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Research Article

A Comparison between Atlantic Canadian and National Correction Equations to Improve the Accuracy of Self-Reported Obesity Estimates in Atlantic Canada

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Objectives. To determine whether obesity correction equations for the Canadian general population, which are dependent on the prevalence of obesity, are appropriate for use in Atlantic Canada, which has the highest obesity rates in the country. Also, to compare the accuracy of the national equations to equations developed specifically for the Atlantic Canadian population. *Methods*. The dataset consisted of Canadian Community Health Survey (CCHS) 2007-2008 data collected on 17,126 Atlantic Canadians and a subsample of adults, who provided measured height and weight (MHW) data. Atlantic correction equations were developed in the MHW subsample. Using separate multiple regression models for men and women, self-reported body mass index (BMI) was corrected by multiplying the self-reported estimate by its corresponding model coefficient and adding the model intercept. Paired t-tests were used to determine whether corrected mean BMI values were significantly more accurate (i.e., closer to measured data) than the equivalent means based on self-reported data. The analyses were repeated using the national equations. *Results*. Both the Atlantic and the national equations yielded corrected obesity estimates that were significantly more accurate than those based on self-report. *Conclusion*. The results provide some evidence of the generalizability of the national equations to atypical regions of Canada.

1. Introduction

Obesity is a major cause of morbidity in Canada and in many parts of the world and it is increasing worldwide [1]. As indicated by a body mass index (BMI) greater than or equal to 30 kg/m^2, obesity is a risk factor for cardiovascular disease, type 2 diabetes, several types of cancer, asthma, gallbladder disease, osteoarthritis, and chronic back pain [1, 2]. Class II+ obesity (BMI $\geq$ 35 kg/m^2) is also associated with an increased risk of all-cause mortality [3]. Obesity and its associated comorbidities exact a heavy toll on health care systems and expenditures. In Canada, the 2006 direct medical cost of overweight and obesity was $6.0 billion [4]. Against a global background comprising of 500 million obese adults [1], obesity has reached a historic high in Canada with one-quarter of adults and 9% of children meeting the definition [5].

Federal government statistical agencies, such as Statistics Canada and the National Center for Health Statistics, use large population-based studies to track nationwide obesity trends. Researchers usually use the BMI as a proxy to gauge obesity in these large national studies. According to Health Canada [6], although the BMI is not a direct measure of an individual's body fat, it is the most useful indicator of the health risks associated with under and overweight at a population level. In addition to using the BMI despite its limitations, large-scale research must rely heavily on self-reported obesity estimates, due to economic and logistical constraints, even though these estimates are distorted by reporting bias and error [7, 8]. As a result of the bias and error, self-reported values underestimate the prevalence of obesity and, consequently, overestimate associations between excess body fat and chronic diseases [7–9].

Accurate obesity prevalence data are not only needed by public health planners and policy makers, but also by those who conduct obesity research. As direct BMI measurements, which are the gold standard for BMI data, are an expensive method of data collection, researchers have recently developed and recommended the use of correction equations based on measured data to correct self-reported values [7, 10–15]. However, correction equations are not without shortcomings. It has been established that correction equations can vary with time [16] and they are survey- and population specific [15]. For example, bias and error between self-reported BMI and physical measurements rise with increasing body weight [8]. Therefore, although Connor Gorber and colleagues [7, 15] generated correction equations in 2008 for Canadians in general and reassessed them in 2011, given that they are population-specific, they may not hold in atypical regions of Canada such as Atlantic Canada, which has unique sociodemographic characteristics and the highest obesity rates in the country [5]. The purpose of this study was to determine whether correction equations developed for the Canadian population were appropriate for use in Atlantic Canada and to compare the accuracy of the national equations to equations that were developed specifically for the Atlantic Canadian population.

2. Methods

This study involved a secondary data analysis of a large national representative survey, specifically the Canadian Community Health Survey (CCHS) 2007-2008, to answer the following main research question: how well do the national correction equations correct self-reported estimates of obesity in Atlantic Canada and is there a significant difference between Atlantic Canadian and national correction equations in yielding corrected obesity estimates that are closer to measured data, as compared to self-reported values? The study was approved by the Interdisciplinary Committee on Ethics in Human Research at Memorial University. Furthermore, study approval was obtained from Statistics Canada and the Social Sciences and Humanities Research Council of Canada (SSHRC).

The CCHS collects data on health status, health care utilization, and health determinants for the Canadian population [17]. Details of the 2007-2008 CCHS are published elsewhere [17, 18]. They will be briefly summarized here. The target population of the 2007-2008 CCHS was persons aged 12 years and over living in private dwellings in all provinces and territories. The survey excludes persons living on Aboriginal reserves and settlements or in institutions, full-time members of the Canadian Forces, and residents of certain remote regions. The 2007-2008 CCHS had three sampling frames to select the sample of households: 49% of the sample of households came from an area frame, 50% were from a list frame of telephone numbers, and 1% came from a random digit dialing sampling frame. The national response rate for the CCHS 2007-2008 cycle was 78% in 2007 and 75% in 2008, with a total of 131,959 Canadian respondents and 17,126 Atlantic respondents. The provincial response rates in the Atlantic region ranged from 77% to 82%. Interviews were conducted between January 2007 and December 2008. Measured height and weight (MHW) data were collected in 2008 by trained interviewers with calibrated equipment for a subsample of about 5,000 Canadians [19]. In the Atlantic Canadian region, the provincial response rates for the MHW subsample ranged from 84% to 90% at the household level and from 51% to 67% for the direct measurement component, yielding overall response rates between 45% and 60%. The MHW subsample size for the current study was 318 Atlantic Canadian adults. To minimize nonresponse bias, Statistics Canada created a sampling weight by redistributing the sampling weights of nonrespondents to respondents using response propensity classes.

The data analyses included all 2007-2008 CCHS Atlantic Canadian respondents, with the exception of pregnant and breastfeeding women and children under the age of 18 because the BMI is not intended for use with these groups [6]. Outliers, with differences between their self-reported and measured BMIs that were more than three standard deviations from the mean, were also excluded from the analyses. Descriptive analyses were conducted to describe the sociodemographic characteristics of the Atlantic Canadian population, as compared to the rest of Canada. Using the correction method employed by Connor Gorber et al. [7], Atlantic correction equations were developed in the MHW subsample. Multiple regression models were used to predict BMI using the self-reported counterpart as the independent variable. No other independent variables (e.g., age) were utilized, as it was previously shown that gains in predictive value were minimal for the Canadian population [7]. Self-reported BMI was corrected by multiplying the self-reported estimate by its corresponding model coefficient and adding the model intercept. The correction model, namely, $\text{BMI}_{\text{measured}} = b_0 + b_1(\text{bmi}_{\text{self-reported}}) + \text{error}$, employed in this study was equivalent to that of Connor Gorber and colleagues' [7] Model 4. BMI estimates were derived with 95% confidence intervals (CI) and exact variance estimates were computed using bootstrap methods. Since bias in BMI is known to differ by sex [8], all data analyses were run for males and females separately. We used the following Health Canada [6] BMI categories: underweight, BMI < 18.5; normal weight, BMI = 18.5–24.9; overweight, BMI = 25.0–29.9; obese, BMI $\geq$ 30. However, due to limited sample sizes, the underweight and normal weight categories were combined. The analyses were repeated using the published national correction equations [7]. Statistics Canada's guidelines for tabulation, analysis, and release were followed [17, 18]. For instance, Statistics Canada mandates that cells computed from fewer than 10 respondents are suppressed and estimates computed from 10 or more respondents with a coefficient of variation (CV) between 16.6% and 33.3% are released with caution, while CVs greater than 33.3% are suppressed [17, 18]. All data analyses were conducted at the Atlantic Research Data Centre (ARDC) at Dalhousie University using

SAS 9.2 statistical software (SAS Institute Inc., Cary, NC, USA).

3. Results

Table 1 shows the sociodemographic characteristics of the 2007-2008 CCHS respondents from Atlantic Canada as compared to those from other regions of Canada. In Atlantic Canada, there were more females and full-time workers ($P < .01$). Also, Atlantic respondents were significantly less educated and had lower household incomes than other Canadians ($P < .0001$). Among the 2007-2008 CCHS respondents, residents of Atlantic Canada were more than twice as likely to live in a rural area. Besides being slightly older (mean age = 44.6 years, 95% CI 44.5–44.7 versus 43.2 years, 95% CI 43.2–43.3), Atlantic Canadians also differed significantly from their Canadian counterparts in terms of ethnicity and immigrant status. Most of those from the Atlantic region were white (92.2%) and Canadian-born (95.3%), compared to about three-quarters of Canadians ($P < .0001$).

The correction equations for the Atlantic region were

Males: BMI (corrected) $= -1.36 + 1.09 * $ BMI (reported)

Females: BMI (corrected) $= 1.71 + .98 * $ BMI (reported).

Table 2 displays information on the direction and magnitude of bias and error in self-reported BMI for both sexes in Atlantic Canada. A negative difference between self-reported and measured BMI indicates underreporting, whereas a positive difference indicates overreporting. Mean BMI values based on self-reported height and weight data were significantly lower ($P < .0001$) than those based on measurements for both sexes. However, male and female corrected BMI means obtained from both the national and Atlantic-specific correction methods were not significantly different from their equivalent measured means. Men and women equally underreported their BMI by 1.4 kg/m^2 on average. The corrected BMI means were only 0.1-0.2 kg/m^2 and 0.3 kg/m^2 away from measurements for women and men, respectively.

We assessed trends in misreporting BMI across the different BMI categories. As presented in Table 3, the degree of misreporting varied by BMI category. With each categorical increase in BMI, the bias and error in self-reported BMI were magnified for both sexes. Therefore, underestimation of BMI was the highest among obese individuals, with obese men under-reporting their BMI by 2.6 kg/m^2 on average and obese women under-reporting their BMI by an average of 3.1 kg/m^2.

Table 3 also provides information on the performance of the national and the Atlantic correction equations across the different BMI categories. For both equations, among men who were underweight or normal weight, both self-reported and corrected BMI means were not significantly different than their measured counterpart. Among women who were underweight or normal weight, the self-reported BMI mean was not significantly different from the measured mean, but this was not the case for either corrected mean. With respect to overweight or obese men and women, the corrected BMI means were more accurate (i.e., closer to the corresponding measured mean) than the comparable means calculated from self-reported data. Indeed, for overweight men and women, the corrected BMI means were significantly better than the equivalent self-reported means and they were identical or nearly identical to the BMI means based on measurements.

4. Discussion

While recognizing their deficiencies, researchers use self-reported BMI data out of necessity in large surveys [8], such as the CCHS in Canada and the National Health Interview Survey in the United States. Initial attempts to correct BMI values based on self-report led Plankey et al. [20] to publicize in 1997 that prediction equations do not eliminate systematic error in self-reported BMI data. Although corrected estimates are not usually identical to direct measurements, in recent years, BMI correction equations have been more successful at bridging the gap between self-reported numbers and measurements [7, 9–15]. The recent success of correction equations may be partly due to the changing nature of the reporting bias/error itself [7]. Since the dawn of correction equations, reporting bias and error have doubled in Canada, which improves the odds of having corrected BMI values that are significantly closer to physical measurements than their corresponding self-reported figures [7, 16]. The latest correction equations show great promise, notwithstanding some caveats for their use. As reporting bias and error can vary from one population to the next and they may not be stable over time [16], correction equations need to be developed specifically for a particular population and monitored periodically [15]. In addition, as observed in this and another Canadian study [7], while the equations bring self-reported overweight and obesity estimates closer to measured values, which is important in this line of research [7, 8, 23], it should be noted that this process skews the underweight and normal weight data.

Atlantic Canada holds the unfavourable distinction of having the highest obesity rates in the country [5]. Moreover, the results of our present analysis comparing Atlantic Canada with the rest of the nation on a number of sociodemographic characteristics demonstrate that Atlantic Canadians are distinct from other Canadians in several respects. Given that correction equations are population specific, we compared the national equations with the ones we developed specifically for this unique region of Canada. Both correction equations significantly improved the accuracy of self-reported Atlantic Canadian obesity data. The results of the current study suggest that the national equations, which are starting to be used elsewhere in the country [3], are generalizable even to atypical regions of Canada. The success of the correction equations used herein also corroborates current assertions by international researchers [7, 10–15] that these equations provide better obesity estimates than those based on self-report.

Table 1: Comparison of sociodemographic characteristics between Canada and the Atlantic region, 2007-2008.

Characteristic	Canada		Atlantic region	
	%	95% confidence interval	%	95% confidence interval
Sex				
Female	50.7	50.6, 50.7	51.5†	51.3, 51.7
Male	49.4	49.3, 49.4	48.5†	48.3, 48.7
Education				
Some secondary	22.6	22.3, 23.0	28.0†	27.1, 28.8
Secondary, No postsecondary	15.6	15.2, 15.9	14.5	13.8, 15.2
Some postsecondary	8.4	8.1, 8.7	8.1	7.6, 8.7
postsecondary Degree/diploma	53.4	52.9, 53.9	49.4†	48.5, 50.4
Area of residence				
Urban	71.9	71.3, 72.5	38.6†	37.0, 40.1
Rural	28.1	27.5, 28.7	61.5†	59.9, 63.0
Employment status				
Employed full-time	83.3	82.9, 83.7	84.8*	83.8, 85.8
Employed part-time	16.7	16.3, 17.1	15.2*	14.3, 16.2
Immigrant status				
Canadian-born	75.2	74.7, 75.7	95.3†	94.8, 95.8
Foreign-born	24.8	24.3, 25.3	4.7†	4.2, 5.3
Ethnicity				
White	77.0	76.3, 77.7	92.2†	91.5, 92.8
Visible minority	23.0	22.4, 23.7	7.8†	7.2, 8.5
Mean household income	$78,135	$77,309, $78,960	$64,271†	$62,877, $65,666
Mean age	43.2	43.2, 43.3	44.6†	44.5, 44.7

*Significantly different from estimate for Canada ($P < 0.01$).
†Significantly different from estimate for Canada ($P \leq 0.0001$).
Data source: 2007-2008 Canadian Community Health Survey, Statistics Canada.

Table 2: Mean body mass index (BMI) and mean difference between measured and self-reported or corrected BMI, by collection method and sex, household population aged 18 years or older, Atlantic Canada, 2007-2008.

Mean BMI (kg/m^2)	Collection method		Correction method		Difference					
	Measured	SR	Atlantic CEs	National CEs	SR minus measured	95% CI	Atlantic corrected minus measured	95% CI	National corrected minus measured	95% CI
Both sexes	28.4	27.0*	28.2	28.3	−1.4	−1.7, −1.0	−0.2	−0.6, 0.1	−0.1	−0.4, 0.3
Males	29.1	27.7*	28.8	28.8	−1.4	−2.0, −0.8	−0.3	−0.9, 0.3	−0.3	−0.9, 0.3
Females	27.7	26.3*	27.5	27.8	−1.4	−1.9, −0.9	−0.2	−0.7, 0.3	0.1	−0.4, 0.6

*Significantly different from measured estimate ($P < 0.0001$).
Abbreviations: CE, correction equation; CI, confidence interval; SR, self-reported.
Data source: 2007-2008 Canadian Community Health Survey, Statistics Canada.

In keeping with other studies [7–16, 22–24], mean BMI based on self-reported height and weight data was significantly lower than mean BMI based on measurements. In the current study, the direction and degree of BMI misreporting were identical for men and women. Most of the research in this area demonstrated that the trend of under-reporting was slightly more pronounced among women [7, 8, 10, 11, 13–16, 22–24]. In sharp contrast, Jain [12] found that under-reporting of obesity prevalence in the United States was 0.7% lower in females than in males. Perhaps the context of the survey used by Jain (i.e., the National Health and Nutrition Examination Survey (NHANES)) played a role in the anomalous finding. As pointed out in a recent publication [15], bias in self-reported BMI depends on survey context, such as whether or not respondents know they will be measured when they report their weight and

Table 3: Mean body mass index (BMI) and mean difference between measured and self-reported or corrected BMI, by collection method, sex, and BMI category, household population aged 18 years or older, Atlantic Canada, 2007-2008.

BMI category (range kg/m^2)	Mean BMI				Mean difference					
	Collection method		Correction method		SR minus measured	95% CI	Atlantic corrected minus measured	95% CI	National corrected minus measured	95% CI
	Measured	SR	Atlantic CEs	National CEs						
Both sexes										
UW and NW (<24.9)	22.7	22.5	23.6*	23.6*	−0.2	−0.7, 0.3	0.9	0.3, 1.5	0.9	0.3, 1.4
OW (25.0 to 29.9)	27.6	26.5*	27.6	27.7	−1.1	−1.6, −0.7	−0.0	−0.5, 0.4	0.1	−0.4, 0.5
Obese (30.0 or more)	34.8	32.0*	33.3*	33.5*	−2.8	−3.6, −2.1	−1.6	−2.3, −0.8	−1.3	−2.0, −0.5
Males										
UW and NW (<24.9)	23.5	23.4	24.2	24.2	−0.1	−1.4, 1.1	0.6	−0.8, 2.0	0.7	−0.7, 2.0
OW (25.0 to 29.9)	27.6	26.6*	27.6	27.6	−1.0	−1.3, −0.6	0.1	−0.3, 0.4	0.1	−0.3, 0.4
Obese (30.0 or more)	34.1	31.5*	32.9*	32.9*	−2.6	−3.6, −1.7	−1.2	−2.2, −0.2	−1.2	−2.2, −0.2
Females										
UW and NW (<24.9)	22.3	22.1	23.4*	23.3*	−0.2	−0.8, 0.3	1.0	0.5, 1.6	1.0	0.4, 1.6
OW (25.0 to 29.9)	27.6	26.3*	27.5	27.8	−1.3	−2.3, −0.4	−0.2	−1.1, 0.8	0.1	−0.9, 1.1
Obese (30.0 or more)	35.7	32.6*	33.7*	34.4*	−3.1	−4.3, −1.9	−2.0	−3.2, −0.9	−1.3	−2.5, −0.1

*Significantly different from estimate for measured ($P < 0.05$).
Abbreviations: CE, correction equation; CI, confidence interval; NW, normal weight; OW, overweight; SR, self-reported; UW, underweight.
Data Source: 2007-2008 Canadian Community Health Survey, Statistics Canada.

height. In the NHANES, at the time of self-reported weight and height, respondents are aware that they will later be measured, which is not the case for the CCHS.

In the current study, underestimation of BMI increased with excess body fat. Other researchers [7, 9, 10, 12–14, 22–24] documented similar results. In a Canadian national study [8], this relationship was only observed outside of the underweight category for men and women alike. Among those who were underweight, BMI was overestimated by males, but there was no significant difference between self-reported and measured BMI for females. Corresponding results were found among American college students [11]. In the current study, we merged the underweight and normal weight BMI categories due to small sample sizes. Thus, we cannot directly compare our findings with the two publications. Notwithstanding this difference, we observed no significant difference between self-reported and measured BMI for males and females in the underweight and normal weight category.

The present study also adds to the existing research literature in two important ways. First, we present measured BMI data for a subset of Atlantic adults. Canadian regional statistics on levels of obesity are normally derived from self-report questionnaires on account of sample size limitations for measured data [5]. Our measured BMI results suggest that obesity may be at a record level in this region of the country. The data analysis revealed a measured mean BMI of 29.1 kg/m^2 (95% CI 28.0–30.1) for men and 27.7 kg/m^2 (95% CI 26.6–28.9) for women in the Atlantic region in 2008. According to an analysis of Canadian Health Measures Survey data [15], the measured mean BMI for Canadian men was 27.5 kg/m^2 (95% CI 27.1–27.9) and it was 26.6 kg/m^2 (95% CI 25.9–27.4) for Canadian women from 2007 to 2009.

Second, this study is innovative in that it equips researchers with data supporting the utilization of the national correction equations throughout the Atlantic region in the absence of measured data. The national equations could be used in future analyses of self-reported BMI data from the CCHS in any or all of the four Atlantic provinces. Bearing in mind the considerable attention drawn to the issue of obesity by health authorities and researchers in the region [25], future research using obesity estimates lies ahead. As it currently stands, a cursory search of PubMed, using the search terms "obesity" and "Atlantic Canada," retrieved 135 citations in the last five years alone. Since obesity prevalence data are the foundation of some other obesity-related research analyses, the accuracy of prevalence data is essential. The application of the national correction equations should strengthen research conducted with self-reported Atlantic Canadian obesity data.

There are some limitations of this study that deserve consideration. Due to small numbers, we could not maintain separate BMI categories for those who were underweight and those who were of normal weight, which precluded a more refined analysis for these groups. Ideally, we would have had a larger subsample size to compute the correction equations for the Atlantic region. However, we used the best data and the largest subsample size available. Furthermore, the regression models used to compute the correction equations for both sexes were highly significant ($F(1, 188) = 1185.8$, $P < .0001$ and $F(1, 108) = 593.0$, $P < .0001$ for females and males, respectively) and the CV for the estimate from either model was less than 7.0, indicating that the level of precision was well within acceptable limits. Another study limitation concerned the response rate. In Atlantic Canada, the provincial overall response rates for the MHW subsample were between 45% and 60%, but this was similar to the response rate for the MHW subsample for the rest of the country [15]. Although a sampling weight created by Statistics Canada was used to adjust for differential participation rates, if the characteristics of non-respondents, such as mean BMI, were significantly different than respondents, then non-response bias may have tainted the study. An additional study limitation involved the measurement of height and weight. Trained interviewers and calibrated equipment were used to collect the data [19], but we cannot exclude significant measurement error as intra- and interrater reliability were not evaluated. Also, although the BMI is frequently used to measure adiposity at the population level, there are well-documented limitations of the BMI as a tool to quantify body fat [26]. Furthermore, Shields and colleagues [7, 9, 15] caution against the indiscriminate use of correction equations because they can change over time [16] and they are dependent upon the population and survey context. For the particular correction method used in this study, sensitivity values are reduced for the normal weight population. In other words, while postcorrection percentages provide a more accurate estimation of overweight and obesity, the precorrection percentages are a better estimation of normal weight because the reporting bias and error are lower in this BMI category [7].

5. Conclusions

This study provides some evidence of the generalizability of the national correction equations to atypical regions of Canada. Also, the results of this study add to a small, but accumulating body of research supporting the efficacy of BMI correction equations. In light of reports that self-reported BMI statistics underestimate the prevalence of obesity and overestimate associations between obesity and chronic diseases [7, 8, 23], we strongly recommend the use of correction equations to other researchers analysing obesity data collected by self-report. In particular, given the nature of BMI correction equations, we recommend that Canadian researchers use the national correction equations [7] in the absence of measured data or compute their own correction equations if they have measured and self-reported obesity data.

Conflict of Interests

The authors declare that they have no conflict of interests.

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