Surveillance Network (CPCSSN) Research, Privacy and Ethics Officer and by the London School of Hygiene and Tropical Medicine MSc Research Ethics Committee.

Data Sharing
No additional data available.

References

1. Institute for Health Metrics and Evaluation. Global Burden of Disease. GBD Compare | Viz Hub, 2013.
2. Tremblay MS, Warburton DER, Janssen I, et al. New Canadian Physical Activity Guidelines. Applied Physiology, Nutrition, and Metabolism 2011;**36**(1):36-46 doi: 10.1139/H11-009[published Online First: Epub Date]|.
3. Department of Health. UK Physical Activity Guidelines, 2011.
4. US Department of Health and Human Services. 2008 Physical Activity Guidelines for Americans, 2008.
5. Brauer P, Connor Gorber S, Shaw E, et al. Recommendations for prevention of weight gain and use of behavioural and pharmacologic interventions to manage overweight and obesity in adults in primary care. Canadian Medical Association Journal 2015 doi: 10.1503/cmaj.140887[published Online First: Epub Date]|.
6. *Obesity: Identification, Assessment and Management of Overweight and Obesity in Children, Young People and Adults: Partial Update of CG43*. London: National Clinical Guideline Centre, 2014., 2014.
7. Jensen MD, Ryan DH, Apovian CM, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and The Obesity Society. Circulation 2014;**129**(25 Suppl 2):S102-38 doi: 10.1161/01.cir.0000437739.71477.ee[published Online First: Epub Date]|.
8. Moyer VA. Screening for and management of obesity in adults: U.S. Preventive Services Task Force recommendation statement. Annals of internal medicine 2012;**157**(5):373-8 doi: 10.7326/0003-4819-157-5-201209040-00475[published Online First: Epub Date]|.
9. Daskalopoulou SS, Rabi DM, Zarnke KB, et al. The 2015 Canadian Hypertension Education Program recommendations for blood pressure measurement, diagnosis, assessment of risk, prevention, and treatment of hypertension. Canadian Journal of Cardiology 2015;**31**(5):549-68
10. James PA, Oparil S, Carter BL, et al. 2014 evidence-based guideline for the management of high blood pressure in adults: Report from the panel members appointed to the eighth joint national committee (jnc 8). JAMA 2014;**311**(5):507-20 doi: 10.1001/jama.2013.284427[published Online First: Epub Date]|.
11. McCormack T, Krause T, O'Flynn N. Management of hypertension in adults in primary care: NICE guideline. The British Journal of General Practice 2012;**62**(596):163-64 doi: 10.3399/bjgp12X630232[published Online First: Epub Date]|.
12. Canadian Diabetes Association Clinical Practice Guidelines Expert Committee. Canadian Diabetes Association 2013 clinical practice guidelines for the prevention and management of diabetes in Canada. Canadian Journal of Diabetes 2013;**37**(suppl 1)
13. National Institute for Health and Care Excellence (NICE). Type 2 diabetes in adults: management: National Institute for Health and Care Excellence, 2015.
14. Association AD. 4. Foundations of care: education, nutrition, physical activity, smoking cessation, psychosocial care, and immunization. Diabetes Care 2015;**38**(Supplement 1):S20-S30
15. Anderson TJ, Grégoire J, Hegele RA, et al. 2012 update of the Canadian Cardiovascular Society guidelines for the diagnosis and treatment of dyslipidemia for the prevention of cardiovascular disease in the adult. Canadian journal of cardiology 2013;**29**(2):151-67
16. Stone NJ, Robinson JG, Lichtenstein AH, et al. 2013 ACC/AHA Guideline on the Treatment of Blood Cholesterol to Reduce Atherosclerotic Cardiovascular Risk in AdultsA Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Journal of the American College of Cardiology 2014;**63**(25_PA):2889-934 doi: 10.1016/j.jacc.2013.11.002[published Online First: Epub Date]|.

17. National Institute for Health and Care Excellence (NICE). Cardiovascular disease: risk assessment and reduction, including lipid modification: National Institute for Health and Care Excellence, 2014.
18. National Institute for Health and Care Excellence (NICE). Physical activity and the environment. Public health guideline: National Institute for Health and Care Excellence, 2008.
19. Mowat D, Gardner C, McKeown D, et al. Improving health by design in the Greater Toronto-Hamilton Area. A Report of Medical Officers of Health in the GTHA 2014.
20. Saelens BE, Handy SL. Built environment correlates of walking: a review. Medicine & Sciece in Sports & Exercise 2008;**40**(7 Suppl):S550
21. Sugiyama T, Neuhaus M, Cole R, et al. Destination and route attributes associated with adults' walking: a review. Medicine & Sciece in Sports & Exercise 2012;**44**(7):1275-86
22. The Ottawa Charter for Health Promotion. First International Conference on Health Promotion; 1986 November 21, 1986; Ottawa.
23. Duncan DT, Aldstadt J, Whalen J, et al. Validation of Walk Score® for Estimating Neighborhood Walkability: An Analysis of Four US Metropolitan Areas. International Journal of Environmental Research and Public Health 2011;**8**(11):4160-79
24. Glazier RH, Weyman JT, Creatore MI, et al. Development and validation of an urban walkability index for Toronto, Canada. Toronto Community Health Profiles Partnership, 2012.
25. Sallis JF, Cerin E, Conway TL, et al. Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. The Lancet 2016;**387**(10034):2207-17
26. Freeman L, Neckerman K, Schwartz-Soicher O, et al. Neighborhood walkability and active travel (walking and cycling) in New York City. Journal of Urban Health 2013;**90**(4):575-85
27. Thielman J, Rosella L, Copes R, et al. Neighborhood walkability: Differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. Preventive medicine 2015;**77**:174-80 doi: http://dx.doi.org/10.1016/j.ypmed.2015.05.011[published Online First: Epub Date]|.
28. Arvidsson D, Eriksson U, Lonn SL, et al. Neighborhood Walkability, Income, and Hour-by-Hour Physical Activity Patterns. Medicine & Sciece in Sports & Exercise 2013;**45**(4):698-705
29. Chiu M, Shah BR, Maclagan LC, et al. Walk Score and the prevalence of utilitarian walking and obesity among Ontario adults: a cross-sectional study. Statistics Canada Catalogue no.82-003-X Health Reports 2015;**26**(7):3-10
30. Glazier RH, Creatore MI, Weyman JT, et al. Density, Destinations or Both? A Comparison of Measures of Walkability in Relation to Transportation Behaviors, Obesity and Diabetes in Toronto, Canada. PLoS ONE 2014;**9**(1):e85295 doi: 10.1371/journal.pone.0085295[published Online First: Epub Date]|.
31. Hajna S, Ross NA, Joseph L, et al. Neighbourhood walkability, daily steps and utilitarian walking in Canadian adults. BMJ Open 2015;**5**(11) doi: 10.1136/bmjopen-2015-008964[published Online First: Epub Date]|.
32. Booth GL, Creatore MI, Moineddin R, et al. Unwalkable neighborhoods, poverty, and the risk of diabetes among recent immigrants to Canada compared with long-term residents. Diabetes Care 2013;**36**(2):302-08
33. Creatore MI, Glazier RH, Moineddin R, et al. Association of Neighborhood Walkability With Change in Overweight, Obesity, and Diabetes. JAMA 2016;**315**(20):2211-20 doi: 10.1001/jama.2016.5898[published Online First: Epub Date]|.
34. Müller-Riemenschneider F, Pereira G, Villanueva K, et al. Neighborhood walkability and cardiometabolic risk factors in australian adults: an observational study. BMC Public Health 2013;**13**(1):1-9 doi: 10.1186/1471-2458-13-755[published Online First: Epub Date]|.
35. Chiu M, Rezai M-R, Maclagan LC, et al. Moving to a Highly Walkable Neighborhood and Incidence of Hypertension: A Propensity-Score Matched Cohort Study. Environ Health Perspect 2015

36. Birtwhistle R, Keshavjee K, Lambert-Lanning A, et al. Building a pan-Canadian primary care sentinel surveillance network: initial development and moving forward. The Journal of the American Board of Family Medicine 2009;**22**(4):412-22
37. Health Quality Ontario. Quality in Primary Care: Setting a foundation for monitoring and reporting in Ontario. Toronto, 2015.
38. Walk Score. Walk Score Methodology. Secondary Walk Score Methodology 2015. https://www.walkscore.com/methodology.shtml.
39. City of Toronto. Neighbourhood Profiles. Secondary Neighbourhood Profiles 2015. http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=ae17962c8c3f0410VgnVCM10000071d60f89RCRD&vgnextchannel=1e68f40f9aae0410VgnVCM10000071d60f89RCRD.
40. Social Development Finance & Administration. Wellbeing Toronto - Civics & Equity Indicators. Secondary Wellbeing Toronto - Civics & Equity Indicators December 17, 2014. 2014. http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=906580ece073b410VgnVCM10000071d60f89RCRD&vgnextchannel=75d6e03bb8d1e310VgnVCM10000071d60f89RCRD.
41. Social Development Finance & Administration, City of Toronto. Boundaries of City of Toronto Neighbourhoods. Secondary Boundaries of City of Toronto Neighbourhoods 2014. http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=04b489fe9c18b210VgnVCM1000003dd60f89RCRD&vgnextchannel=75d6e03bb8d1e310VgnVCM10000071d60f89RCRD.
42. Statistics Canada. Postal Code Conversion File (PCCF) Reference Guide: June 2013 postal codes. Catalogue no. 92-154-G: Statistics Canada, 2013.
43. Statistics Canada. Forward Sortation Area Boundary File, Reference Guide: Census year 2011. Catalogue no. 92-179-G: Statistics Canada, 2011.
44. Williamson T, Green ME, Birtwhistle R, et al. Validating the 8 CPCSSN Case Definitions for Chronic Disease Surveillance in a Primary Care Database of Electronic Health Records. Annals of Family Medicine 2014;**12**(4):367-72 doi: 10.1370/afm.1644[published Online First: Epub Date]|.
45. Friesen D, Rajagopalan P, Strashin J. Toronto Crime by Neighbourhood. Secondary Toronto Crime by Neighbourhood April 15, 2015 2011. http://www.cbc.ca/toronto/features/crimemap/.
46. Toronto Community Health Profiles Partnership. DA & CT ON-Marg Data, 2006., 2006.
47. Toronto Community Health Profiles Partnership. Ontario Marginalization Index (ON-Marg). Secondary Ontario Marginalization Index (ON-Marg) 2015. http://www.torontohealthprofiles.ca/onmarg.php.
48. Ekoé J-M, Punthakee Z, Ransom T, et al. Screening for Type 1 and Type 2 Diabetes. Canadian Journal of Diabetes 2013;**37**(Supplement):S12-S15
49. Matheson FI, Dunn J, Smith KLW, et al. Ontario Marginalization Index User Guide Version 1.0. Toronto: Centre for Research on Inner City Health, 2012.
50. Manaugh K, El-Geneidy A. Validating walkability indices: How do different households respond to the walkability of their neighborhood? Transportation research part D: transport and environment 2011;**16**(4):309-15
51. Carr LJ, Dunsiger SI, Marcus BH. Walk score™ as a global estimate of neighborhood walkability. American Journal of Preventive Medicine 2010;**39**(5):460-63
52. City of Toronto, City Planning Social Policy Analysis & Research. 2011 Census: Age and Sex Counts. Toronto: City of Toronto, 2012.
53. City of Toronto. Toronto Health Indicators - A Comparative Look. Secondary Toronto Health Indicators - A Comparative Look 2014. http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=d69e6032bcaa6410VgnVCM10000071d60f89RCRD.
54. Toronto Community Health Profiles Partnership. Age-Standardized Hypertension Prevalence Rate (%) Among Adults 20+, 2012. Secondary Age-Standardized Hypertension Prevalence Rate (%) Among

Adults 20+, 2012.
http://www.torontohealthprofiles.ca/a_documents/TM_allCateg_maps/TM_maps_AHD/3_AHD_HBP_All_MF_N_2012_20plus_NB.pdf.

55. Connor Gorber S, Tremblay M, Moher D, et al. A comparison of direct vs. self-report measures for assessing height, weight and body mass index: a systematic review. Obesity reviews : an official journal of the International Association for the Study of Obesity 2007;**8**(4):307-26 doi: 10.1111/j.1467-789X.2007.00347.x[published Online First: Epub Date]|.
56. Statistics Canada. Canadian Health Measures Survey: Household and physical measures data, 2012 to 2013. The Daily: Statistics Canada, 2013.
57. Hirsch JA, Diez Roux AV, Moore KA, et al. Change in walking and body mass index following residential relocation: the multi-ethnic study of atherosclerosis. American Journal of Public Health 2014;**104**(3):e49-e56
58. Sallis JF, Saelens BE, Frank LD, et al. Neighborhood built environment and income: examining multiple health outcomes. Social Science & Medicine 2009;**68**(7):1285-93
59. McCormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int J Behav Nutr Phys Act 2011;**8**(125):10.1186
60. Li F, Harmer P, Cardinal BJ, et al. Built environment and changes in blood pressure in middle aged and older adults. Preventive medicine 2009;**48**(3):237-41
61. Mayne SL, Auchincloss AH, Michael YL. Impact of policy and built environment changes on obesity-related outcomes: a systematic review of naturally occurring experiments. Obesity reviews : an official journal of the International Association for the Study of Obesity 2015;**16**(5):362-75 doi: 10.1111/obr.12269[published Online First: Epub Date]|.
62. Berke EM, Koepsell TD, Moudon AV, et al. Association of the built environment with physical activity and obesity in older persons. American Journal of Public Health 2007;**97**(3):486-92
63. Whelton SP, Chin A, Xin X, et al. Effect of aerobic exercise on blood pressure: a meta-analysis of randomized, controlled trials. Annals of internal medicine 2002;**136**(7):493-503
64. Robitaille C, Dai S, Waters C, et al. Diagnosed hypertension in Canada: incidence, prevalence and associated mortality. Canadian Medical Association Journal 2012;**184**(1):E49-E56 doi: 10.1503/cmaj.101863[published Online First: Epub Date]|.
65. Umpierre D, Ribeiro PA, Kramer CK, et al. Physical activity advice only or structured exercise training and association with HbA1c levels in type 2 diabetes: a systematic review and meta-analysis. JAMA 2011;**305**(17):1790-99
66. Shaw K, Gennat H, O'Rourke P, et al. Exercise for overweight or obesity. The Cochrane database of systematic reviews 2006(4):CD003817 doi: 10.1002/14651858.CD003817.pub3[published Online First: Epub Date]|.
67. Leon AS, Sanchez OA. Response of blood lipids to exercise training alone or combined with dietary intervention. Medicine and science in sports and exercise 2001;**33**(6; SUPP):S502-S15
68. Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. Circulation 2002;**106**(25):3143-421
69. Lee IM, Shiroma EJ, Lobelo F, et al. Impact of Physical Inactivity on the World's Major Non-Communicable Diseases. Lancet (London, England) 2012;**380**(9838):219-29 doi: 10.1016/S0140-6736(12)61031-9[published Online First: Epub Date]|.
70. Rose G. Sick individuals and sick populations. International journal of epidemiology 2001;**30**(3):427-32

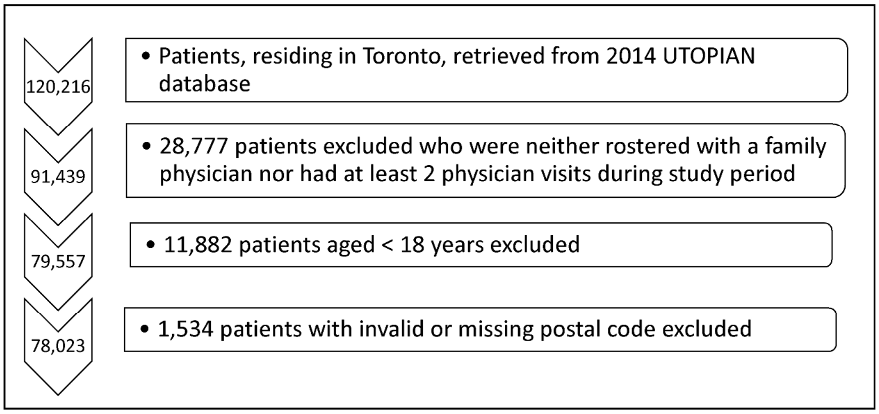

Figure 1. Sequence of steps in generation of study sample.
Figure 1
338x190mm (300 x 300 DPI)

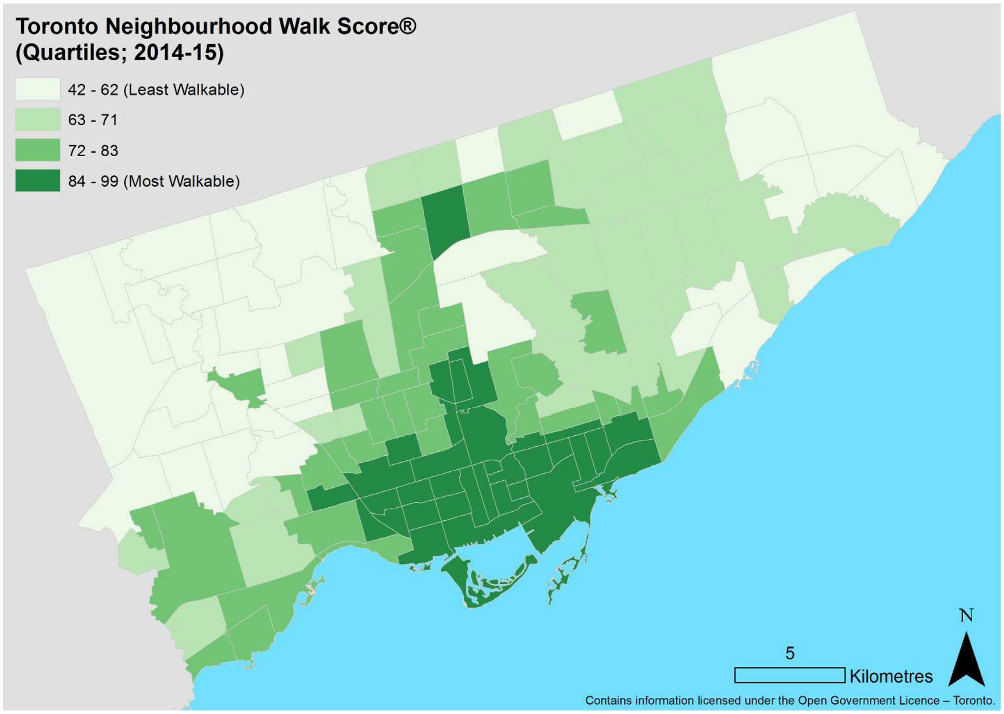

Figure 2. Map of Toronto neighbourhood walkability as measured by neighbourhood Walk Scores®. Walk Scores® for Toronto neighbourhoods (n=140) were retrieved from www.walkscore.com [40].
Figure 2
297x209mm (300 x 300 DPI)

Supplementary Table 1. Adjusted linear regression coefficients comparing differences in mean health measures between the highest three quartiles (Q2-Q4) of neighbourhood walkability and the lowest quartile (Q1). Results are presented for all ages and for each age category. Regression coefficients represent differences in the mean health measure, adjusting for covariates of age, sex, BMI (except in the model where BMI is the health outcome measure) current smoking status, relevant medications and medical diagnoses, neighbourhood violent crime rates, and neighbourhood indices of material deprivation, ethnic concentration, dependency, and residential instability.

Health measure [unit]	Q2-Q1 regression coefficient (95% CI)	p-value	Q3-Q1 regression coefficient (95% CI)	p-value	Q4-Q1 regression coefficient (95% CI)	p-value
BMI [kg/m^2] – all ages ≥ 18	-2.00 (-2.22 to -1.78)	<0.001	-2.02 (-2.25 to -1.79)	<0.001	-2.64 (-2.98 to -2.30)	<0.001
18 ≤ age < 40	-3.54 (-4.00 to -3.08)	<0.001	-3.51 (-3.99 to -3.03)	<0.001	-4.44 (-5.09 to -3.79)	<0.001
40 ≤ age ≤ 65	-1.83 (-2.16 to -1.50)	<0.001	-1.92 (-2.27 to -1.57)	<0.001	-2.74 (-3.24 to -2.23)	<0.001
age > 65	-0.79 (-1.14 to -0.43)	<0.001	-0.91 (-1.30 to -0.52)	<0.001	-0.87 (-1.48 to -0.26)	0.005
sBP [mmHg] – all ages ≥ 18	0.14 (-0.29 to 0.56)	0.52	-0.95 (-1.40 to -0.50)	<0.001	-1.35 (-2.01 to -0.70)	<0.001
18 ≤ age < 40	0.30 (-0.44 to 1.04)	0.43	-0.75 (-1.52 to 0.018)	0.056	-0.64 (-1.68 to 0.41)	0.23
40 ≤ age ≤ 65	0.21 (-0.40 to 0.83)	0.49	-0.74 (-1.39 to -0.095)	0.025	-1.97 (-2.91 to -1.03)	<0.001
age > 65	0.012 (-0.86 to 0.88)	0.98	-1.22 (-2.17 to -0.26)	0.012	-0.64 (-2.14 to 0.85)	0.40
dBP [mmHg] – all ages ≥ 18	-0.42 (-0.72 to -0.13)	0.005	-0.33 (-0.64 to -0.012)	0.042	-0.60 (-1.06 to -0.14)	0.010
18 ≤ age < 40	-0.47 (-1.04 to 0.10)	0.11	-0.29 (-0.89 to 0.30)	0.33	0.12 (-0.68 to 0.93)	0.76
40 ≤ age ≤ 65	-0.26 (-0.68 to 0.16)	0.23	-0.31 (-0.75 to 0.13)	0.16	-1.30 (-1.94 to -0.66)	<0.001
age > 65	-0.69 (-1.24 to -0.14)	0.014	-0.57 (-1.18 to 0.030)	0.063	-0.19 (-1.13 to 0.75)	0.69
HbA1c [%] – all ages ≥ 18	-0.035 (-0.060 to -0.0093)	0.007	-0.041 (-0.068 to -0.014)	0.003	-0.063 (-0.11 to -0.021)	0.003
18 ≤ age < 40	-0.027 (-0.10 to 0.047)	0.47	-0.051 (-0.13 to 0.027)	0.20	-0.12 (-0.23 to -0.019)	0.021
40 ≤ age ≤ 65	-0.037 (-0.075 to 0.00049)	0.053	-0.046 (-0.086 to -0.0055)	0.026	-0.059 (-0.12 to 0.0026)	0.060
age > 65	-0.018 (-0.054 to 0.018)	0.34	-0.015 (-0.055 to 0.018)	0.46	-0.013 (-0.078 to 0.051)	0.69
FBG [mmol/L] – all ages ≥ 18	0.0098 (-0.031 to 0.051)	0.64	0.0041 (-0.041 to 0.049)	0.86	0.030 (-0.038 to 0.099)	0.39
18 ≤ age < 40	-0.020 (-0.12 to 0.081)	0.69	-0.072 (-0.18 to 0.039)	0.20	-0.086 (-0.24 to 0.073)	0.29
40 ≤ age ≤ 65	0.0060 (-0.052 to 0.064)	0.84	0.00032 (-0.062 to 0.063)	0.99	0.028 (-0.068 to 0.12)	0.57
age > 65	0.018 (-0.050 to 0.085)	0.60	0.032 (-0.043 to 0.11)	0.40	0.083 (-0.036 to 0.20)	0.17
total cholesterol [mmol/L] – all ages ≥ 18	0.038 (0.00077 to 0.074)	0.045	0.020 (-0.019 to 0.060)	0.31	0.061 (0.00025 to 0.12)	0.049
18 ≤ age < 40	-0.029 (-0.13 to 0.074)	0.58	-0.047 (-0.16 to 0.063)	0.40	-0.023 (-0.18 to 0.13)	0.77
40 ≤ age ≤ 65	0.066 (0.016 to 0.12)	0.010	0.041 (-0.013 to 0.095)	0.13	0.11 (0.024 to 0.19)	0.012
age > 65	0.039 (-0.019 to 0.096)	0.19	-0.012 (-0.075 to 0.051)	0.72	-0.023 (-0.13 to 0.078)	0.65
HDL [mmol/L] – all ages ≥ 18	0.0046 (-0.0093 to 0.019)	0.52	0.0018 (-0.013 to 0.017)	0.82	0.052 (0.029 to 0.075)	<0.001
18 ≤ age < 40	-0.039 (-0.078 to 0.00044)	0.053	-0.054 (-0.096 to -0.012)	0.012	0.022 (0.038 to 0.081)	0.47
40 ≤ age ≤ 65	-0.00062 (-0.020 to 0.019)	0.95	0.0014 (-0.019 to 0.022)	0.90	0.052 (0.020 to 0.084)	0.001
age > 65	0.028 (0.0044 to 0.051)	0.020	0.021 (-0.0043 to 0.047)	0.10	0.060 (0.019 to 0.10)	0.004
LDL [mmol/L] – all ages ≥ 18	0.016 (-0.015 to 0.047)	0.31	0.0084 (-0.025 to 0.042)	0.62	0.010 (-0.041 to 0.062)	0.69
18 ≤ age < 40	-0.014 (-0.10 to 0.071)	0.74	0.0014 (-0.090 to 0.093)	0.98	-0.0088 (-0.14 to 0.12)	0.89
40 ≤ age ≤ 65	0.033 (-0.010 to 0.077)	0.13	0.016 (-0.030 to 0.062)	0.49	0.026 (-0.044 to 0.096)	0.47
age > 65	0.019 (-0.029 to 0.067)	0.44	-0.015 (-0.068 to 0.038)	0.59	-0.036 (-0.12 to 0.049)	0.41
triglyceride [mmol/L] – all ages ≥ 18	0.031 (0.00050 to 0.061)	0.046	0.019 (-0.013 to 0.052)	0.24	-0.0031 (-0.053 to 0.047)	0.90
18 ≤ age < 40	0.0079 (-0.12 to 0.13)	0.90	-0.051 (-0.18 to 0.082)	0.46	-0.14 (-0.33 to 0.047)	0.14
40 ≤ age ≤ 65	0.056 (0.014 to 0.097)	0.009	0.035 (-0.010 to 0.079)	0.13	0.038 (-0.029 to 0.11)	0.27
age > 65	0.00043 (-0.041 to 0.042)	0.98	-0.0032 (-0.049 to 0.042)	0.89	-0.041 (-0.11 to 0.033)	0.28

RESEARCH CHECKLIST

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (p. 2)
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found (p.2)
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported (p. 4)
Objectives	3	State specific objectives, including any prespecified hypotheses (p. 4)
Methods		
Study design	4	Present key elements of study design early in the paper (p. 4)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection (p.4-5)
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants (p. 4-5)
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable (p.4-6)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group (p. 4-5)
Bias	9	Describe any efforts to address potential sources of bias (p. 4-6)
Study size	10	Explain how the study size was arrived at (p.6)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why (p. 5-6)
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (p. 5-6)
		(*b*) Describe any methods used to examine subgroups and interactions (p. 6)
		(*c*) Explain how missing data were addressed – data from EMR; N indicated for each variable of interest (p. 4-6, 8)
		(*d*) If applicable, describe analytical methods taking account of sampling strategy **–** N/A
		(*e*) Describe any sensitivity analyses – N/A
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (p. 6)
		(b) Give reasons for non-participation at each stage (p. 6)
		(c) Consider use of a flow diagram (p. 6)
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (p. 7-8)
		(b) Indicate number of participants with missing data for each variable of interest – data from EMR; N indicated for each variable of interest (p. 8)
Outcome data	15*	Report numbers of outcome events or summary measures (p. 8)

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (p. 10-11)
		(*b*) Report category boundaries when continuous variables were categorized (p. 8-11)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period – N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses (p. 6, 11)
Discussion		
Key results	18	Summarise key results with reference to study objectives (p. 11)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias (p. 12)
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence (p. 11-14)
Generalisability	21	Discuss the generalisability (external validity) of the study results (p. 12)
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based – N/A

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.