Population-level trends in the distribution of body mass index in Canada, 2000-2014

Canadian body mass index trend 2000-2014

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Conflict of interest

The authors declare that they have no conflict of interest.

ABSTRACT

OBJECTIVE: Research studying population-level body mass index (BMI) trends document increases in mean or prevalence of overweight/obese but less consideration has been given to describing the changing distribution of BMI. The objective of this research was to perform a detailed analysis of changes in the BMI distribution in Canada.

DESIGN: Using data from the CCHS (2000-2014), we analyzed distributional parameters of BMI for 492,886 adults aged 25–64 y. We further stratified these analyses for women and men, education level, and region of residence.

RESULTS: Mean BMI has increased for most subgroups of the Canadian population. Mean BMI values were higher for men, while SD of the BMI distribution was systematically higher in women. Increases in mean BMI were accompanied with increases in standard deviation (SD) of BMI across cycles. Across survey cycles, the 95th percentile increased by more than 10-times the 5th percentile, showing a very unequal change between extreme values in the BMI distribution over time. There was a relationship between SD with BMI, but these relations were generally not different between educational categories and regions. This suggests that the growing inter-individual inequalities (i.e. dispersion) in BMI were not solely attributable to socioeconomic and demographic factors.

CONCLUSIONS: This study supports the hypothesis that the simultaneous increase in mean BMI and SD of the BMI distribution are occurring and suggests the need to move beyond the mean-centric paradigm when studying a complex public health phenomena such as population change in BMI.

Keywords: Body mass index, trends, education, sex, Canada

INTRODUCTION

The worldwide increase in obesity and related chronic diseases is recognized to be driven in part by global trade liberalization, economic growth and rapid urbanization.[1-3] These factors continue to influence important changes in living environments, diets and lifestyles in ways that promote positive energy balance.[4] The rise in body mass index (BMI=kg/m^2) is often reported in the research literature and in public health reporting as prevalence of specific BMI categories (e.g. overweight or obese) or as mean change[5]. For example, the increase of the average BMI has been 0.5 kg/m^2 per decade globally; this rate was shown to be faster in wealthier countries such as USA and Canada where the rate of increase in BMI was over 1 kg/m^2 per decade.[6]

Research studying BMI trends in developed countries suggest that along with increase in overall mean BMI, differential increases have occurred within sub-populations grouped by sex, race and socioeconomic status (SES).[7] Some studies revealed a slight negative inflection of the BMI growth curve potentially due to a leveling-off of the rise in mean BMI within countries.[8-10] However, most of these studies do not take account of the changing shape of the BMI distribution with time, and assume that BMI increases at a proportional rate within all categories[5]. Few studies have examined whether inequalities in weight gain are occurring within social groups or specific segments of the population, which is a measure of inter-individual inequalities rather than between-group inequalities.[11] An increasing body of work suggests that bringing a distributional perspective to BMI changes may reveal important information about population health[12, 13] and may contribute to the discussion on the relative merits of the population strategy compared with the high-risk strategy.[14]

Motivated by this concern, Krishna et al.[13] showed that increase in mean BMI in the US was correlated to the increase in the spread of the BMI distribution, suggesting that mean BMI cannot fully describe population changes in BMI. Moreover, they showed a similar increase in dispersion within socioeconomic and demographic groups, suggesting that growing inequalities in BMI at the population level are not driven solely by individual factors. A recent analysis came to similar conclusion in England.[12] In Canada, weight categories were observed to evolve at different rate in the general adult population without taking into account individual determinants of obesity.[10] Other Canadian studies showed significant geographic variations in BMI above individual determinants of obesity such as age, sex, education level and lifestyle indicators.[15] Detailed sociospatial description of the BMI distributional changes in Canada over time may contribute to prior reporting which often focused on point estimates (mean or prevalence), geographic variation, or a specific period, and for which the dispersion is rarely the focus.[10, 15, 16] This work will also allow comparison to BMI distributional changes observed in Canada versus other high income countries and among sub-groups of the population commonly associated with BMI.[12, 13]

The objective of this research was to perform a detailed analysis in the BMI distribution changes in Canada by sex, education level and region of residence.

METHODS

Data sources

Data were retrieved from the Canadian Community Health Survey (CCHS), a multiple cross-sectional health survey performed by Statistics Canada since the year 2000. The CCHS provides self-reported information for a nationally representative sample of the non-institutionalized civilian population 12 years and older in the 10 Canadian provinces, thereby excluding territories.[17] Data collection for the first three cycles was every two years: cycle1.1(2000-2001), cycle 2.1(2003), cycle 3.1(2005). Samples were approximately 130,000 Canadian individuals per cycle. From the 4th cycle, the data collection was performed annually and included about 65,000 individuals per year. To standardize data collection, the annual investigations have been grouped as follows: 2007-2008(cycle 4); 2009-2010(cycle 5); 2011-2012(cycle 6); 2013-2014(cycle 7).

Study population and sample size

We restricted the analyses on 25 to 64 years old in order to be consistent with previous work using distributional change in BMI[12, 13]. Moreover, because an artificial increase of BMI due to shrinkage in stature in older adults,[18] the use of BMI may not be appropriate to compare older individuals with younger ones.[19] We also excluded pregnant women, and individuals with missing data on key variables of interest such as sex, BMI value, those living in households where the highest education levels was not reported. We also excluded extreme BMI values that are often considered to be as extreme outliers or reporting errors (12<BMI>70= less than 1% observations)[20]. The 25-64y subsample represents 59% of the CCHS sample for all cycles. Exclusion criteria represent 8% of the subsample. CCHS sample weights were normalized to take account of the sample plan and the exclusion criteria[21]. The final sample included 492,886 individuals (Table 1).

Outcome

The distribution of BMI was the outcome of interest. BMI is measured as a ratio of weight (kg) to the square of height (m). The 5th and 95th percentiles, and the standard deviation (SD) of the BMI distribution were used as outcomes to study changes in the shape of the distribution over time relative to the median and the mean of BMI.

Key independent variables

Sex, age stratified into 5-y groups, and education level stratified into 4 categories based on number of years at school and diploma attainment.[20] The "No diploma" category includes those who had been less than 12 years at school or more than 12 years at school but had no diploma. The ‘‘High school’’ category includes only those who successfully finished high school (secondary-5 diploma or 13th year completed). The ‘‘College’’ category includes all those who did some post-secondary, with or without a college diploma, including those who received a university certificate (e.g. one year at the university). Finally the ‘‘Graduate studies’’ category includes those with a baccalaureate diploma or higher.

The BMI and SD distributions trends were also disaggregated by province. Since Canadian provinces greatly vary by population size, some of them were grouped into regions comparable to other Canadian studies describing spatial dispersion of BMI:[15, 16] Saskatchewan and Manitoba was named the Prairie region, and Newfoundland, Prince-Edward-Island, New-Brunswick and Nova-Scotia are known as the Atlantic provinces.

Graphical analysis of patterns in BMI distributional changes in time

We used quantile-quantile (QQ) plots to examine patterns of distributional change in BMI.[13, 22] A QQ plot was constructed by plotting percentiles of BMI from the most-recent survey (2013-2014) against percentiles of BMI from the baseline survey (2000-2001). If there was no change in distributions between the two survey cycles the points would lie on the line of the equality (y = x). Points above the line represented increases in BMI at the same percentile in the most recent year from baseline. QQ plots are particularly effective in presenting changes at the tails of distributions.[23] We constructed QQ plots separately for women and men.

Analysis of BMI distribution trends

CCHS data from 2000 to 2014 were pooled to allow for the comparison of distributional changes over time. We conducted analyses by sex, educational level and region of residence to disaggregate distributional changes within subgroups of the population. Stratifying by sex, we had two subgroups; stratifying by educational level and sex, we had eight subgroups; for the stratification by region and sex, we had 12 subgroups.

To estimate the BMI distribution trends, ordinary least square (OLS) regressions were used for modelling the mean, the SD, and the BMI value at the 5th and 95th percentiles. For analyses on the entire sample, we adjusted BMI for age, sex and educational level. When stratifying by sex, by sex and educational level, or by sex and region, we adjusted only for age. CCHS sample weights were normalized for each subgroup analyses. Thus, each analysis was weighted according to the subsample population size.

Analysis of the relation of distributional parameters of BMI

To fully characterize the distributions trends, we further analyzed the relationship between centrality indicators of the BMI distributions (mean and median) predicting their dispersion indicators (SD, and 5th and 95th percentiles). Changes in mean BMI were related to the SD of BMI (spread of the distribution) and changes at the 5th and 95th percentiles of BMI (extremities or tails of the distribution) were related to the median (50th percentile).

In this study, we utilized standard deviation (SD) and percentiles of the BMI distribution as measures of inequality to assess the population level dispersion across individuals within groups. The theoretical framework of our study is based on what Murray and Gakidou defined as “health inequality”, which is variation in health status across individuals in a population[24, 25]. This approach aims to complete the measurement of social group inequalities by differences in mean values or the prevalence of health outcomes between social groups more frequently used[11].

Fitted OLS regression lines for changes in these distributional parameters over time were plotted for women and men as well as subgroups disaggregated by educational levels and the six Canadian regions. For all models, units of analysis were survey cycles (two-year groups; n= 7 cycles). Model significance tests were conducted using *t-tests*; differences in changes between categories were tested using *Wald* tests. All analyses were performed using SAS 9.4.

RESULTS

Table 1 shows a distribution of the CCHS pooled sample for 2000–2014 surveys. The final sample comprised 492,886 Canadian adults proportionally distributed across age groups, education level categories and regions.

Table 1. Distribution of pooled CCHS sample of adults aged 25-64 years old, 2000-2014

Variable	Women	Men
Sample size	242201,3	250684,7
Proportion	49,1%	50,9%
Age group		
25-29	11,6%	12,2%
30-34	11,4%	12,1%
35-39	13,1%	13,1%
40-44	14,6%	14,8%
45-49	14,1%	13,7%
50-54	13,7%	13,1%
55-59	11,8%	11,7%
60-64	9,7%	9,4%
Education		
No high school	11,3%	12,7%
High school	18,0%	16,9%
College	44,7%	44,6%
Graduate studies	26,0%	25,7%
Region		
Atlantic	7,5%	7,2%
Quebec	24,0%	24,0%
Ontario	38,9%	38,4%
Prairies	6,0%	6,2%
Alberta	10,2%	10,9%
British-Columbia	13,4%	13,2%
Cycle		
1 (2001-2002)	49,1%	50,9%
2 (2003-2004)	48,9%	51,1%
3 (2005-2006)	49,0%	51,0%
4 (2007-2008)	49,5%	50,5%
5 (2009-2010)	49,3%	50,7%
6 (2011-2012)	48,9%	51,1%
7 (2013-2014)	49,3%	50,7%

Graphical analysis of patterns of BMI distributional changes in Canada

Comparing the BMI mean at multiple points in the distribution revealed that lower BMI subgroups of the population had very little change in the mean BMI, while the higher BMI subgroups showed a substantial increase (Figure 1). For both, women and men, we observed a similar pattern indicating a progressive augmentation in the mean BMI for subgroups of the population having a higher mean BMI at base-line.

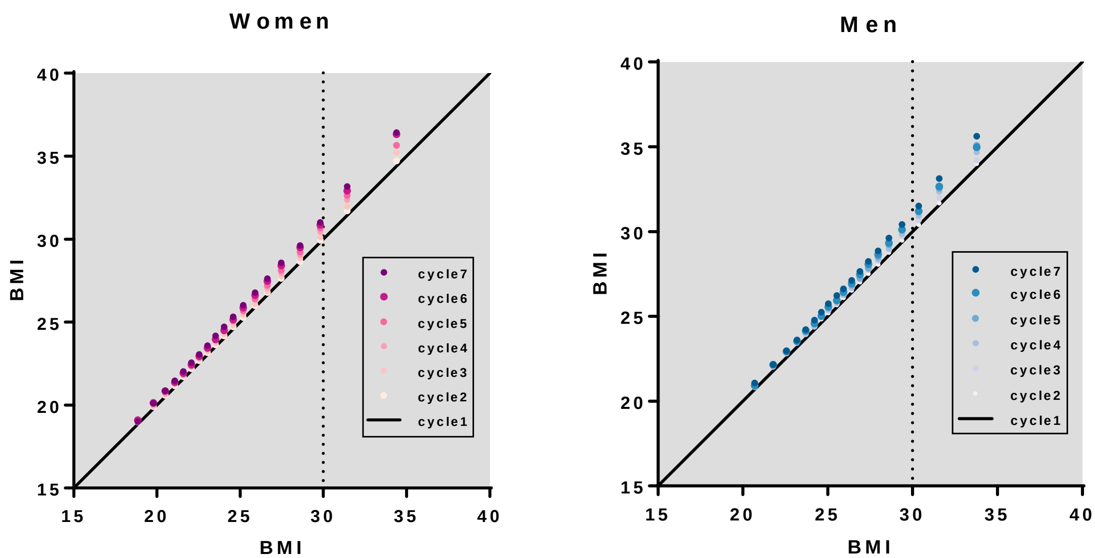

Figure 1 - Evolution of the distribution of BMI for women and men in Canada, 2000-2014

Analysis of BMI distribution trends in Canada

Figure 2 shows the evolution of four distributional parameters of the BMI distribution for women and men: the mean BMI, its standard deviation (SD), the value at 5th and 95th percentile. These parameters were stratified by sex, by sex and education level, and by sex and the region of residence. Detailed results of the OLS parameter estimations are available in Supplement Table 1.

The mean, the SD and the value at 95th percentile significantly increased between 2000 and 2014 (*p<0.05*), while the value at 5th percentile increased very slightly (*p<0.10*). The 95th percentile increased by 0.33 BMI/cycle which is more than 10 times than for the 5th percentile (0.029 BMI/cycle).

Stratification by sex – Mean BMI and SD increased significantly for women and men during the 15 year period. The increase in the 5th percentile was significant only for men. The 95th percentile significantly increased for both, the increase was slightly higher for women (0.35 kg/m^2 per cycle in women; 0.30 kg/m^2 per cycle in men), but no significant differences was observed between women and men in the evolution of all four parameters.

Stratification by sex and education level- We observed a significant increase in mean, SD and 95th percentile of BMI for women in all education level categories. There was a marked and significant difference in the mean and the 95th percentile between educational levels, suggesting the BMI distribution evolves differently for women according to their education level. The increase in the 95th percentile was substantially less for women with graduate degrees versus all other groups.

For men, although mean, SD and 95th percentile of the BMI distribution raised significantly for all educational groups, no statistical difference was observed between them. At the 5th percentile, the value of the SD tend to increase faster for men without high school degree than other educational categories (p-value < 0.10) and increased at the same pace than the mean (0.14 BMI/cycle).

Stratification by sex and region of residence- All four BMI distributional parameters increased significantly for all Canadian regions in women, except for British-Columbia (BC) where no increase was observed on any of the distributional parameters over 15 years, and in Alberta where the value of the 5th percentile stayed about the same. Taken globally, the increase of the mean, 5th and 95th percentile were statistically different between regions. This regional variation was particularly spread for the mean and the 95th percentile suggesting that the change in the BMI distribution among women varies according to the region of residence.

The mean, SD and 95th percentile also increased significantly for men in all Canadian regions. The increase at the 5th percentile was also significant for most regions, and only Ontario and Quebec showed a relative stable value during the study period. Although the between-region variation was less pronounced than for women, the increase of all the four distributional parameters was significantly different between the six Canadian regions.

Taken globally, Figure 2 shows that BMI was consistently higher for men over the 15-year period, while the SD was systematically higher for women. The mean, SD and 95th percentile increased for all educational levels for both sexes. Changes in these three parameters were also observed in all Canadian regions, and where the increase in the 95th percentile was especially pronounced for both sexes.

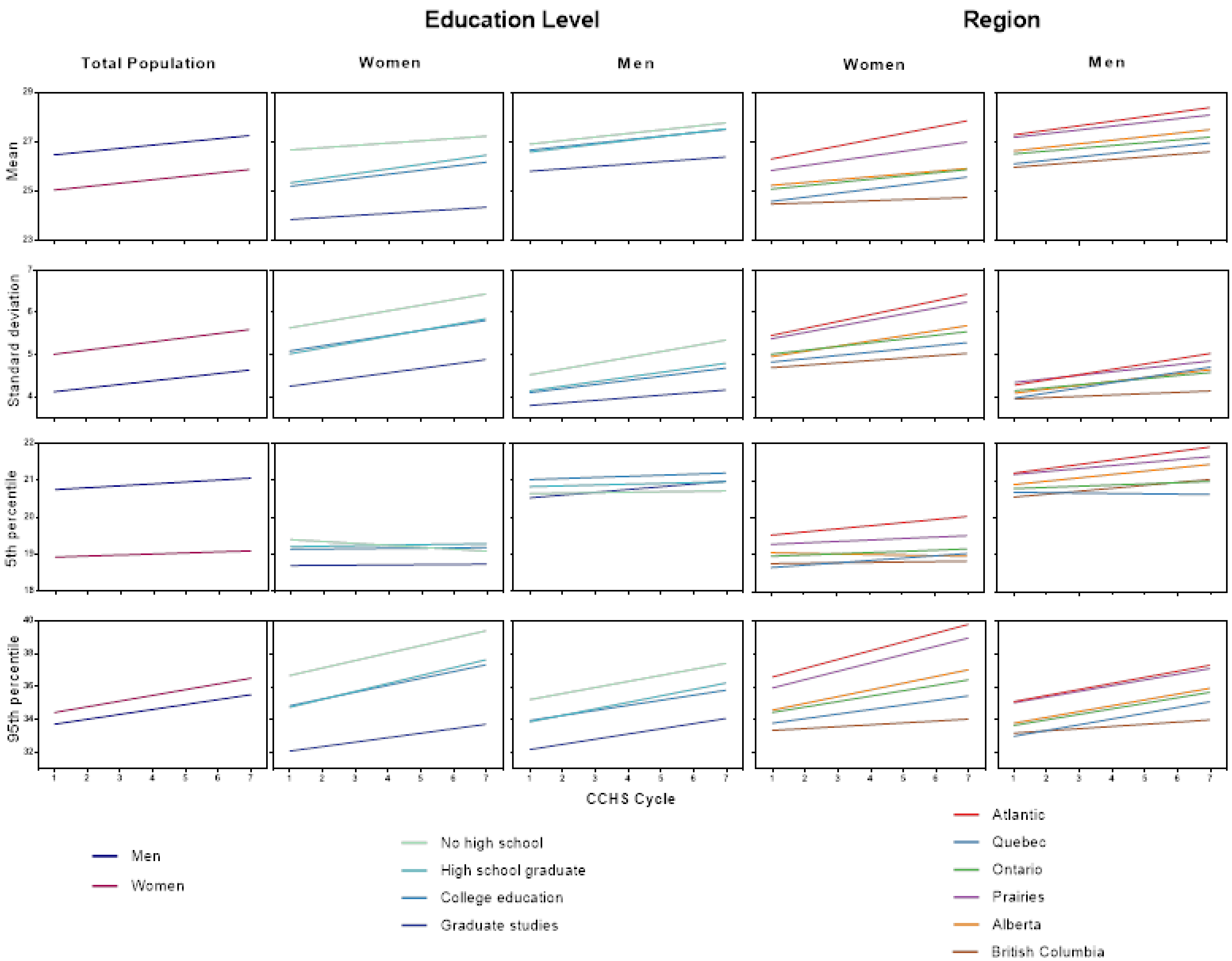

Figure 2. Evolution of BMI distributional parameters in CCHS from 2000 to 2014 for women and men and by education level and region of residence.

Relative changes in distributional variables of BMI

Figure 3 shows the relation between dispersion indicators and centrality indicators of the BMI distribution, the relation between the SD and the mean BMI, and the relation between the 5th and

95th percentiles and the median BMI. Detailed results of the OLS parameter estimations are available in Supplement Table 2.

Stratification by sex – An increase in mean BMI was significantly associated with an increase with the SD for both women and men. The value at the 5th percentile did not increase significantly in women. However, the 95th percentile was estimated to rise by 3.27 kg/m^2 for an increase of 1 kg/m^2 in the median. This is suggesting that an increase in the BMI median value is driving an increase over three times more important at the 95th percentile of the distribution. Since the BMI value at the 5th percentile did not change significantly, these observations demonstrate that this subgroup of the population saw a flattening of its BMI distribution.

In men, there was a significant increase in the 5th percentile (0.52 kg/m^2) as well as for the 95th percentile (2.75 kg/m^2), suggesting that the distribution curve is simultaneously flattening and moving toward higher BMI values.

Stratification by sex and education level- An increase in women's mean BMI was associated in an increase of the SD in all educational categories, but no significant differences were observed between education levels.

For men, we also observed that an increase of the mean BMI was associated with an increase in SD in all educational categories, but without significant difference between them. No significant relationship was observed between the 5th percentile and the median of the distribution except for to most educated men. This subgroup showed an increase of the 5th percentile that almost match the increase of the median (0.99 kg/m^2), suggesting that the educated men BMI distribution is not flattening and is globally moving toward higher BMI values.

Stratification by sex and regions- The increase of the women's mean BMI significantly resulted in an augmentation of the SD in all Canadian regions. The increase of the BMI dispersion was particularly important among BC women (1.11 kg/m^2) as compare to other regions such as Quebec (0.48 kg/m^2) or the Atlantic (0.65 kg/m^2), resulting in a statistically significant difference in the SD-BMI relationship between regions (p=0.041). Most regions showed a positive relationship with an increase in the median BMI for the 95th percentiles, but no significant difference was observed between regions.

For men, all associations with the SD with mean BMI showed a positive and significant relationship, but no significant difference was observed between regions. A similar relationship was observed between the 95th percentiles and the median, but again no significant difference was observed between regions.

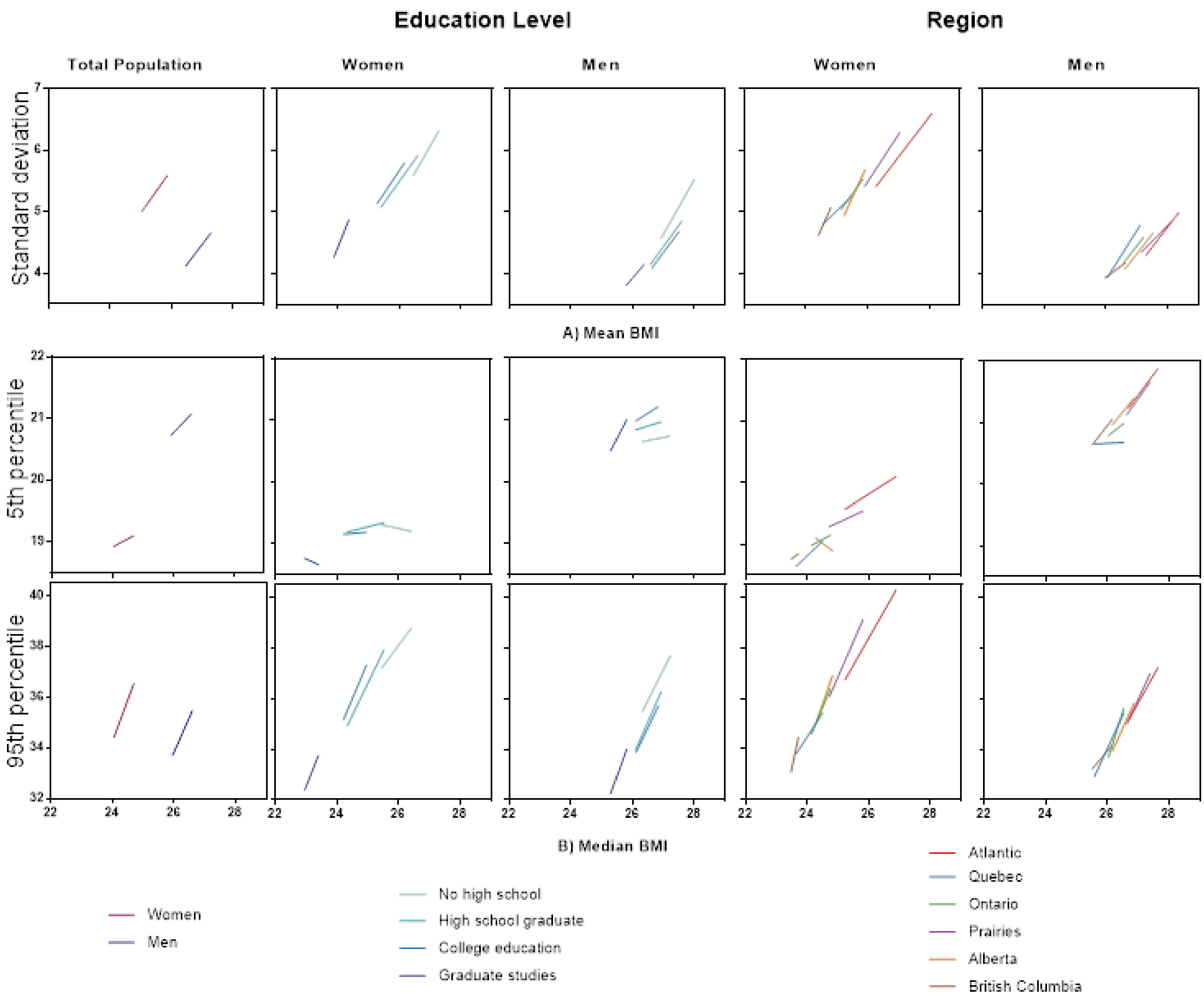

Figure 3. BMI distributional variables association with centrality indicators for men and women, by education level and region of residence.

DISCUSSION

This study presents a detailed analysis of trends in BMI variation in Canada by sex, education level and province of residence, and has two main findings. First, the mean BMI increased over time at different pace according to the education level or the geographic location, and was generally accompanied by an increase in dispersion (SD, 5th and 95th percentiles range). Second, most dispersion indicators were positively and significantly associated with centrality measures, but taken globally, these relationships were not statistically different between women and men, between education levels, and between Canadian regions. Finding an increase of the mean BMI during the last 15 years was expected. However, the fact that this BMI increase goes along with an increased dispersion which can actually predict the BMI increase, independently of sex, education and the geographical context, has never been clearly demonstrated in Canada.

Previous population research linking individuals' BMI with socioeconomic status (SES) in high-income countries showed that individuals with lower SES, those with lower educational attainment or working in lower grade occupation, are more likely to have higher BMIs than individuals in higher-SES groups.[7, 26, 27] Longitudinal studies showed that both adults and children of low SES are more likely to become obese than those in higher-SES groups, with more-pronounced differences in women.[28, 29] Our findings are in concordance with those observations, but went slightly further by demonstrating that increase in BMI dispersion occurs in most sub-groups of the population independently of SES.

Our results also support other studies suggesting the context where one lives could also have an influence on obesity indicators.[10, 15, 16, 30] In effect, the evolution of all four distributional parameters, including the 5th percentile, vary significantly when the analyses are stratified by sex and regions. These differences are partly driven by the observations in BC where no significant trend was observed for women, and a much lower increase of the mean, SD and 95th percentile for men. Paradoxically, the BMI of BC men in the 5th percentile increased more importantly than other regions such as in Quebec or in Ontario. Underlying these specific sex-context trends scenarios, we further observed there was about no significant differences between subgroups of the population in the relationship between distributional parameters and the centrality measures (mean and median). This is suggesting that the growing inter-individual inequalities (i.e. dispersion) in BMI were not solely attributable to demographic, socioeconomic and geographic factors in Canada. Said differently, the increasing BMI dispersion occurs in a similar way within all sub-groups of the population and everywhere in Canada.

These observations confirm that the Canadian population is experiencing a similar phenomenon that what was recently observed in the USA[31] and the UK.[12] This systematic increase in dispersion suggests that other causes such as unmeasured genetic, physiologic, or social characteristics might be at work. The biological mechanism of fat distribution in the body differ between women and men and may partly explain why the BMI distribution is more variable in women.[32] However, it is not clear if only the biological differences are involved in this variation since social perception concerning weight status may also vary by gender (i.e. social roles), and thus provide different daily opportunities and constraint regarding weight related behaviors.

Other theories have been proposed and discussed to explain increasing dispersion at the individual level,[33-35] and many suggest this may be the result of the interaction between the individuals' genetic susceptibility and environment factors.[36, 37] These new findings put forward several unanswered questions. Why the mean BMI evolves sometimes differently between men and women in the same region?[38] Could this be linked to provincial policies, social norms, or local urban planning practices?[39] Which underlying mechanisms are at play in the increasing dispersion we observed in all the population?[40] Are there unmeasured genetic characteristics which make some individuals more vulnerable to some specific contextual characteristics?[41] Beside presenting trends in BMI change and variation, this study contributes to an increasing body of evidence that supports researchers and policy makers in moving away from a mean-centric paradigm[40] when investigating important public health issues such as the obesity epidemic. A better understanding of the underlying variability mechanisms in space and time need to be considered in order to propose adapted interventions, rather than narrowing the observations on point estimates such as mean or prevalence[14].

The detailed analysis of trends in BMI variation in Canada had to deal with several challenges and comprises some limitations. The self-reported BMI increased the uncertainty of measurements, which may also differ between women and men. The correlation between measured and self-reported BMI in Canada was estimated at 0.89[42], we assumed this bias was constant through the CCHS cycles, and we stratified analyses by sex to control for the gender effect. Merging many survey cycles may bring some systematic biases due to a modification in the sampling strategy or in the questionnaire. The large and consistent sample by cycle of the CCHS is a strength of this research and reduces potential biases that could be induces by methodological changes in time. We verified the BMI related questions were the same for all cycles and we make sure the educational level we comparable in time and between regions by creating the categories on the reported number of years at school and diploma attainment. The number of subgroups that were analysed and compared may have induced some ambiguity in the results. Nevertheless, we are confident the overall results strongly support our interpretation.

CONCLUSION

This study shows that the increase in mean BMI was associated with increased group and inter-individual inequalities in weight gain in different social and demographic groups in. It contributed to the understanding of this complex causal web behind rising BMI, by highlighting the evolution of the BMI distribution and variation between sex, education level and the region of residence. In turn, this leads to new relevant research questions that may help to address underlying social forces that drive the obesity epidemic in high-income countries.

Although great effort were deployed to enhance healthy lifestyle and lower obesity rate in Canada, limited success was achieved during the last decade.[16] Beside presenting trends in BMI change and variation, this study contributes to an increasing body of evidence that supports researchers and policy makers in moving away from a mean-centric paradigm when investigating important public health issues such as the obesity epidemic, and to also consider the variability of the phenomena in order to propose adapted intervention.

REFERENCES

1. Hawkes, C., *Uneven dietary development: linking the policies and processes of globalization with the nutrition transition, obesity and diet-related chronic diseases.* Globalization and health, 2006. **2**(1): p. 4.
2. Kelly, B.B. and V. Fuster, *Promoting Cardiovascular Health in the Developing World:: A Critical Challenge to Achieve Global Health*. 2010: National Academies Press.
3. Popkin, B.M., L.S. Adair, and S.W. Ng, *Global nutrition transition and the pandemic of obesity in developing countries*. Vol. 70. 2012. 3-21.
4. Malik, V.S., W.C. Willett, and F.B. Hu, *Global obesity: trends, risk factors and policy implications.* Nat Rev Endocrinol, 2013. **9**(1): p. 13-27.
5. NCD-RisC, *Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults.* The Lancet, 2017.
6. Finucane, M.M., G.A. Stevens, M.J. Cowan, G. Danaei, J.K. Lin, C.J. Paciorek, et al., *National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9· 1 million participants.* The Lancet, 2011. **377**(9765): p. 557-567.
7. McLaren, L., *Socioeconomic Status and Obesity.* Epidemiologic Reviews, 2007. **29**(1): p. 29-48.
8. Flegal, K.M., M.D. Carroll, B.K. Kit, and C.L. Ogden, *Prevalence of Obesity and Trends in the Distribution of Body Mass Index Among US Adults, 1999-2010.* JAMA: The Journal of the American Medical Association, 2012. **307**(5): p. 491-497.
9. Krueger, P.M., K. Coleman-Minahan, and R.N. Rooks, *Race/ethnicity, nativity and trends in BMI among US adults.* Obesity, 2014. **22**(7): p. 1739-1746.
10. Twells, L.K., D.M. Gregory, J. Reddigan, and W.K. Midodzi, *Current and predicted prevalence of obesity in Canada: a trend analysis.* Canadian Medical Association Open Access Journal, 2014. **2**(1): p. E18-E26.
11. Vaezghasemi, M., F. Razak, N. Ng, and S. Subramanian, *Inter-individual inequality in BMI: An analysis of Indonesian Family Life Surveys (1993–2007).* SSM-Population Health, 2016. **2**: p. 876-888.
12. Green, M., S. Subramanian, and F. Razak, *Population-level trends in the distribution of body mass index in England, 1992–2013.* Journal of epidemiology and community health, 2016: p. jech-2015-206468.
13. Krishna, A., F. Razak, A. Lebel, G.D. Smith, and S. Subramanian, *Trends in group inequalities and interindividual inequalities in BMI in the United States, 1993–2012.* The American journal of clinical nutrition, 2015. **101**(3): p. 598-605.
14. Razak, F., G.D. Smith, and S. Subramanian, *The idea of uniform change: is it time to revisit a central tenet of Rose's "Strategy of Preventive Medicine"?* The American journal of clinical nutrition, 2016. **104**(6): p. 1497-1507.
15. Dutton, D.J. and L. McLaren, *How important are determinants of obesity measured at the individual level for explaining geographic variation in body mass index distributions? Observational evidence from Canada using Quantile Regression and Blinder-Oaxaca Decomposition.* Journal of epidemiology and community health, 2016. **70**(4): p. 367-373.
16. Gotay, C.C., P.T. Katzmarzyk, I. Janssen, M.Y. Dawson, K. Aminoltejari, and N.L. Bartley, *Updating the Canadian obesity maps: an epidemic in progress.* Can J Public Health, 2013. **104**(1): p. e64-e68.

17. Statistics Canada. *Canadian Community health Survey*. 2012 2016-12-08]; Available from: http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=3226&lang=en&db=imdb&adm=8&dis=2.
18. Sorkin, J.D., D.C. Muller, and R. Andres, *Longitudinal change in height of men and women: implications for interpretation of the body mass index: the Baltimore Longitudinal Study of Aging.* American journal of epidemiology, 1999. **150**(9): p. 969-977.
19. Ogden, C.L., S.Z. Yanovski, M.D. Carroll, and K.M. Flegal, *The epidemiology of obesity.* Gastroenterology, 2007. **132**(6): p. 2087-2102.
20. Lebel, A., Y. Kestens, C. Clary, S. Bisset, and S. Subramanian, *Geographic Variability in the Association between Socioeconomic Status and BMI in the USA and Canada.* PloS one, 2014. **9**(6): p. e99158.
21. Canada, S., *Canadian Community Health Survey (CCHS) Annual component: User guide 2010 and 2009-2010 Microdata files*. 2011, Statistics Canada: Ottawa. p. 100.
22. Wilk, M.B. and R. Gnanadesikan, *Probability plotting methods for the analysis of data.* Biometrika, 1968. **55**(1): p. 1-17.
23. Wilk, M.B. and R. Gnanadesikan, *Probability plotting methods for the analysis for the analysis of data.* Biometrika, 1968. **55**(1): p. 1-17.
24. Gakidou, E.E., C.J. Murray, and J. Frenk, *Defining and measuring health inequality: an approach based on the distribution of health expectancy.* Bulletin of the World Health Organization, 2000. **78**(1): p. 42-54.
25. Murray, C.J., E.E. Gakidou, and J. Frenk, *Health inequalities and social group differences: what should we measure?* Bulletin of the World Health Organization, 1999. **77**(7): p. 537.
26. Silventoinen, K., T. Tatsuse, P. Martikainen, O. Rahkonen, E. Lahelma, M. Sekine, et al., *Occupational class differences in body mass index and weight gain in Japan and Finland.* J Epidemiol, 2013. **23**(6): p. 443-50.
27. Neuman, M., I. Kawachi, S. Gortmaker, and S.V. Subramanian, *Urban-rural differences in BMI in low- and middle-income countries: the role of socioeconomic status.* Am J Clin Nutr, 2013. **97**(2): p. 428-36.
28. Baum, C.L., 2nd and C.J. Ruhm, *Age, socioeconomic status and obesity growth.* J Health Econ, 2009. **28**(3): p. 635-48.
29. Howe, L.D., K. Tilling, B. Galobardes, G.D. Smith, A.R. Ness, and D.A. Lawlor, *Socioeconomic disparities in trajectories of adiposity across childhood.* Int J Pediatr Obes, 2011. **6**(2-2): p. e144-53.
30. Lebel, A., Y. Kestens, C. Clary, S. Bisset, and S.V. Subramanian, *Geographic Variability in the Association between Socioeconomic Status and BMI in the USA and Canada.* PLoS ONE, 2014. **9**(6): p. e99158.
31. Krishna, A., F. Razak, A. Lebel, G.D. Smith, and S. Subramanian, *Trends in group inequalities and interindividual inequalities in BMI in the United States, 1993–2012.* The American Journal of Clinical Nutrition, 2015: p. ajcn. 100073.
32. Tchernof, A. and J.-P. Després, *Pathophysiology of human visceral obesity: an update.* Physiological reviews, 2013. **93**(1): p. 359-404.
33. Jenkins, A.B. and L.V. Campbell, *Variation in genetic susceptibility drives increasing dispersion of population BMI.* The American journal of clinical nutrition, 2015. **101**(6): p. 1308-1308.
34. Frohlich, K.L. and L. Potvin, *Transcending the Known in Public Health Practice.* American Journal of Public Health, 2008. **98**(2).
35. Kivimäki, M., S. Stenholm, and I. Kawachi, *The widening BMI distribution in the United States.* The American journal of clinical nutrition, 2015. **101**(6): p. 1307-1308.

36. Jenkins, A. and L.V. Campbell, *Future management of human obesity: understanding the meaning of genetic susceptibility.* 2014.
37. Razak, F., G.D. Smith, A. Krishna, A. Lebel, and S. Subramanian, *Reply to M Kivimäki et al. and AB Jenkins and LV Campbell.* The American journal of clinical nutrition, 2015. **101**(6): p. 1308-1309.
38. Glymour, M.M. and D. Spiegelman, *Evaluating public health interventions: 5. Causal inference in public health research—do sex, race, and biological factors cause health outcomes?* American journal of public health, 2017. **107**(1): p. 81-85.
39. Organization, W.H., *Obesity and inequities: Guidance for addressing inequities in overweight and obesity.* Regional office for Europe. Copenhagen: World Health Organization. ISBN, 2014. **978**(92): p. 890.
40. Merlo, J., *Contextual Influences on the Individual Life Course: Building a Research Framework for Social Epidemiology.* Psychosocial Intervention, 2011. **20**(1): p. 109-118.
41. Ludwig, J., L. Sanbonmatsu, L. Gennetian, E. Adam, G.J. Duncan, L.F. Katz, et al., *Neighborhoods, obesity, and diabetes—a randomized social experiment.* New England Journal of Medicine, 2011. **365**(16): p. 1509-1519.
42. Shields, M., S.C. Gorber, I. Janssen, and M.S. Tremblay, *Bias in self-reported estimates of obesity in Canadian health surveys: An update on correction equations for adults.* Health Reports, 2011. **22**(3): p. 35-45.