CLINICAL RESEARCH ARTICLE

Biological and socioeconomic determinants of prediabetes in youth: an analysis using 2007 to 2011 Canadian Health Measures Surveys

Celia Rodd¹, Allison Feely², Allison Dart³, Atul Sharma⁴ and Jon McGavock⁵

OBJECTIVES: To describe rates of prediabetes among youth in Canada and the associated social and biological characteristics.

METHODS: We analyzed the cross-sectional data from the first (2007–2009) and second (2009–2011) cycles of the Canadian Health Measures Survey (CHMS) for youth aged 6–19 years. Prediabetes was defined using the glycated hemoglobin (A1C) guidelines set out by the American Diabetes Association (ADA) and the Canadian Diabetes Association (CDA) of A1C ranges 5.7–6.4% (38.8–46.4 mmol/mol) and 6.0–6.4% (42.1–46.4 mmol/mol), respectively.

RESULTS: An elevated A1C was observed in 22.8% of our sample ($n = 3449$) based on the ADA definition and 5.2% of youth using the CDA definition. Independent predictors in a fully adjusted model for prediabetes were non-White (odds ratio (OR) 2.62: 95% Confidence intervals 2.05–3.35), obese (OR 1.53: 1.19–1.96), less physically active youth (0.97: 0.95–0.99), and parents with high school education or less (1.34: 1.02–1.74). Moreover, significant regional variations were noted with higher rates for all regions except Ontario.

CONCLUSION: Prediabetes is relatively common in Canada and associated with common biologic and socioeconomic factors. Importantly, regular physical activity was significantly associated with reduced odds of prediabetes. Targeted screening and continued emphasis on physical activity may help curb the increasing rates of prediabetes.

Pediatric Research (2018) 84:248–253; <https://doi.org/10.1038/s41390-018-0025-9>

INTRODUCTION

The burden of diabetes mellitus for youth, families, and the health care system is growing exponentially, especially in the last 2 decades.^{1,2} It has also been predicted that as many as 1 in 3 American adults will have diabetes by 2050 if present trends continue.³ Type 2 diabetes mellitus (T2DM) is due to insulin resistance and β -cell dysfunction and is associated with being overweight, obese, certain ethnicities, and lower socioeconomic status (SES).^{4,5} The earliest detectable biomarker for the progression of T2DM is the presence of elevated blood sugars or elevated glycated hemoglobin (A1C) (i.e., prediabetes).⁴ Nearly 50% of the adults with prediabetes will go on to develop T2DM.⁶ Given the risk of progression, recognition and screening for prediabetes is critical to attempt to prevent conversion to frank diabetes mellitus.⁷

Currently, rates of elevated A1C among low-risk or unselected youth are not well described. Clinic-based samples suggest that 25% of the obese youth display prediabetes, while convenience samples suggest rates of ~10–49%.^{8–12} Moreover, we acknowledge that for some children, a slightly elevated A1C may reflect differences in red blood cell biology rather than a metabolic derangement.¹³ Among children and adolescents, an A1C between 5.7 and 6.4% is associated with a 4–7-fold increased risk of progressing to frank diabetes, compared to adolescents with an A1C <5.3%.⁶ Additionally, A1C was as accurate as fasting

and 2-h glucose levels during oral glucose tolerance test for predicting progression to T2DM in children and adolescents.^{6,8} Despite limitations, the primary objective of our study is to describe the rates of prediabetes/elevated A1C among youth in Canada using data from the recent Canadian Health Measures Survey (CHMS).^{14,15} Our secondary objective is to describe the social and biological characteristics among youth with prediabetes in Canada using the same survey data. We hypothesized that prediabetes would be more common among youth with low SES and that both biological and socioeconomic determinants would be associated with prediabetes in youth.

METHODS

Sample and data source

Our sample was obtained from the first (2007–2009) and second (2009–2011) cycles of the CHMS.^{14,15} The CHMS was conducted by Statistics Canada in partnership with Health Canada and the Public Health Agency of Canada to create national baseline data for a variety of important health indicators. It includes an in-home health questionnaire followed by a visit to a mobile clinic where direct physical measurements were taken (e.g., anthropometric measures, blood samples).¹⁶ Participation was voluntary and informed written consent was acquired from respondents aged 14 years or older. For children aged 13 years or younger, a written

¹Department of Pediatrics and Child Health, Section of Pediatric Endocrinology, Winnipeg, Manitoba R3E 0Z2, Canada; ²University of Manitoba, Winnipeg, Manitoba R3T 2M8, Canada; ³Department of Pediatrics and Child Health, Section of Pediatric Nephrology, Winnipeg, Manitoba R3E 0Z2, Canada; ⁴Department of Pediatrics and Child Health, Winnipeg, Manitoba R3A 1S1, Canada and ⁵Children's Hospital Research Institute of Manitoba, 511 - 715 McDermot Ave, Winnipeg, Manitoba R3E 3P4, Canada
Correspondence: Celia Rodd (crodd@hsc.mb.ca)

Received: 22 November 2017 Revised: 24 March 2018 Accepted: 1 April 2018

Published online: 13 June 2018

consent was provided by a parent/guardian, in addition to written assent from the child.¹⁷

Data from the first and second cycles of the CHMS were collected from nationally representative samples of the Canadian population aged 6–79 and 3–79 years, respectively, who lived in private households. The residents of First Nation communities, institutions, and certain remote regions, as well as full-time members of the Canadian forces, were excluded. In general, the CHMS represented more than 96% of the Canadian population.¹⁸ Detailed information about the survey content and design for both cycles can be found in the *CHMS Data User Guide: Cycle 1* and *CHMS Data User Guide: Cycle 2*.^{14,15}

Our study included youth aged 6–19 years, who provided A1C samples in either cycle. Also excluded were the youth already diagnosed with diabetes mellitus or cancer, those who took medication for diabetes or medications that predispose to diabetes, such as corticosteroids, or an A1C $\geq 6.5\%$ (47.5 mmol/mol i.e., overt diabetes).

Prediabetes definition

Prediabetes was defined using guidelines from both the American Diabetes Association (ADA) and the Canadian Diabetes Association (CDA).^{5,19} Prediabetes is diagnosed when the blood glucose levels are higher than normal, but not yet high enough to be diagnosed as T2DM. It can be identified by blood sugar levels or by A1C, which reflects time-averaged or overall blood sugar concentrations in the previous three months. The ADA defines pediatric prediabetes as an A1C range of 5.7–6.4% (38.8–46.4 mmol/mol).⁴ A more restrictive prediabetes definition with an A1C range of 6.0–6.4% (42.1–46.4 mmol/mol) is used for adults only by the CDA.¹⁹ Below these thresholds, the subjects are considered to be euglycemic. Although both ADA and CDA provide alternate definitions of prediabetes based on more traditional fasting plasma glucose (FPG) levels, very few youth provided fasting blood samples in the CHMS.^{5,19} For this reason, FPG was not used in this study.

Exposure variables

The health questionnaire portion of the CHMS provided information for biologic and socioeconomic risk factors for prediabetes and metabolic syndrome. Biological determinants included in our study were age (years), sex, race/ethnicity (pooled as White and non-White), body mass index (BMI) (weight/height^2) Z scores (BMIz), weight Z scores (Wtz), height Z scores (Htz), waist circumference Z scores (WCz), waist:height ratio Z scores (WHz), systolic blood pressure Z scores (SBPz), and diastolic Z scores (DBPz). Since anthropometric parameters in children vary with age and sex, all are routinely expressed as Z scores to allow for comparisons across sex and age.²⁰ In all cases, Z scores were based on World Health Organization reference charts (WHO; height, weight, BMI) or National Health and Nutrition Examination Survey (NHANES; waist circumference, waist: height, blood pressure) reference population.^{20–22} In addition, WHO BMIz thresholds were used to determine whether or not the subject was overweight or obese.²⁰ For this age group, the subjects are considered overweight or obese (overweight/obese) if they had a BMIz >1 and obese if they had a BMIz >2 .²³

Self-reported physical activity was determined using separate questionnaires for children under 12 years of age and adolescents 12 years and older. The need for two measures was based on the availability of age-appropriate questionnaires.^{14,15}

We included four socioeconomic factors in our study. Income adequacy is a Statistics Canada measure of total household income adjusted for the number of family members in the household. It is categorized by low, low-middle, upper-middle, and high. For example, the highest category includes families with incomes $>\$60,000$ with 1–2 family members or larger families (>2) with incomes $>\$80,000$. Due to small sample sizes, we pooled the

low and low-middle categories and labeled it low-income adequacy. Upper-middle was relabeled as middle-income adequacy. Highest level of education in a household was categorized as high school vs. less any post-secondary education. Immigration status was defined as immigrant or non-immigrant. Region was defined using Statistics Canada's standard regional boundaries, i.e., British Columbia, the Prairies (Alberta, Saskatchewan, or Manitoba), Ontario, Quebec, or the Atlantic provinces (Newfoundland and Labrador, Prince Edward Island, Nova Scotia, and New Brunswick).

Statistical analyses

Cycles 1 and 2 of the CHMS were merged into one dataset.^{14,15} Means and standard deviations (SD) were calculated for continuous variables, and counts and percentages were calculated for categorical variables. For the youth with or without prediabetes, the mean values were compared using two-sample t-tests and proportions were compared using χ^2 tests. Only comparisons using the ADA definition are reported, as the CDA definition produced small cell sizes, which cannot be reported under Statistics Canada privacy policies. Given the relatively small number of cases, all analyses are unweighted, i.e., sample weights were not used to estimate the population parameters and bootstrap weights were not used to adjust for survey design. Statistical significance was set at $p < 0.05$.

Multivariable logistic regression was used to calculate odds ratios (ORs) with accompanying 95% confidence intervals (CIs) for prediabetes using both ADA and CDA definitions. Baseline ORs with obligate covariates, age and sex, were calculated for each of the biological and socioeconomic determinants that were significantly different between the youths with euglycemia and prediabetes. Variables identified this way were also added to our final model. Final ORs were adjusted for age, sex, race/ethnicity, obesity, income adequacy, highest household education, immigrant status, and region.

To adjust for physical activity in our regression models, we performed a stratified analysis of our final ADA model for the youth <12 years of age and ≥ 12 years of age. For the youth <12 years of age, physical activity was defined as the total number of hours of physical activity per week. For the youth ≥ 12 years of age, physical activity was defined as the monthly frequency of physical activity episodes of >15 min. To facilitate interpretation of the OR in the logistic regression analysis, monthly frequency was divided by 10 so the OR measures the impact of 10×15 min monthly exercise sessions.

Assuming a CDA prediabetes prevalence of 12.5% in adults, an a priori power calculation confirmed that we were powered to estimate the prevalence with a CI half-width of 1% with 95% confidence.²⁴ All analyses were performed in R version 3.2.²⁵

Approval was granted by the Research Board at the University of Manitoba and Statistics Canada Research Data Centre.

RESULTS

In total, 3449 youth aged 6–19 years provided A1C samples in either survey. Overall, 785 (22.8%) of the youth had prediabetes based on the ADA definition and 179 (5.2%) had an elevated A1C based on the CDA definition.¹⁹ Sample characteristics and characteristics of euglycemic (healthy) and dysglycemic youth based on the ADA definition are shown in Table 1.⁴ The mean age of our sample was 12.2 years, with the prediabetes youth being slightly younger than those with euglycemia (11.8 years, $p < 0.001$). About half (51.7%) of our sample were male; dysglycemic youth were more likely to be male (55.4 vs. 50.6, $p = 0.02$). The majority of the youth in our sample were White, but dysglycemic youth were more likely to be non-White (24.8 vs. 14.6, $p < 0.001$).

There were no significant differences in BMIz, Wtz, Htz, WCz, WHz, SBPz, or DBPz between the youth with prediabetes vs.

Table 1. Sample characteristics of healthy and dysglycemic youth based on ADA definition

Characteristic ^a	Total sample	ADA definition	
		Healthy	Dysglycemic
Number	3449	2664 (77.2)	785 (22.8)
Biological determinants			
Age (years)*	12.19 ± 3.59	12.31 ± 3.65	11.77 ± 3.38
Sex***			
Female	1666 (48.3)	1316 (49.4)	350 (44.6)
Male	1783 (51.7)	1348 (50.6)	435 (55.4)
Race*			
White	2732 (79.2)	2175 (81.6)	557 (71.0)
Non-White	584 (16.9)	389 (14.6)	195 (24.8)
Missing	133 (3.9)	100 (3.8)	33 (4.2)
BMIz	0.48 ± 1.23	0.45 ± 1.20	0.55 ± 1.34
Wtz	0.50 ± 1.18	0.48 ± 1.16	0.57 ± 1.26
Htz	0.28 ± 1.01	0.27 ± 1.01	0.30 ± 1.01
WCz	−0.17 ± 1.04	−0.17 ± 1.01	−0.14 ± 1.11
WHz	−0.39 ± 1.05	−0.40 ± 1.03	−0.35 ± 1.12
SBPz	−1.05 ± 0.84	−1.06 ± 0.83	−1.03 ± 0.87
DBPz	−0.14 ± 0.68	−0.14 ± 0.67	−0.13 ± 0.72
Weight status			
Overweight/obese	1062 (30.8)	805 (30.2)	257 (32.7)
Obese*	415 (12.0)	288 (10.8)	127 (16.2)
Physical activity 6–11 y ^b	12.4 ± 4.4	12.2 ± 4.4	12.5 ± 4.4
Physical activity ≥12 y ^c	70.6 ± 74.3	73.6 ± 76.6	59.0 ± 63.5
Income adequacy**			
Low	759 (22.0)	598 (22.4)	161 (20.5)
Middle	970 (28.1)	714 (26.8)	256 (32.6)
High	1720 (49.9)	1352 (50.8)	368 (46.9)
Highest household education**			
High school or less	421 (12.2)	303 (11.4)	118 (15.0)
Any post-secondary	3028 (87.8)	2361 (88.6)	667 (85.0)
Immigrant***	296 (8.6)	213 (8.0)	83 (10.6)
Region*			
British Columbia	557 (16.1)	398 (14.9)	159 (20.3)
Prairies	521 (15.1)	332 (12.5)	189 (24.1)
Ontario	1172 (34.0)	1037 (38.9)	135 (17.2)
Quebec	870 (25.2)	730 (27.4)	140 (17.8)
Atlantic	329 (9.5)	167 (6.3)	162 (20.6)

^aMean ± SD for continuous variables, count (%) for categorical variables
^bPhysical activity for ages 6–11 years: number of hours per week
^cPhysical activity for ages ≥12 years: number of monthly exercise sessions >15 min
* <0.001, ** <0.01, *** <0.05

euglycemia. Approximately 31% of the sample were overweight/obese and 12.0% of our sample were obese. There was no significant difference between the rates of overweight/obesity; however, the youth with prediabetes were more likely to be obese (BMIz > 2) by WHO criteria (16.2% vs. 10.8%; $p < 0.001$).²⁰ Those 12 years and older with prediabetes were significantly less physically active with 20% fewer physical activity sessions (>15 min) per month compared to those with euglycemia (59.0 vs. 73.6; $p < 0.001$); no comparable difference was not noted in those under 12 years.

In addition, those with prediabetes were more likely to live in households with middle-income adequacy, have a household

education of high school or less, and be an immigrant. The majority of our sample lived in Ontario and Quebec, but the youth with prediabetes were more likely from British Columbia, the Prairies, or Atlantic Canada (Fig. 1).

Table 2 summarizes the baseline (adjusted for age and sex) and fully adjusted ORs for prediabetes based on the ADA and CDA definitions, as well as the stratified models adjusted for physical activity. As age increased, the adjusted odds of ADA prediabetes decreased; although the clinical significance of this effect appears to be small.

However, non-White race/ethnicity, obesity, middle-income adequacy, highest household education of high school or less significantly increased the adjusted odds of ADA-defined prediabetes. Living in British Columbia, the Prairies, Quebec, or Atlantic Canada compared to Ontario also significantly increased the adjusted odds of ADA-defined prediabetes (Fig. 1). Male sex, non-White race/ethnicity, and not living in Ontario all significantly increased the odds of CDA-defined prediabetes.

For children <12 years, physical activity did not significantly affect the adjusted odds of ADA-defined prediabetes. However, for youth ≥12 years, as physical activity increased, the adjusted odds of ADA prediabetes significantly decreased.

DISCUSSION

Just over 20% of the CHMS surveys population was diagnosed with prediabetes using the ADA's A1C criteria of 5.7–6.4% (8.8–46.4 mmol/mol).⁴ This contrasts with the most recent population-based survey (NHANES 1999–2010) where now 34% of children aged ≥12 years have prediabetes, using the same criteria.²⁶ Because prediabetes is one of the first clinical indicators in the natural history of T2DM, these data imply a significant public health burden of diabetes risk in Canada.⁴ The lower rates of prediabetes in Canadian children may be related to lower rates of overweight/obesity in Canada (27%) compared to 30% in the USA. Note that in the USA, rates of overweight/obesity are based on growth charts and definitions from the Centers for Disease Control and Prevention (CDC).^{27,28} If one used the WHO charts and diagnostic criteria for overweight/obesity as used in Canada, the American rates would be 8–10% higher and proportionate with the higher rate of prediabetes in that country.²⁷

Previous smaller studies have evaluated the rates of prediabetes, but the vast majority were small samples (<1000 children) and usually targeted populations of overweight or obese children.^{8,11,29} In these studies, the rates of prediabetes varied from 14 to 49%; these rates are challenging to compare with representative samples of a country because of selection biases. Older age in the multivariable models seemed to be protective in our pediatric Canadian data; this level of granular evaluation was not assessed in the latest NHANES data.²⁶

Interestingly in both the American and Canadian population-based surveys, boys usually seemed to be at increased risk of prediabetes, which may reflect their greater likelihood to be overweight or obese compared to girls.^{28,30} Interestingly, girls are more frequently diagnosed with T2DM¹; this may reflect sex differences in seeking medical care and diagnoses. Alternatively, we might speculate that males with elevated A1Cs may revert to euglycemia more frequently than girls⁶ or have a slower course. Additional, longitudinal studies are required to clarify this issue. Other biological variables not included in our assessment, such as diet or hormonal (pubertal) status, might also explain this difference. As described above, it has been recognized that some races/ethnicities are at higher risk for T2DM; this includes, but is not limited to, Asian, First Nations, Black, and Hispanic populations.⁴ Due to our relatively small sample size, we needed to pool our ethnic data and could only determine that non-Whites were at higher risk than Whites. NHANES data demonstrated prediabetes

Fig. 1 Proportion and adjusted ORs of prediabetes by region in Canada

in those of Mexican-American ancestry compared to non-Hispanic Whites or non-Hispanic Blacks in an adjusted model.²⁶ These racial differences may be explained by variations in the genetic background related to risk for T2DM or social factors clustering with racial minorities. Teasing out these biological variables allows practitioners to target prevention strategies and focus on the selection of those who might need screening. Currently, this study confirms that biologic risk factors include males, non-White race/ethnicity, and those who are obese.

There is mounting evidence that poverty and social deprivation are associated with an increased risk of obesity and type 2 diabetes.⁵ Our data suggest that even after adjusting for biological variables, lower education and middle-income adequacy were associated with increased odds of prediabetes. The non-linear association with income adequacy may speak to a more complex relationship with SES. We previously reported in the Canadian Community Health Survey and CHMS that low income and lower levels of education were associated with higher odds of obesity or overweight/obesity in an adjusted regression model independent of age, sex, or race.²⁸ The current data extend these findings along the natural history of T2DM in youth, suggesting an important role of poverty/social factors in the etiology of cardiometabolic risk among youth. The observed socioeconomic or regional variations that persist after multivariable adjustment speak about additional sociodemographic or cultural factors not consistently captured in these surveys, such as community resources, food insecurity, and opportunities for physical activity.³¹

In terms of remediable factors, our data clearly demonstrate that increased physical activity was significantly associated with a reduced risk of prediabetes for those 12 years or older in the fully adjusted model. If an adolescent undertook 60 min of vigorous daily activity as recommended by our national Healthy Active Living standards, this would confer a 30% reduction in the odds of developing prediabetes.³² This is one of the few modifiable factors that health care professionals can encourage to potentially help reduce the risk of prediabetes and ultimately T2DM itself.

Most of the discussion has focused on the data using ADA criteria because the number of children with prediabetes were larger ($n = 785$) than using the more restricted adult definition from the CDA ($n = 179$; A1C = 6.0–6.4% (42.1–46.4 mmol/mol)). The univariate analyses using the CDA definition are not materially different from those with the ADA definition, but the sample size limitations with the CDA definition make it difficult to interpret the fully adjusted model.³³

Some of the strengths of this study are the large number of children with prediabetes and the wide variety of biological and socioeconomic variables collected in these surveys. Moreover, this sample has significantly fewer selection biases than many smaller studies exclusively targeting overweight or obese children. Additionally, the prediabetes state not only may be a harbinger of T2DM, but in itself has been associated with less desirable lipid profiles, such as smaller LDL and HDL particles or increased left ventricular wall thickness.^{10,34} Early detection of metabolic abnormalities is a priority to target interventions with the goal of attenuating lifelong diabetes and/or cardiovascular risk.

This study is not without limitations. Perhaps the major one is the use of A1C alone to diagnosis prediabetes. In 2010, the ADA adopted an A1C of 5.7–6.4% to denote prediabetes alone without concomitant glucose thresholds.^{4,13} Controversy has ensued as to whether this accurately defines prediabetes.^{8,35,36} Unlike in adults, an elevated A1C is not a robust predictor of progression to frank T2DM.^{36,37} Additionally, A1C varies with race, iron status, or hemoglobinopathies.¹³ For these reasons, we add an additional cautionary note regarding the diagnosis of prediabetes using a single A1C, as we did in our study. Nevertheless, Dr. Arslanian's group elegantly demonstrated that children with prediabetes based on the A1C definition had discernible β -cell dysfunction compared to those with normal A1C.¹² Recent research also demonstrates that clinicians are following this ADA recommendation, are more frequently screening with A1C, and are finding increased numbers of cases of prediabetes.^{38,39} Part of the attractiveness of using A1C alone is that it can be done in a non-fasting manner, with fewer day-to-day perturbations and pre-analytic stability.

Additional limitations reflect that the cross-sectional CHMS survey is a biased sample; it does not include First Nations reserves and there is a non-responders bias.¹⁵ Some have argued that this may underestimate the true prevalence of prediabetes in Canada. Moreover, the association of euglycemia with increased physical activity may be a surrogate for healthier lifestyles and/or diet.⁴⁰ Inability to fully account for survey design may lead to imprecise CIs. Lastly, analysis was restricted to the sample of generally healthy Canadian children, and sample means and prevalences do not necessarily generalize to the population as a whole.

CONCLUSION

This study demonstrates that prediabetes is relatively common in a national survey and that there are important biological risk

Table 2. Baseline and adjusted ORs (95% CI) for dysglycemia in youth by definition

Variable	ADA definition		CDA definition	
	Baseline ^a	Adjusted ^b	Baseline ^a	Adjusted ^b
Age	0.96 (0.94–0.98)	0.97 (0.95–0.99)	0.96 (0.92–1.00)	0.98 (0.94–1.03)
Male (vs. Female)	1.22 (1.04–1.43)	1.18 (0.99–1.41)	1.77 (1.30–2.44)	1.69 (1.22–2.36)
Non-White (vs. White)	1.94 (1.59–2.36)	2.62 (2.05–3.35)	3.26 (2.36–4.48)	4.40 (2.96–6.51)
Obesity	1.56 (1.24–1.95)	1.53 (1.19–1.96)	1.53 (1.01–2.26)	1.50 (0.97–2.26)
Income adequacy (vs. high)				
Low	0.97 (0.79–1.19)	0.87 (0.68–1.11)	1.02 (0.68–1.51)	0.85 (0.54–1.32)
Middle	1.31 (1.09–1.58)	1.27 (1.04–1.56)	1.25 (0.88–1.76)	1.20 (0.82–1.73)
High school or less	1.38 (1.09–1.73)	1.34 (1.02–1.74)	1.62 (1.07–2.38)	1.56 (0.99–2.40)
(vs. any post-secondary)				
Immigrant	1.41 (1.07–1.84)	0.88 (0.63–1.22)	1.87 (1.17–2.86)	0.81 (0.47–1.35)
Region (vs. Ontario)				
British Columbia	3.03 (2.35–3.93)	3.09 (2.36–4.05)	3.45 (2.06–5.89)	3.24 (1.90–5.62)
Prairies	4.36 (3.39–5.62)	4.85 (3.72–6.34)	6.04 (3.75–10.03)	7.08 (4.32–11.95)
Quebec	1.48 (1.15–1.92)	1.70 (1.30–2.21)	1.49 (0.85–2.64)	1.89 (1.06–3.38)
Atlantic	7.33 (5.54–9.73)	8.90 (6.61–12.02)	5.19 (3.03–9.01)	7.79 (4.41–13.96)
Physical activity 6–11 y	1.01 (0.99–1.14)	1.01 (0.99–1.04)	1.00 (0.95–1.05)	NA
hours per week				
Physical activity ≥12 y	0.96 (0.94–0.98)	0.97 (0.95–0.99)	0.96 (0.92–0.99)	NA
monthly frequency of >150 min of exercise				

^aBaseline ORs are from univariate logistic regression with covariates age and sex
^bORs adjusted for age, sex, race, obesity, income adequacy, highest household education, immigrant status, and region

factors, including being male, obese, non-White, or coming from certain regions of Canada, all of which increase the odds of the prediabetes state. Most importantly for health care professionals, we have confirmed a robust association between physical activity and reduced odds of prediabetes even after controlling for other risk factors. For this reason, targeted screening and continued emphasis on meeting national recommendations for physical activity/healthier lifestyles may potentially help curb the high rates of prediabetes and ultimately T2DM.

ACKNOWLEDGEMENTS

The study was funded by a grant from the Canadian Institutes of Health Research (CPP-137910) awarded to Dr. Jonathan McGavock.

ADDITIONAL INFORMATION

Competing interests: The authors declare no competing interests.

Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

- Dabelea, D. et al. Prevalence of type 1 and type 2 diabetes among children and adolescents from 2001 to 2009. *JAMA* **311**, 1778–1786 (2014).
- Mayer-Davis, E. J. et al. Incidence trends of type 1 and type 2 diabetes among youths, 2002–2012. *N. Engl. J. Med.* **376**, 1419–1429 (2017).
- American Diabetes Association. *Fast Facts—Data and Statistics About Diabetes*. http://professional.diabetes.org/content/fast-facts-data-and-statistics-about-diabetes/?loc=dorg_statistics. (2017) Accessed 10 Apr 2017.
- American Diabetes Association. Diagnosis and classification of diabetes mellitus. *Diabetes Care*. **33**, S62–S69 (2010).
- Robbins, J. M., Vaccarino, V., Zhang, H. & Kasl, S. V. Socioeconomic status and type 2 diabetes in African American and non-Hispanic white women and men: evidence from the Third National Health and Nutrition Examination Survey. *Am. J. Public Health* **91**, 76–83 (2001).
- Vijayakumar, P., Nelson, R. G., Hanson, R. L., Knowler, W. C. & Sinha, M. HbA1c and the prediction of type 2 diabetes in children and adults. *Diabetes Care*. **40**, 16–21 (2017).
- Abraham, T. M. & Fox, C. S. Implications of rising prediabetes prevalence. *Diabetes Care*. **36**, 2139–2141 (2013).
- Brar, P. C., Mengwall, L., Franklin, B. H. & Fierman, A. H. Screening obese children and adolescents for prediabetes and/or type 2 diabetes in pediatric practices: a validation study. *Clin. Pediatr. (Phila.)* **53**, 771–776 (2014).
- Chan, C. L. et al. Continuous glucose monitoring and its relationship to hemoglobin A1c and oral glucose tolerance testing in obese and prediabetic youth. *J. Clin. Endocrinol. Metab.* **100**, 902–910 (2015).
- Burns, S. F. et al. Pre-diabetes in overweight youth and early atherogenic risk. *Metabolism* **63**, 1528–1535 (2014).
- Morrison, K. M. et al. Screening for dysglycemia in overweight youth presenting for weight management. *Diabetes Care*. **35**, 711–716 (2012).
- Sjaarda, L. A. et al. HbA(1c) diagnostic categories and β -cell function relative to insulin sensitivity in overweight/obese adolescents. *Diabetes Care*. **35**, 2559–2563 (2012).
- Herman, W. H. et al. Differences in A1C by race and ethnicity among patients with impaired glucose tolerance in the Diabetes Prevention Program. *Diabetes Care*. **30**, 2453–2457 (2007).
- Statistics Canada. *Canadian Health Measures Survey (CHMS) Data User Guide: Cycle 1*. (Statistics Canada, Ottawa, 2011). www23.statcan.gc.ca/imdb-bmdi/document/5071_D2_T1_V1-eng.html. Accessed 2 Apr 2017.
- Statistics Canada. *Canadian Health Measures Survey (CHMS) Data User Guide: Cycle 2*. (Statistics Canada, Ottawa, 2013). Accessed 1 Apr 2017.
- Tremblay, M., Wolfson, M., & Connor Gorber, S. Canadian Health Measures Survey: rationale, background and overview. *Health Rep.* **18**(Suppl.), 7–20 (2007).
- Day, B., Langlois, R., Tremblay, M., & Knoppers, B.-M. Canadian Health Measures Survey: ethical, legal and social issues. *Health Rep.* **18**(Suppl.), 37–51 (2007).
- Giroux, S. Canadian Health Measures Survey: sampling strategy overview. *Health Rep.* **18**(Suppl.), 31–36 (2007).
- Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, Goldenberg, R. & Punthakee, Z. Definition, classification and diagnosis of diabetes, prediabetes and metabolic syndrome. *Can. J. Diabetes* **37**(Suppl. 1), S8–S11 (2013).
- de Onis, M. et al. Development of a WHO growth reference for school-aged children and adolescents. *Bull. World Health Organ.* **85**, 660–667 (2007).
- National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. *Pediatrics* **114**, 555–576 (2004).
- Sharma, A. K., Metzger, D. L., Daymont, C., Hadjiyannakis, S. & Rodd, C. J. LMS tables for waist-circumference and waist-height ratio Z-scores in children aged 5–19 y in NHANES III: association with cardio-metabolic risks. *Pediatr. Res.* **78**, 723–729 (2015).
- Corby, L. & Secker, D. *Growth Monitoring Of Infants And Children Using The 2006 World Health Organization [WHO] Child Growth Standards and 2007 WHO Growth References*.

- https://www.dietitians.ca/Downloads/Public/Growth_Charts_backgrounder_eng.aspx. Accessed 10 Apr 2017.
24. Rosella, L. C., Lebenbaum, M., Fitzpatrick, T., Zuk, A. & Booth, G. L. Prevalence of prediabetes and undiagnosed diabetes in Canada (2007–2011) according to fasting plasma glucose and HbA1c screening criteria. *Diabetes Care*. **38**, 1299–1305 (2015).
25. R Foundation for Statistical Computing. *R: A Language and Environment for Statistical Computing*. (R Core Team, Vienna, Austria, 2016). <https://www.r-project.org/>. Accessed 10 Apr 2017.
26. Bullard, K. M. et al. Secular changes in U.S. Prediabetes prevalence defined by hemoglobin A1c and fasting plasma glucose: National Health and Nutrition Examination Surveys, 1999–2010. *Diabetes Care*. **36**, 2286–2293 (2013).
27. Shields, M. & Tremblay, M. S. Canadian childhood obesity estimates based on WHO, IOTF and CDC cut-points. *Int. J. Pediatr. Obes.* **5**, 265–273 (2010).
28. Rodd, C. & Sharma, A. K. Recent trends in the prevalence of overweight and obesity among Canadian children. *CMAJ* **188**, E313–E320 (2016).
29. Ek, A. E., Rössner, S. M., Hagman, E. & Marcus, C. High prevalence of prediabetes in a Swedish cohort of severely obese children. *Pediatr. Diabetes* **16**, 117–128 (2015).
30. Ogden, C. L., Carroll, M. D., Fryar, C. D. & Flegal, K. M. Prevalence of obesity among adults and youth: United States, 2011–2014. *NCHS Data Brief* **219**, 1–8 (2015).
31. Ball, G. D. C., Ambler, K. A. & Chanoine, J.-P. Pediatric weight management programs in Canada: where, what and how? *Int. J. Pediatr. Obes.* **6**, e58–e61 (2011).
32. Lipnowski, S. & Leblanc, C. M. Canadian Paediatric Society, Healthy Active Living and Sports Medicine Committee. Healthy active living: physical activity guidelines for children and adolescents. *Paediatr. Child Health* **17**, 209–212 (2012).
33. Peduzzi, P., Concato, J., Kemper, E., Holford, T. R. & Feinstein, A. R. A simulation study of the number of events per variable in logistic regression analysis. *J. Clin. Epidemiol.* **49**, 1373–1379 (1996).
34. Eklioğlu, B. S., Atabek, M. E., Akyürek, N. & Alp, H. Prediabetes and cardiovascular parameters in obese children and adolescents. *J. Clin. Res. Pediatr. Endocrinol.* **8**, 80–85 (2016).
35. Lee, J. M. et al. Screening practices for identifying type 2 diabetes in adolescents. *J. Adolesc. Health* **54**, 139–143 (2014).
36. Kim, J. Y., Goran, M. I., Toledo-Corral, C. M., Weigensberg, M. J. & Shaibi, G. Q. Comparing glycemic indicators of prediabetes: a prospective study of obese Latino Youth. *Pediatr. Diabetes* **16**, 640–643 (2015).
37. Jaruratanasirikul, S., Thammaratchuchai, S., Puwanant, M., Mo-Suwan, L. & Sriplung, H. Progression from impaired glucose tolerance to type 2 diabetes in obese children and adolescents: a 3–6-year cohort study in southern Thailand. *J. Pediatr. Endocrinol. Metab.* **29**, 1267–1275 (2016).
38. Vijayadeva, V. & Nichols, G. A. Impact of implementing glycated hemoglobin testing for identification of dysglycemia in youth. *Perm. J.* **18**, 21–27 (2014).
39. Lee, J. M., Gebremariam, A., Wu, E.-L., LaRose, J. & Gurney, J. G. Evaluation of nonfasting tests to screen for childhood and adolescent dysglycemia. *Diabetes Care*. **34**, 2597–2602 (2011).
40. Katzmarzyk, P. et al. An evolving scientific basis for the prevention and treatment of pediatric obesity. *Int. J. Obes.* **38**, 887–905 (2005). 2014.