Evidence for a Paradigm Shift in Preventive Nutrition: Measuring the Role of Dietary Patterns in Chronic Disease Risk in Canada

by

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Abstract

National nutrition surveys are the cornerstones of nutritional surveillance for developing dietary guidelines and policies. Some recent studies have questioned the usefulness of nutrition surveys due to their methodological limitations. The overall goal of this thesis was to use the Canadian Community Health Survey (CCHS) 2.2 to address these limitations as the first step in population-based dietary pattern analysis, an essential component for development of evidence-based nutritional guidelines and policies. In the first study of this thesis, different methods for handling dietary misreporting were compared and "adjusting for misreporting bias" was identified as the most appropriate technique, which was used in all subsequent studies of this thesis. In the second study, we observed that closer adherence to the only Canadian *a priori* index, Health Canada's Surveillance Tool Tier System (HCST) 2014, developed based on the Eating Well with Canada's Food Guide 2007 (EWCFG) was associated with higher probability of meeting dietary reference intakes (DRI) for nutrients, even though it was not related to obesity risk. These findings were explained in the third study, where the strict focus of the EWCFG on single nutrients, rather than dietary patterns was identified as its main limitation. The first Canadian dietary pattern analyses using energy-based *a priori* (Study 4) and hybrid

(Study 5) techniques were then conducted to address this limitation. Lack of adherence to the recommendations of 2015 Dietary Guidelines for Americans Adherence Index (DGAI), an *a priori* dietary quality index, and consumption of an energy-dense, high-fat and low-fiber dietary pattern derived from the weighted partial least squares, were associated with 2-3 times higher risk of obesity. Overall, studies in this thesis demonstrate that application of rigorous methodological techniques to survey data can enhance the usefulness of nutrition surveys for capturing the diet-disease relationships and for informing evidence-based national nutrition guidelines and policies.

Dedications

This thesis is dedicated to the most amazing parents in the world, Mehri Khaki and Jafar Jessri, whose endless support, encouragement and love always lightens up my darkest times. They have sacrificed their own personal gains to provide me with opportunities to pursue my aspirations in all aspects of life, and for that I will always be grateful.

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List of Abbreviations

%EF	Percentage of energy as fat
ADG	Australian Dietary Guidelines
AIC	Akaike information criterion
ANCOVA	Analysis of covariance
AMPM	Automated Multiple Pass Method
AUC	Area under the curve
BBR	Bootstrap balanced repeated replication
BIC	Bayesian information criterion
BNS	Bureau of Nutritional Sciences
BMI	Body mass index
BMR	Basal Metabolic Rate
CA	Cluster analysis
CCHS	Canadian Community Health Survey
CI	Confidence Intervals
CNF	Canadian Nutrient File
CV	Coefficient of variation
CVD	Cardiovascular diseases
DGA	Dietary Guidelines for Americans
DGAI	Dietary Guidelines for Americans Adherence Index
DLW	Doubly Labelled Water
DQI	Diet quality index
DRI	Dietary Reference Intake
ED	Energy density
ED, HF, LFD	Energy-dense, high-fat, and low fiber density
EER	Estimated energy requirements
EFA	Exploratory factor analysis
EI	Energy intakes
EWCFG	Eating Well with Canada’s Food Guide
FAO	Food and Agriculture Organization
FD	Fiber density

FoodEx	Food Expenditure Survey
FSANZ	Food Standards Australia New Zealand
GI	Glycemic index
GLM	Generalized logit model
HCST	Health Canada's Surveillance Tool Tier System
HEI	Healthy eating index
HEI-C	Healthy Eating Index-Canada
HHS	Health and Human Services
IOM	Institute of Medicine
MB	Manitoba
MET	Metabolic Equivalents
MSDPS	Mediterranean Style Dietary Pattern Score
MUFA	Monounsaturated fatty acid
NEL	Nutrition Evidence Library
NHANES	National Health and Nutrition Examination Survey
NIPALS	Nonlinear iterative partial least squares
NPSC	Nutrient Profiling Scoring Criterion
NS	Not significant
ON	Ontario
ONQI	Overall Nutritional Quality Index
OR	Odds Ratio
PAL	Physical activity level
PCA	Principal component analysis
pER	Predicted energy requirement
PLS	Partial least squares
PUFA	Polyunsaturated fatty acids
RA	Reference amount
rEI	Reported energy intake
ROC	Receiver operating characteristic
RRR	Reduced rank regression
SAS	Statistical Analysis Software
SD	Standard Deviation

SEM	Standard Error of Mean
SK	Saskatchewan
SoFAS	Solid fats and added sugars
T2DM	Type 2 diabetes mellitus
TEE	Total energy expenditure
UL	Upper intake level
UN	United Nations
USDA	United States Department of Agriculture
VIP	Variable importance in the projection
WHO	World Health Organization
wPLS	Weighted partial least squares

Chapter 1

1 Introduction

Research in the field of preventive nutrition has led to a comprehensive understanding of the role of foods, nutrients and bioactive compounds in the etiology of chronic diseases (1). However, during the past few decades the prevalence of obesity and other diet-related chronic diseases has increased dramatically worldwide. In Canada, the rate of adult obesity has increased from 6.1% in 1985 to 18.3% in 2011 (2). Based on measured height and weight from the Canadian Health Measures Survey, 62% of those 18-79 years of age were classified as overweight and obese in 2012/3 (3). In addition, 31% of children and adolescents 5-17 years of age were classified as overweight and obese (4). This rising prevalence of overweight and obesity has been in parallel with an epidemic outbreak of chronic diseases in Canada, including type 2 diabetes mellitus (T2DM) and cardiovascular diseases (CVD) (5). In fact, T2DM, CVDs and some cancers are common co-morbidities of obesity (6). According to the Public Health Agency of Canada, out of every 5 Canadians ≥20 years, 4 are at risk of developing a chronic disease and at least 3 have a chronic disease, with the majority of cases being attributable to unhealthy lifestyle behaviours, including poor dietary intakes (7). Traditionally, analysis of single foods or nutrients was considered as the only means of providing scientific evidence regarding role of dietary factors in risk of diseases (8). However, new approaches are needed to study dietary risk factors responsible for the modern-age diseases of excess. Comprehensive examination of overall dietary patterns is more relevant to the real world as individuals consume varied meals with complex combinations of foods and nutrients rather than single isolated foods (8, 9). In fact, the strong inter-correlations between foods and nutrients make it difficult to interpret the results from studies that focus merely on single food effects (10, 11). In addition, the comprehensive approach taken in dietary pattern analysis is in line with the current dietary recommendations as overall dietary patterns are easier for the public to understand and readily translate into daily eating habits (12).

In 2013, the United States Department of Agriculture (USDA) Nutrition Evidence Library (NEL) completed a systematic review on health effects of different dietary patterns (13). Even though this systematic review shed light on cumulative and interactive effects of nutritional components, only moderate to weak conclusions were supported for the associations between dietary patterns and risk of obesity and type 2 diabetes (13). This lack of consistency between studies on dietary patterns and disease outcomes may be due to the methodological differences (13) and reliance of nutritional studies on self-reported memory-based dietary intakes (14), which are prone to under- and over-reporting biases (14). Globally, it is estimated that 10-50% of individuals underreport their dietary intakes (14-20), with the rates being higher among obese individuals and those with chronic diseases (14, 21). In addition, there is a higher tendency towards under-reporting of foods that are socially undesirable (i.e., high in fat and added sugars) (22, 23). Misreporting of energy intakes poses a serious challenge for epidemiologists as it can attenuate, hide or reverse the diet-disease relationships (24). As a result, many of the reported associations in nutritional epidemiology may be biased due to ignoring the systematic differential error, and validity of public health policies that are developed based upon these data is undermined (14). Despite the importance, rigorous techniques to control for the systematic misreporting bias have not been well-studied and validated in large-scale surveys to ensure validity of diet-disease relationships and avoidance of erroneous conclusions.

Currently, several organizations have adopted the dietary pattern paradigm at the core of their conceptual models, including the United States Dietary Guidelines for Americans (DGA) (25). However, this does not apply to the national Eating Well with Canada's Food Guide (EWCFG) 2007 (26), which is mainly based upon meeting the nutrient Dietary Reference Intake (DRI) requirements, rather than ensuring an overall healthy dietary pattern for prevention of chronic diseases (27). In light of the EWCFG limitations, concerns have been raised that the current national dietary guidelines in Canada released in 2007, may be obesogenic (27-29), even though no previous study has tested this hypothesis in form of a rigorous survey at the national level. On the other hand, the very first step towards development and implementation of evidence-based and culturally-relevant national Canadian dietary guidelines is to identify major dietary patterns at the population level using rigorous dietary pattern techniques and to examine their potential for reducing chronic diseases among different population subgroups (27).

The overall goal of this thesis project was to provide the evidence-base for informing future update of the Canadian food guide and national nutrition policies, through conducting comprehensive population-based dietary pattern analyses using the Canadian national nutrition survey. In order to ensure that the relationships between dietary patterns and health outcomes would not be influenced by systematic errors, different methods for handling misreporting bias were evaluated in the first project of this thesis and an appropriate adjustment technique was identified and then applied to all subsequent studies. This PhD thesis was conducted in two main phases, each encompassing separate studies with the underlying goal of improving the current evidence-base in nutritional epidemiology for informing national nutrition guidelines and policies that may result in population-wide reduction of chronic diseases:

Phase I: Evaluation of different methods to handle misreporting in nutrition surveys

In the first study, we evaluated different methods for handling dietary misreporting, which was then used in all subsequent studies of this thesis to ensure the most appropriate statistical methods were used to examine diet-disease relationships based on self-reported dietary recalls (Chapter 4).

Phase II: Dietary pattern analyses

In the second study of this thesis, adherence to the only Canadian *a priori* index, Health Canada's Surveillance Tool Tier System (HCST) 2014, which is modelled based on the Eating Well with Canada's Food Guide 2007 (EWCFG), was tested in relation to diet quality and obesity risk (Chapter 5). To explain the lack of significant association between the HCST 2014 and obesity risk, the EWCFG guidelines were critically reviewed and the strict focus of the EWCFG on single nutrients, rather than on dietary patterns, was identified as the main limitation (Chapter 6). This limitation was addressed in Studies 4 and 5 (Chapters 7 and 8), where *a priori* and hybrid dietary pattern techniques were used to characterize the dietary patterns of Canadians. Study 4 evaluated the validity and reliability of an energy-based *a priori* dietary quality index, the 2015 Dietary Guidelines for Americans Adherence Index (DGAI), and tested its association with risk of obesity with and without an accompanying chronic disease (unhealthy and healthy obesity). Study 5 examined another approach and derived a dietary pattern associated with reduced risk of obesity using weighted partial least squares analysis (hybrid method), and tested its association with risk of unhealthy and healthy obesity among Canadians. Study 5 also identified the key food groups with the highest contribution to obesity risk in the Canadian diet (Chapter 8).

Overall, these five studies demonstrate that application of appropriate methodological techniques for handling dietary misreporting and using a number of dietary pattern analysis methods can enhance the usefulness of national nutrition survey data for capturing diet-disease relationships. These approaches can be used to inform evidence-based national nutrition guidelines and policies which could eventually lead to reduction of diet-related chronic diseases in Canada.

Chapter 2

2 Background and Literature Review

This chapter provides the foundation for research in my thesis by briefly reviewing the concepts and latest research conducted in the area of measurement errors (particularly dietary misreporting) and dietary pattern analyses. The first (Section 2.1) and the second (Section 2.2) sections review “measurement errors in nutritional epidemiology” and concepts of “dietary misreporting”, while Section 2.3 focuses on “dietary patterns in nutritional epidemiology”.

2.1 Measurement errors in nutritional epidemiology

Self-reported dietary assessment methods are the dominant means of collecting dietary data in national nutrition surveys, such as the Canadian Community Health Survey 2.2 (CCHS) (30) and the National Health and Nutrition Examination Survey (NHANES), and are also used in experimental nutritional studies (31, 32). These memory-based methods are the cornerstone of developing national nutrition policy and recommendations (25, 26, 33) and their accuracy, as a result, can directly influence national nutrition guidelines and programs. Several studies have confirmed that measurement of dietary data involves several sources of measurement errors (14, 19, 23, 34-36). Section 2.1 will briefly review the measurement error models and consequences of ignoring these errors in nutritional epidemiology.

Researchers are typically interested in the association between true intake of a given nutrient (T) and risk of a disease (D), where associations are examined through application of complex regression models. In this case, T is considered a latent variable since it cannot be measured directly and is only self-reported (memory-based). In fact, dietary assessment instruments measure surrogate reported measures (Q) of the T, which are associated with several inherent measurement errors (32, 37-39). To ensure that diet-disease models account for the measurement errors in statistical analyses, one should identify the type and nature of the error. In Section 2.1.1, different types of measurement error will be outlined.

2.1.1 Nature and type of measurement errors

2.1.1.1 Random and systematic errors

Generally, measurement error in nutritional studies increases the variance, reduces the precision of dietary intake estimates, attenuates regression coefficients towards the null and leads to false-negative conclusions. Random and systematic errors are the two main types of measurement errors, both of which can occur between or within individuals (40). As the name indicates, random errors are randomly-distributed and their expected values are scattered around the true value (group mean estimates are unbiased). The effect of random errors can be reduced by increasing the sample size, since the average of a large number of values measured with random errors will approach the T due to high power (32, 37-39). In short-term dietary assessment methods, random non-differential (within-person) error is the most common type of error which is caused by day-to-day variation (41). This error is not a major concern for large-scale studies as a higher sample size can reduce the effect of random error on measures of association. The following equation describes the structure of within-person random error (32, 37-39):

$R_{ij} = T_i + \varepsilon_{ij}$ (j subscript refers to the sequence number in repeated recalls; the term εij is within-person variation which is 0 on average)

The second type of measurement errors are systematic errors, which are non-randomly distributed and measurements depart from the true value in the same direction (42). Unlike the random error, systematic errors cannot be attenuated by increasing the sample size and averaging the dietary data from many administrations of instrument does not approximate the true value. Three types of systematic errors include: a) additive error, b) intake-related error, and c) person-specific error, which are described below:

a) *Additive systematic bias:* This is the simplest type of error and occurs when an instrument produces every dietary measurement to be larger or smaller by a constant additive amount (β_0) (Figure 2.1). This error causes the regression lines and population intake distributions to shift from the true intake by a constant factor (β_0), leading to wrong conclusions regarding the percentage of population at risk of dietary deficiencies (37-39, 42-44). As demonstrated in the following equation, all reported values are different from the true value by a constant (β_0):

$R_i=\beta_0+T_i$ (Where R_i is reported usual intake of individual i, and T_i is the true usual intake of individual i)

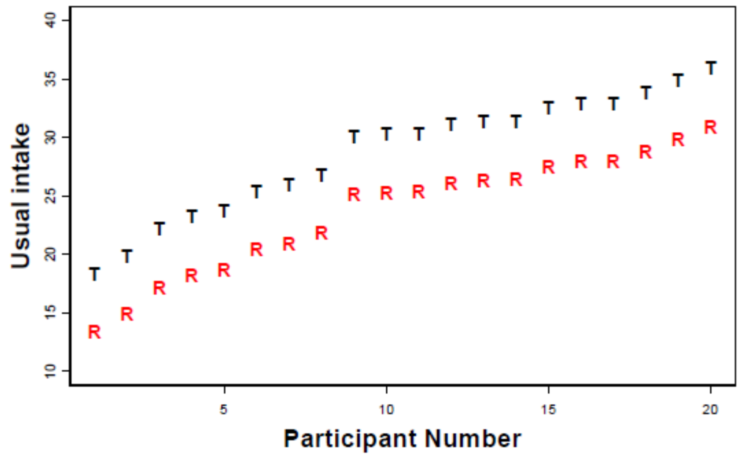


Figure 2.1. Additive systematic bias with T representing true intakes and R representing reported intakes (adapted with permission from Freedman L. 2011 (44))

b) *Multiplicative and additive systematic error:* This bias is intake-related and is proportional by β_1 to the true nutrient intake, as presented in the below equation: $R_i=\beta_0+\beta_1\times T_i$

As can be seen, the true value is decreased or increased by factor β_1 in addition to the additive bias (β_0). Since β_1 is not known, it is not easy to account for its effect on the regression estimates (37-39, 42-44)(Figure 2.2).

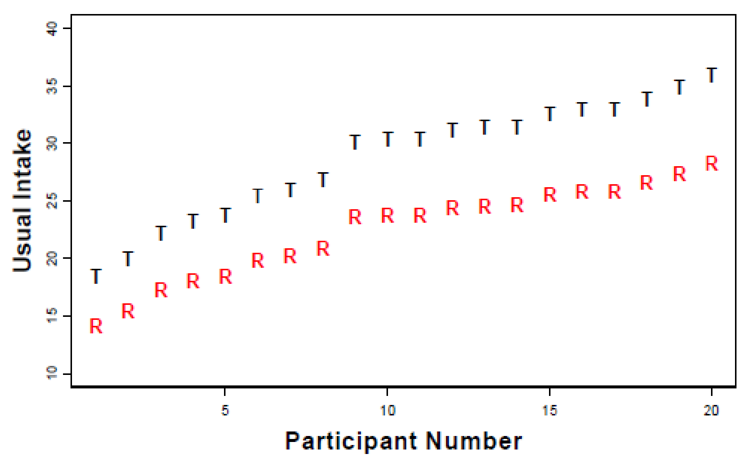


Figure 2.2. Multiplicative and additive bias with T representing true intakes and R representing reported intakes (adapted with permission from Freedman L. 2011 (44))

c) *Person-specific error:* This type of error is related to participants' characteristics such as age, sex, and body mass index and is at the individual level (Figure 2.3). If the person-specific error occurs in a random manner that cancel out at the population level, then the scatter around the regression line would increase, significance tests would be less powerful and the study power would decrease, leading to attenuated results. However, in most cases the person-specific error is not random and occurs differentially (e.g., misreporting). Handling the systematic person-specific error (e.g., misreporting) is difficult and has not been addressed in nutritional epidemiology previously (see Section 2.2). The following equation describes the person-specific error:

$R_i=\beta_0+\beta_1\times T_i+u_i$ (u_i is a bias that varies for each individual i)

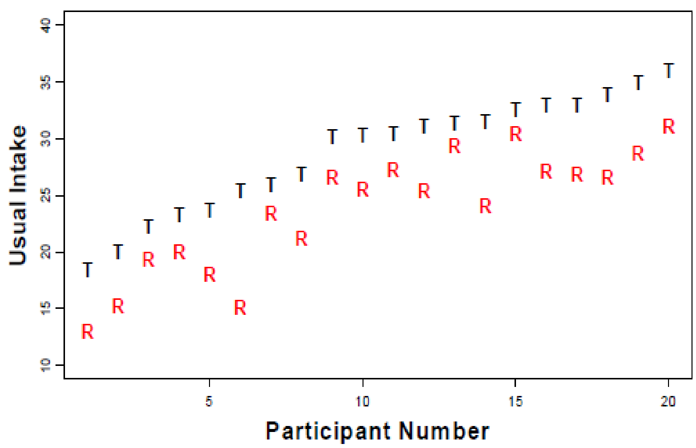


Figure 2.3. Person-specific error with multiplicative and additive biases; T represents true intakes and R represents reported intakes (adapted with permission from Freedman L. 2011 (44))

As mentioned previously, a common systematic person-specific error is under- and over-reporting of dietary intakes, which can potentially lead to between-person error and distort the group mean estimates (45). The misreporting bias can covary with the outcome of interest, leading to non-random distribution of bias in study population (14). According to Beaton (1994), if obese individuals underreport and lean individual over-report, diet-disease relationships would be masked or even reversed leading to erroneous conclusions (41).

2.1.1.2 Differential and non-differential errors

Another way of categorizing measurement errors is based on their occurrence as differential or non-differential. Non-differential measurement errors occur non-differentially in cases and non-cases (participants with or without an outcome of interest) and they require that the disease distribution (D) given (T and Q) to be dependent only on the true intake T. On the other hand, differential errors do not occur randomly in relation to outcome and have serious implications for the regression results and population distributions (37). Misreporting is an example of a differential error and there is currently a lack of formal agreement on how best to handle this systematic bias in dietary data analyses.

2.2 Dietary misreporting

This section provides a brief overview of the concepts and nature of misreporting bias and how it can affect regression results when evaluating diet-disease relationships. In addition, methods of identifying misreported recalls are also reviewed.

Misreporting (under- and over-reporting) of dietary intakes is one of the main and most common sources of measurement error in nutritional surveys. Dietary misreporting can potentially bias the estimates of energy and nutrient intakes in dietary assessment. “Under-reporting” can occur in the form of undereating, which is defined as eating less than required for survival and maintenance of body weight (46). It can also occur as underrecording, in which case the reported energy intakes (EI) are lower than the measured total energy expenditure (TEE), assuming an energy balance. Since the EI and TEE should coincide for energy balance, the state in which EI is smaller than TEE is an indication of underrecording, where participants had not reported all foods consumed or have reported smaller portion sizes. Both undereating and underrecording lead to erroneously low estimates for usual intakes, since even dieting days are exceptional days at the population level and do not reflect usual intakes (46). In contrast, overreporting comprises of both overeating and overrecording, which are defined analogous to undereating and underrecording but in reverse. Qualitatively, misreporters can be categorized as intentional or unintentional to distinguish between those who are unaware of misreporting and those who intentionally skip or add meals or food items or report larger or smaller portion sizes than what was actually consumed (39). Unintentional misreporting usually occurs due to memory lapses or difficulty in estimating portion sizes (especially in proxy-reported data), while social desirability, health-related perceptions and omissions are the main reasons for intentional misreporting (47-51).

Several studies have demonstrated that dietary misreporting is a differential error that affects estimates of food and nutrient intakes differently and to varying extents, which is referred to as "selective misreporting" (14, 22, 52). Particularly, food items that are perceived as unhealthy have higher likelihood of being omitted due to social desirability (50). In addition, participants' characteristics (e.g., age, sex, sociodemographic status, etc.) differentially influence the misreporting bias (22, 46), with a major issue being the different direction of estimates among subjects with and without a chronic disease (52, 53).

2.2.1 Methods of identifying dietary misreporters

2.2.1.1 Gold standard: Doubly Labelled Water (DLW)

The doubly labelled water (DLW) technique was first developed in the early 1950s by Lifson and McClintock (54) and is currently recognized as the gold standard for TEE measurement throughout the life cycle (55-57). In practice, DLW method involves administration of the enriched heavy, non-radioactive form of deuterium (stable isotope deuterium (^{2}H)) and oxygen-18 (^{18}O). Following administration, participants' elimination rate of ^{2}H and ^{18}O will be measured over a period of time through sampling of body water (blood, urine and saliva). The ^{18}O is excreted from body as $C^{18}O_2$ and water ($H_2^{18}O$), while the deuterium is excreted as water $^{2}H_2O$. The difference in slopes (rate) of washout/excretion of these two isotopes represents the amount of carbon dioxide (CO_2) produced over time (57). As presented in Figure 2.4, the disappearance rate of ^{18}O is faster than that of the ^{2}H, as some of the former is lost through the CO_2 excreted from the body. The CO_2 production is equal to the difference between the two disappearance lines in Figure 2.4. The measured CO_2 is then used to estimate TEE from the standard equations of indirect calorimetry (58). The DLW method has been shown to have the accuracy of 1% with within-person variation between 5 to 8% in different studies (59).

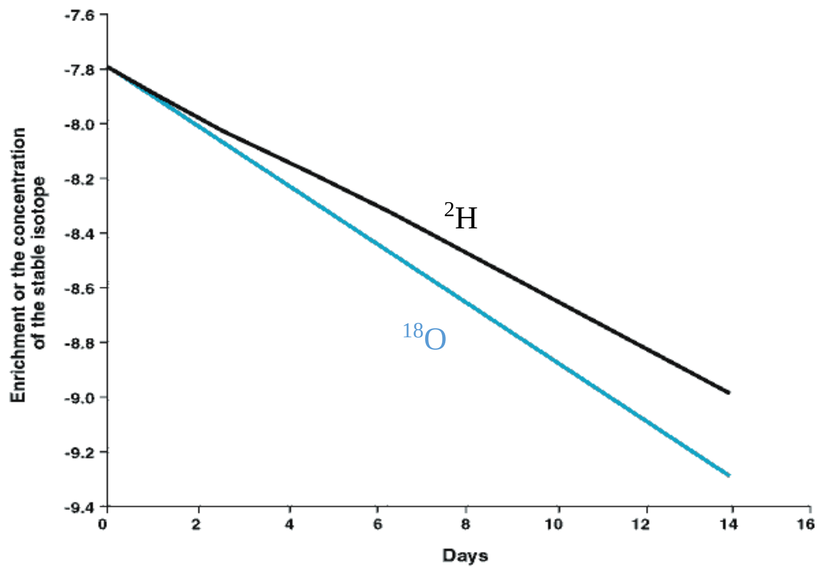


Figure 2.4. Rates of disappearance for ^{2}H and ^{18}O from the body water (adapted from the Food and Agriculture Organization of the United Nations (57))

The DLW method has several strengths and limitations. The strengths include: a) being the gold standard for TEE measurement in free living subjects, b) having high safety for use in infants, pregnant women and elderly, and c) having easy administration, sample collection, transportation and storage (57). However, its limitations include: a) technical and analytical complexity, high cost and being time-consuming, b) not providing day-to-day variation in TEE, c) not providing data on physical activity patterns, and d) being hard to interpret in the absence of precise physical activity measures (60). Due to these limitations, DLW is not routinely used in epidemiologic studies. Generally, for validating dietary information using the DLW method, the TEE will be compared to the EI with the presumption of weight balance in participants, and the difference between the two will serve as the magnitude of energy misreporting (46).

2.2.1.2 Algorithm-based methods

In 1991, Goldberg calculated the minimum and maximum levels of physiologically-plausible EI as a factor of Basal Metabolic Rate (BMR) and defined the ratio of EI/BMR as an index for validating the EI bias. In fact, he proposed that if the EI is much different than the BMR then the participant is likely to have misreported their dietary intakes (34). The BMR can be estimated through predictive equations, such as the age- and sex-specific equations developed by the Schiefield in 1985 and endorsed by the Food and Agriculture Organization (FAO)/World Health

Organization (WHO)/United Nations (UN) (61). To calculate the Goldberg cut-points, several factors need to be considered including the sample size, number of dietary recalls, and intra-individual variation in the physical activity, BMR and EI. However, it is noteworthy that this derived cut-point is less conservative for accounting for very high or low intakes in cases where only single recalls are available (34).

Cut-off derivation

Goldberg et al. were the first to classify individuals as under-reporters, plausible reporters and over-reporters by using the coefficient of variation (CV) of their energy intake (CV_{wEI}), basal metabolic rate (CV_{wB}) and variation in total physical activity level (CV_{tP}) to create a confidence interval (34). In 2000, Black developed a practical guide for calculating the Goldberg cut-point which also explained the limitations of this method (62). Finally, this method was further improved by McCrory et al. who directly compared the EI with predicted energy expenditure using the Institute of Medicine (IOM) equations for calculating the estimated energy requirements (EER) (23, 36). Despite the improvements, both of these studies considered all participants as "low active" (23, 36). This limitation was addressed by considering 4 levels of physical activity for individuals (sedentary, low active, active or very active) in the report *"What America Drinks"* (63).

The confidence interval for the ratio of reported EI (rEI) to predicted energy requirement (pER) was created as follows:

$$S=\sqrt{\frac{CV_{rEI}^2}{d}+CV_{pER}^2+CV_{mTEE}^2}$$

Where CV_{rEI}^2 is the intra-individual coefficient of variation (CV) for EI

d is the number of recall days

CV_{pER}^2 is the error for predicted energy requirements

CV_{mTEE}^2 is the day-to-day variation and error for total energy expenditure based on DLW

For calulating these parameters, the CV_{mTEE}^2 is estimated at 8.2% based on Black and Cole's calculation (64), CV_{pER}^2 should be calcuated based on the population under study, and CV_{rEI}^2 is derived as follws:

$CV_{rEI}^{2} = \sqrt{\sum_{rEI}^{n} \frac{CV_i^2}{n}}$

Where CV_i is the CV for each individual

CV_{rEI}^{2} *is the average standard error of individual predicitions for population divided by the average prediction of energy expenditure for the same population*

Since the distribution of energy intake is skewed at the population level, the confidence intervals need to be log-transformed and cut-offs to be exponentiated. The following equation is used to calculate the confidence interval (cut point) for plausible reporting as a ratio of energy intake to energy expenditure (19):

$$\text{EI:EER} \in [\exp(-\alpha \times SD)\,;\exp(\alpha \times SD)\,]$$

A multiplicative of α can be applied to the SD to create the confidence interval. Using this derived cut-point, individuals will be either classified as under-reporters (EI/EER<lower cut-off), plausible-reporters (lower cut-off ≤ EI/EER ≤ upper cut-off) or over-reporters (if EI/EER >upper cut-off) (14, 23, 34-36).

The only limitation of these improved methods however, is their inability to detect selective misreporting of specific nutrients or foods, as only EI is tested for plausibility based on estimates of energy requirement, and not the foods or nutrients. To date, studies have only compared nutrient and food intakes of under-, plausible and over-reporters to illustrate the indication of selective misreporting, even though it is still unclear how to test selective misreporting in nutritional epidemiology (46).

2.3 Dietary patterns in nutritional epidemiology

This doctoral thesis aimed at providing the first comprehensive picture of the relationship between dietary patterns of Canadians and chronic diseases by applying different dietary pattern methods to the national nutrition data, an area that has not been explored previously. The following section briefly reviews the importance of dietary patterns in nutritional epidemiology.

2.3.1 Dietary pattern approach

Based on the food synergy principles, total diet is more than sum of its parts and it includes several complex aspects of dietary intakes. In this regard, dietary pattern analysis has emerged as a comprehensive, complementary and alternative approach to reductionist technique in nutritional epidemiology by considering multiple aspects of diet simultaneously. This new perspective considers the joint effect of foods and nutrients and benefits from collinearity of foods to represent a comprehensive picture of dietary exposures (65).

From a public health perspective, the combination of immediately identifiable foods may be a more useful basis for developing dietary recommendations for obesity prevention and treatment (66). In 2013, the USDA released the first comprehensive systematic review of dietary patterns in relation to health outcomes (13), which eventually informed the 2015-2020 Health and Human Services (HHS)/USDA Dietary Guidelines for Americans (DGA) (67). Notably, the conclusions of the USDA systematic review confirmed that more studies are needed to standardize the dietary pattern definition and to improve the current methodologies (13). Dietary pattern analysis has contributed significantly to understanding the link between nutrition and chronic disease risk, even though the evidence-base is still limited for some areas (13). To our knowledge, no previous study has examined the dietary patterns of Canadians using the large-scale Canadian national nutrition survey.

Dietary pattern limitations

A few limitations have been noted in the dietary pattern field. This approach has been criticized for being subjective in assignment of foods into food groups, labelling (naming) the extracted patterns and being dependent on the population under study (except for *a priori* methods). Simplified dietary patterns were proposed by Schulz et al in 2003, mainly to reduce the error associated with weights of foods in order to produce replicable results (68). Generally, a simplified dietary pattern score is calculated by summing the unweighted standardized food groups with high loadings on a dietary pattern extracted from exploratory or hybrid dietary pattern techniques with the aim of omitting non-informative weights and food groups (68).

2.3.2 Methods of defining dietary patterns

Various approaches have been defined for studying dietary patterns (Figure 2.5) (69). In hypothesis-oriented or *a priori* dietary pattern methods, scores or indexes of overall diet quality are constructed based on national healthy eating guidelines (70). In the *a posteriori* dietary pattern approach, on the other hand, the underlying dietary data is used to derive dietary patterns using statistical methods such as exploratory factor analysis (EFA), principal component analysis (PCA), and cluster analysis (CA) (9, 11). In the EFA and PCA, dietary pattern variables are constructed based on the underlying interrelationships between dietary components and linear combinations of foods with high inter-correlations. In CA, population subgroups are created based on individuals with similar dietary intakes within a cluster and those with different dietary intakes are put in different clusters (maximally different eating patterns are constructed) (10). *Hybrid* methods are the most recently-developed techniques which combine *a priori* and *a posteriori* methods to derive dietary patterns by a combination of underlying dietary data and biological pathways (71). Partial least squares (PLS) and reduced rank regression (RRR) are hybrid methods that can be applied to define linear combination of food groups that maximally explain the variation in food groups and predictors of disease (PLS), or only predictors of disease (RRR), respectively (71).

Application of each of the three dietary pattern methods (*a priori*, *a posteriori* and hybrid) depend on the purpose of research. For example, *a priori* diet quality indexes usually measure adherence to predefined dietary guidelines and may also be used in relation to health outcomes. *A posteriori* data-driven methods, on the other hand, aim to identify current eating practices in a population or can be used to identify unknown relationships between specific food components and disease outcomes (9).

Since *a priori* and hybrid methods are comprehensively studied in this thesis, their general concepts are discussed in more details in the following sections.

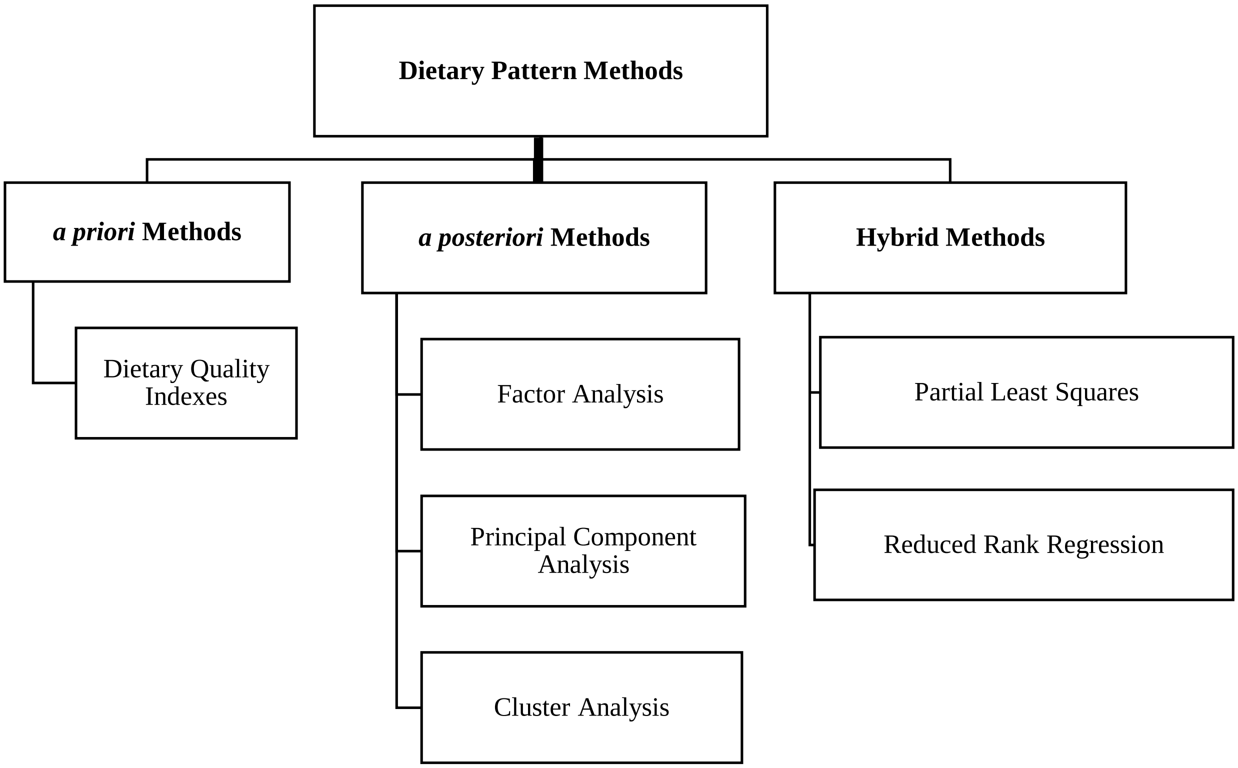


Figure 2.5. Different methods for studying dietary patterns

2.3.2.1 *A priori* dietary quality indexes

Indexes of diet quality examine adherence of individuals' dietary intakes to pre-existing dietary guidelines or specific dietary patterns proposed to be healthy for prevention of chronic diseases (e.g., Mediterranean diet), and score individuals' diets accordingly (70, 72). Using indexes to consider several dimensions of dietary intakes simultaneously is a useful way to avoid statistical issues related to intercorrelated data. Typically, participants are given a score for each food or nutrient used in the index as a component and these component scores are then summed to create an overall dietary index score (9).

Based on their scope, diet quality indexes are categorized as: a) nutrient-based *a priori* indexes (e.g., nutrient profiling systems such as Health Canada's Surveillance Tool Tier System (HCST) 2014) (73); b) indexes based on foods or food groups; and c) indexes based on nutrients and food groups (74). Indexes that use a combination of foods and nutrients have shown significant associations with risk of chronic diseases (75). Commonly used examples include diet quality index (DQI) (76, 77) and the healthy eating index (HEI) (78, 79), which were developed based on combinations of both foods and nutrients. However, one major oversight of these dietary quality indexes is lack of consideration of an overconsumption penalty for energy-dense food items. In fact, Fogli-Cawley et al.'s DGA Adherence Index (DGAI) 2005 is the only diet quality index to include an overconsumption penalty to ensure that no participant receives higher scores solely by energy overconsumption (80). However, no previous study has evaluated the validity and reliability of the DGAI, which is important as diet quality indexes need to be critically evaluated for validity and reliability before application in a given study (9, 81).

2.3.2.2 Hybrid dietary patterns

The basic principle of hybrid dietary patterns is combing the *a priori* and *a posteriori* dietary pattern approaches (71). Hybrid methods derive multivariate dietary patterns based on predictors (food groups) as well as response variables relevant for chronic disease risk (71). Response variables in this context are intermediate risk factors for a diet-related disease and could be nutrients related to outcome of interest (9) or biomarkers (82). RRR is the most commonly used hybrid technique in nutritional sciences, which defines linear combination of foods that maximally explain the variation in a set of intermediate response variables (71, 82). PLS on the other hand, is a compromise between the PCA and RRR and derives patterns that explain both a high variation in food groups (predictors) and intermediate variables important for risk of chronic diseases (response variables) (71). In general, hybrid approaches are useful for identifying combination of dietary components relevant for a given health outcome. However, RRR is only useful for health outcomes for which sufficient knowledge about intermediate risk factors are available (11, 71, 83). PLS on the other hand, is more flexible and allows exploration of outcomes with only partial knowledge about biochemical pathways (9). Similar to the *a priori* diet quality indexes, findings from hybrid dietary patterns need to be confirmed in independent populations and subgroups, for example in randomly split samples. Confirmation of findings in other populations using the same weight and dietary components as in the original study and without having the biomarker data available is also promising (71, 84). In addition, cross-validation of results would ensure that subjectivity is reduced in derivation of patterns (9).

Chapter 3

3 Scope and Hypotheses of Thesis

3.1 Scope and objectives

This thesis was designed to generate the evidence-base to ultimately inform future update of the Canadian dietary guidelines by conducting the first dietary pattern analyses using Canadian national nutrition survey data. To achieve this goal, an important methodological limitation of self-reported nutrition surveys, i.e., dietary misreporting, was first addressed by identifying an appropriate adjustment technique and applying it to all subsequent analyses.

Recently, there have been some criticisms regarding the value of national nutrition data in informing public health nutrition policy due to the potential measurement errors in survey data (85-89). In fact, some researchers have called research using self-reported surveillance data as "pseudoscience" and claimed that national guidelines developed based upon these studies are misguided (85, 89). These claims do not consider the efforts of nutritional epidemiologists to address measurement errors through improving dietary instruments or applying appropriate statistical techniques (90). However, measurement errors and in particular systematic errors have not yet been taken into consideration when developing national nutrition guidelines and policies, mostly due to lack of agreement on the most appropriate technique for handling the systematic misreporting bias. Therefore, the first step towards development of evidence-based and rigorous dietary guidelines and nutritional policies is to evaluate different methods that could be used to control for the systematic misreporting bias when analyzing national nutrition surveys, which are the cornerstone of developing nutrition policies.

An additional gap addressed in this thesis is that to our knowledge no previous study has characterized the dietary patterns of Canadians in relation to risk of obesity and other chronic diseases at the national population level, as the focus has mostly been on the analysis of single isolated foods and nutrients. Importantly, the association of dietary patterns with chronic diseases in Canada has not been documented in a nationally-representative sample while controlling for systematic misreporting bias. Indeed, such comprehensive evidence-base is urgently needed to inform the next Canadian dietary guidelines given its current observed limitations (27).

Therefore, the overall objective of this thesis was to provide the evidence-base for use in updating the EWCFG and other nutrient-focused dietary guidelines and policies in Canada through conducting comprehensive dietary pattern analysis using the Canadian national nutrition survey (i.e., CCHS 2.2). In order to conduct nationally-representative dietary pattern analysis using self-reported data, an appropriate statistical technique for handling dietary misreporting was identified in Study 1 and was used in all subsequent dietary pattern analyses.

Five interrelated studies were conducted in 2 Phases of this thesis to address this overall goal, with the following specific objectives:

Phase I: Evaluation of different methods to handle misreporting in nutrition surveys

1. *Objective 1 (Study #1):* Identify an appropriate method for handling systematic misreporting bias in nutritional surveys using self-reported dietary recalls in the CCHS 2.2

Phase II: Dietary pattern analyses

2. *Objective 2 (Study #2):* Evaluate the associations between adherence to the only Canadian *a priori* index, Health Canada's Surveillance Tool Tier System (HCST) 2014, and diet quality and obesity risk among participants of the CCHS 2.2

3. *Objective 3 (Study #3):* Systematically evaluate the limitations of current Eating Well with Canada's Food Guide (EWCFG) released in 2007, which is the basis for HCST 2014, and provide suggestions for its future improvement

4. *Objective 4 (Study #4):* Examine the validity and reliability of the 2015 DGAI for measuring diet quality of Canadians and test its relationship with diet quality and risk of obesity with and without an accompanying chronic disease (unhealthy and healthy obesity) among participants of the CCHS 2.2

5. *Objective 5 (Study #5):* Characterize dietary patterns of Canadians associated with reduced risk of obesity using the weighted partial least square (wPLS) analysis (energy dense, high-fat and low-fiber), and determine its association with risk of unhealthy and healthy obesity among participants of the CCHS 2.2

3.2 Specific hypotheses

The overall hypothesis of this thesis is that by identifying an appropriate method for handling dietary misreporting and conducting comprehensive dietary pattern analyses, some of the major methodological deficiencies in nutritional epidemiology can be surmounted to better describe the relationship between dietary exposures and chronic diseases at the population level.

The specific hypotheses are as follows:

1. *Hypothesis 1 (Study #1):* The systematic misreporting bias can be accounted for by adjustment of the statistical analysis for the misreporting status

2. *Hypothesis 2 (Study #2):* Closer adherence to the HCST 2014 recommendations may not necessarily associate with reduced obesity risk but it may result in better diet quality, due to the strict focus of the EWCFG 2007 and the HCST 2014 on nutrients and lack of consideration of total dietary pattern approach

3. *Hypothesis 3 (Study #3):* The EWCFG 2007 is obesogenic in nature and may not be well-developed for reduction of obesity and other chronic diseases in Canada due to its strict focus on meeting the nutrient DRI requirement

4. *Hypothesis 4 (Study #4):* The 2015 DGAI is a valid and reliable tool for measuring the overall diet quality of Canadians and adherence to recommendations of this index can lead to better diet quality and lower risk of chronic diseases

5. *Hypothesis 5 (Study #5):* An energy-dense, high-fat and low-fiber dietary pattern is significantly associated with reduced risk of obesity with and without an accompanying chronic disease among Canadians

3.3 Preview of Chapters 4-8

As mentioned earlier, the overall goal of this thesis was to provide an evidence-base for use in informing the next Canadian food guide by conducting dietary pattern analyses using different techniques. The first step in comprehensive dietary pattern analysis is ensuring that the dietary survey data used are not biased by the differential systematic measurement error. Therefore, the first study in this thesis (Chapter 4) presents the largest known research to compare seven different approaches for handling dietary misreporting bias in self-reported nutrition data using a nationally representative sample. This study provides important knowledge on the most appropriate technique for handling the differential systematic error when analyzing diet-disease relationships. In the second Phase of this thesis, a series of dietary pattern analyses was conducted using different methods (Study 2, Study 4, and Study 5). Specifically, Study #2 addressed the second objective of this thesis by using the only Canadian *a priori* index (i.e., HCST 2014) to characterize dietary patterns and determined its association with diet quality and obesity risk (Chapter 5). Since the HCST 2014 was developed based on the EWCFG 2007 recommendations, Study #3 systematically evaluated the EWCFG 2007 guidelines and its development process to explain the lack of significant associations observed in Study #2 (Chapter 6). Study 4 and 5 provide the most comprehensive population-based dietary pattern analyses of the Canadian population using *a priori* (Chapter 7) and hybrid (Chapter 8) dietary pattern techniques. Objective 4 was addressed in Study #4 where the reliability and validity of the 2015 DGAI were examined as well as its relationship with risk of healthy and unhealthy obesity. Finally, Study #5 demonstrated the association of a wPLS-derived energy-dense, high-fat and low-fiber dietary pattern with risk of healthy and unhealthy obesity among population subgroups. Studies 4 and 5 addressed objectives 4 and 5 respectively, to provide the first evidence-base on the role of dietary patterns in risk of obesity among different population subgroups in Canada.

Together these 5 studies can be used to inform the next steps that need to be taken in the development and update of effective public health nutrition policies and guidelines in Canada. The two phases of this thesis were conducted to ensure that the next generation of dietary guidelines will reflect: a) national nutrition datasets with appropriate adjustments for systematic misreporting bias; and b) current state of knowledge regarding the role of dietary patterns in risk of obesity and chronic diseases among population subgroups. Overall, these studies demonstrate how application of appropriate and rigorous methodological techniques can enhance the usefulness of national nutrition survey data for capturing associations of dietary exposures with disease outcomes and for informing dietary guidelines that can eventually lead to reduction of non-communicable chronic diseases.

Phase I

Evaluation of Different Methods to Handle Misreporting in Nutrition Surveys

Chapter 4

4 Study #1: Evaluation of different methods to handle misreporting in obesity research: evidence from the Canadian national nutrition survey

This manuscript has been published (14): Jessri M, Lou WY, L'Abbé MR. Evaluation of different methods to handle misreporting in obesity research: evidence from the Canadian national nutrition survey. Br J Nutr. 2016 Jan;115(1):147-59. doi: 10.1017/S0007114515004237. Epub 2015 Nov 2. Available from: http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=10052772&fileId=S0007114515004237

This study addressed the objective #1 of my thesis, to:

- Identify an appropriate method for handling systematic misreporting bias in nutritional surveys using self-reported dietary recalls in the CCHS 2.2

Student's contribution:

I conceptualized and designed the original study, independently performed all coding of this project, ran the analyses at the Research Data Center of Statistics Canada, and prepared data tables. I also interpreted all results and independently drafted and revised the final manuscript which was eventually published in the "*British Journal of Nutrition".*

4.1 Abstract

The association of dietary exposures with health outcomes may be attenuated or reversed as a result of energy intake (EI) misreporting. This study evaluated several methods for dealing with implausible recalls when analyzing the association between dietary factors and obesity. We examined data from 16,187 Canadians aged ≥12 years in the nationally-representative Canadian Community Health Survey 2.2. Under- and over-reporting were defined as the ratio of EI to estimated energy requirement <0.7 and >1.42, respectively. Multinomial logistic regression-GLM was conducted to test the utility of different methods for handling misreporting, including a) adjusting for variables related to misreporting, b) excluding misreported recalls, c) adjusting for reporting groups (under-, plausible-and over-reporters), d) adjusting for propensity score, and e) stratifying the analyses by reporting groups. In the basic model, EI showed a negative association with overweight (OR: 0.988 (0.979-0.998)), and obesity (OR: 0.989(0.977-0.999)). Similarly, the association between total energy density and overweight (OR: 0.670 (0.487-0.923)) and obesity (OR: 0.709(0.495-1.016) was inverse. Among all methods of handling misreporting, adjusting for the reporting status revealed the most satisfactory results, where a positive association between EI and overweight (OR:1.037(1.019-1.055) and obesity (OR:1.109(1.082-1.137) was observed (p<0.0001), as well as direct positive associations between energy density and % energy from solid fats and added sugars with obesity (p<0.05). The results of this study can help advance knowledge about the relationship between dietary variables and obesity and demonstrate to researchers and nutrition policy makers the importance of adjusting for recall plausibility in obesity research, which is highly relevant in light of global obesity epidemic.

4.2 Introduction

Nutritional studies often rely on self-reported dietary intakes due to feasibility of this approach especially in large-scale national surveys (91). Inevitably, self-reported dietary intakes involve misreporting (i.e., under- and over-reporting) and implausible intakes (35). The prevalence of underreporting varies between 10-50% in different studies depending on the cut-point used for identifying misreporters (15-17). Misreporting of energy and nutrients can be both variable and substantial, hence it poses a challenge for epidemiologists trying to find a clear relationship between dietary intakes and health outcomes (92). Some studies have confirmed that there is a tendency towards omission of food items that are socially undesirable (i.e., high in fat, added sugars and alcohol), also referred to as "selective misreporting" (22, 23, 92). In addition, energy intake (EI) reporting is influenced by subjects' characteristics (22, 53, 91, 93), for example the magnitude of underreporting increases with increasing body mass index (BMI) which may falsely lead into the conclusion that overweight and obese individuals consume less calories compared to their normal-weight counterparts (differential misreporting) (15, 21). As a result, misreporting is a particular problem for studies investigating the association of diet and obesity since it may render the relationship ambiguous or attenuated, diminishing the usefulness of nutrition data in informing public health policy (bias towards the null) (24).

The misreporting phenomenon is still largely overlooked in obesity research. Several procedures have been proposed for identifying implausible dietary recalls (34, 36), even though methods of handling physiologically implausible recalls are less well-studied. Thus far, only few studies (none in adolescents) have investigated methods of handling implausible recalls (23, 24, 91, 94), and none have compared all available methods among different age groups, especially in a large-scale national survey. The purpose of this study is therefore to systematically compare the utility of seven different statistical approaches for handling inaccurate reports of dietary intakes among a nationally representative sample of Canadian adolescents (12-17 years) and adults (≥18 years), when examining the relationship between dietary intakes and obesity. The following methods were used for correcting the misreporting: 1) adjusting for variables related to misreporting, 2) excluding misreported recalls, 3) adjusting for the reporting groups (under-reporter, plausible reporter, and over-reporter), 4) adjusting for the propensity score (94, 95), 5) adjusting for both reporting groups and propensity score, 6) stratifying the analyses by reporting groups, and 7) stratifying the analyses by reporting groups and adjusting for the propensity score (94, 95).

Propensity score is a statistical technique aimed at reducing bias by equating groups based on variables associated with misreporting (94, 95). Adjustment for propensity score in nutrition surveys has only been used among children (proxy reports) and was found to be a useful tool for counteracting attenuation of risk estimates caused by misreporting (94).

Additionally, we examined the validity of participants' self-estimated intake amount (less than, the same, or more than the usual amount) collected as part of the 24-hour recall procedure, through comparison with the calculated cut-off points for identifying misreporters. Recommendations on how best to counteract attenuation of risk estimates caused by misreporting bias in obesity research are also given.

4.3 Subjects and Methods

4.3.1 Study population

Data for this study were collected under the authority of the Statistics Act of Canada and all data analyses were conducted at the Statistics Canada's Research Data Center. The Canadian Community Health Survey (CCHS) cycle 2.2 (2004-5) provides the most complete nutritional data on Canadian dietary intakes and is the only available national nutrition data in >30 years (96). CCHS 2.2 is a complex multistage nationally representative survey including cross-sectional nutritional and health data from 35,107 Canadians of all ages, representing >98% of the Canadian population from 10 provinces (97). Details on the CCHS 2.2 study design, sample and procedures have been published previously (96) . For the purpose of this study, we excluded all pregnant (n=175) and lactating (n=92) women, those under 12 years of age (n=8,335) and participants with invalid self-reported dietary recalls (as defined by Statistics Canada) (n=39). Data from all respondents with complete data on physical activity and measured weight and height were included, resulting in a final sample of 16,187 subjects. Only participants ≥12 years were included in this study, since only this group had self-reported dietary recalls (as opposed to proxy reports for children). In order to evaluate the association of misreporting with lifestyle and socio-economic characteristics, missing values for these variables were additionally removed, leaving a total of 15,722 individuals for regression analyses. None of the socio-demographic or lifestyle characteristics of individuals included in the final analyses were significantly different than those who were excluded due to missing variables (data not shown).

4.3.2 Data collection

Detailed dietary intake data were collected by the 24-hour recall method using a 5-step modified version of the US Department of Agriculture (USDA) Automated Multiple Pass Method (AMPM) (98, 99). Respondents were asked to recall all foods and beverages consumed in the previous 24 hours (midnight to midnight), and energy and nutrient composition of reported foods were derived from the Health Canada's Canadian Nutrient File (CNF) (2001b Supplement) (100). As part of the 24-hour recall procedure, participants also responded to a question about whether they ate less than the usual amount, the same as usual or more than the usual amount during the recall day (96). We additionally used these data to test whether the self-reported usual intake (subjective measure of misreporting) was valid as compared to the cut-off points calculated to identify misreporters (objective measure of misreporting).

Trained interviewers measured height and weight according to standard protocols and BMI in adults was used as a measure of body fatness using the standard cut-offs for overweight (≥25-29.99 kg/m^2) and obesity (≥30 kg/m^2). For adolescents, Cole et al.'s categories were used (101). Data on socio-demographic characteristics, lifestyle behaviours and health history were collected using interviewer-administered questionnaires (96). Anthropometric measurements and data collection interviews were conducted in person and at participants' homes (96).

Energy intake (Kcal/day) (in 100s of Kcal), fiber density (g/1000 Kcal), percentage of energy intake from solid fats and added sugars (SoFAS), percentage of energy intake from fruits and vegetables, and dietary energy density (Kcal/g) were used as exposure measures in this study since these have been repeatedly associated with overweight and obesity risk (102-104). Fiber density was derived by calculating grams of non-starch polysaccharide fiber intake (g) consumed per 1000 kcal energy intakes. Fruits and vegetables were defined based on the World Health Organization (WHO) Global Strategy on Diet, Physical activity and Health and included all fruits and vegetables reported by participants excluding potatoes, nuts, and juices (105). SoFAS were defined by the HHS/USDA Dietary Guidelines for Americans as high-calorie low nutrient-dense food items that need to be limited (103). Dietary energy density was calculated using two definitions; (i) dividing the total energy from foods/beverages (Kcal) by total weight of foods/beverages (in grams) or (ii) as above, using foods alone (excluding all drinks) (106-108).

All analyses were performed in terms of EI and not the absolute amounts to reduce extraneous variability and to control for confounding (109, 110). The effect of EI was evaluated as a 100-unit offset from the mean, while for all other dietary variables a 1-unit change was applied. Descriptive analyses were stratified by sex and age categories, as defined in the Institute of Medicine (IOM) Dietary Reference Intakes (111).

4.3.3 Identification of implausible reporters

Each respondent was categorized as either under-reporter, plausible reporter or over-reporter based on the comparison of their total estimated energy requirement (EER) and their reported EI. The EER was calculated using the IOM factorial equations which were developed from a meta-analyses of studies using doubly-labelled water as the criterion measure of EER (112). These equations use participants' age, sex, BMI, weight, height and physical activity level (PAL) (sedentary, low active, moderately active, highly active) to estimate their EER (112). Since CCHS 2.2 only includes energy expenditure in terms of Metabolic Equivalents (MET) (Kcal/kg/day), the IOM method was used to convert MET (intensity of an activity compared to the resting metabolic rate) to the PAL (ratio of total energy expenditure to basal energy expenditure) which was then used in equations to predict EER (112).

Among several methods developed for detecting implausible recalls, McCrory et al.'s method is currently the most detailed procedure by which EI is directly compared with EER using cut-offs for their agreements based on error propagation calculations (23, 36). This is important since other commonly-used procedures of identifying misreporters (e.g., Goldberg et al. (34)) are prone to several potential errors, especially in assigning appropriate PALs to individuals (36). In this study, we applied McCrory et al.'s intervals for 4 different levels of physical activity to data from adolescents and adults, using the level of physical activity each participant reported (19, 23, 63). Since the EI distribution was skewed, we constructed the confidence intervals in the Log scale and exponentiated the cut-off points, in line with previous studies (19, 23). Based on our dataset, individuals whose EI was less than 70% of their EER were classified as under-reporters and those whose EI was more than 142% of their EER were classified as over-reporters (±1SD). Equations used for this calculations have been published elsewhere (19, 23, 36). We additionally classified individuals based on the ±2SD cut off points using the 50% and 198% as the cut-points for the EI/EER ratio.

4.3.4 Statistical analyses

All statistical analyses were performed using Statistical Analysis Software (SAS) (version 9.3; SAS Institute Inc, Cary, NC). To account for the complex multistage sampling frame of the CCHS 2.2, variance estimation was performed using the bootstrap balanced repeated replication (BRR) technique (113, 114) and the sample survey weights calculated by the Statistics Canada. To maintain a nationally representative sample, a specific weight calculated by Statistics Canada was used in all analyses which was based on respondent classes with similar socio-demographic characteristics. A two-tailed p-value <0.05 was used to define statistical significance. Group comparison with Tukey post-hoc adjustment was used to evaluate the characteristics of participants classified as under-reporters, plausible reporters and over-reporters (PROC SURVEYREG).

4.3.4.1 Calculation of the propensity score

Step-wise elimination in the logistic regression was applied to identify lifestyle and socio-demographic factors significantly associated with underreporting among adolescents and adults. We started fitting a model containing all determinants of underreporting mentioned in previous studies, and the backward selection procedure was applied to screen out non-relevant factors. The following variables were significant in the final model for adolescents: age, sex, physical activity, alcohol intake in the past 12 months, highest household education, self-reported health, smoking status, province of residence, and income. For adults, variables that remained significant in the final model included: age, sex, physical activity, having a chronic disease, province of residence, highest household education, self-reported health, and smoking status. BMI was not used in the construction of the propensity score since it was the main outcome in the present research (94). The conditional probability of being classified as an under-reporter given the above-mentioned variables was calculated for adolescents and adults using two separate multiple logistic regression models, as follows (94):

Propensity score= estimated probability (under-reporter ∣covariates)

4.3.4.2 Statistical models for handling misreporting

To compare the utility of different procedures for handling misreporting, the association of overweight/obesity was assessed in relation to a number of key food items identified by the WHO as the main determinants of obesity (102). Multinomial logistic regression- generalized logit model (PROC SURVEYLOGISTIC) was conducted using a classification variable indicating overweight and obesity as outcomes of interest and six dietary variables as exposure measures: EI (Kcal/day), fiber density (g/1000 kcal), % energy from SoFAS, % energy from fruits and vegetables, total energy density (Kcal/g) and food-only energy density (Kcal/g). The following eight models were then examined and compared. The first model (basic model) was only adjusted for individuals' age and sex (Model I). The second model was the same as the basic model but also adjusted for all confounding variables used in calculation of the propensity score (Model II). Model III on the other hand, was identical to the basic model with recalls identified as under-reporter or over-reporter using McCrory et al.'s method (36) being removed (Model III). Other models were the same as the basic model but additionally adjusted for the reporting group (Model IV), propensity score (Model V), and both the reporting group and propensity score at the same time (Model VI). Further analyses were conducted stratifying the analyses by the reporting group (Model VII), and stratifying the analyses by the reporting group and adjusting for the propensity score simultaneously (Model VIII).

4.4 Results

4.4.1 Part A: Prevalence and determinants of misreporting

Based on the ±1SD cut-off point, 40.47% of Canadian adolescents and 42.3% of adults were categorized as misreporters, while the corresponding percentages using the ±2SD cut-point were 12.18% and 13.6%, respectively (Supplementary Figure 4.1). Throughout this study the more stringent cut-off (±1SD) was used for screening out implausible recalls.

Generally, the weighted mean ratio of EI to EER was significantly lower in overweight and obese individuals compared to their normal weight counterparts ($p<0.0001$) (Table 4.1). In addition, the ratio of EI to EER decreased by age among both genders and was lower for females compared to males; however, after approximately 50 years of age, men consistently showed lower total EI/EER values ($p<0.024$) (Supplementary Figure 4.2). In Table 4.1, disparity values between the reported EI and the recommended EER were also calculated in order to estimate the amount of calories being misreported among different age, sex and BMI categories. Disparity values were calculated by subtracting the IOM EER (112) from the EI reported in the CCHS 2.2. Negative disparity values represent the magnitude of energy underreporting while positive values show over-reporting. Among normal-weight males, disparity values were positive and significantly higher in adolescents compared to adults (p=0.013). Disparity values among overweight and obese individuals were consistently negative, with the highest value being -888 (±110) among obese males 12-17 years, followed by -662 (±104) among obese females of the same age group (an underreporting of approximately 25% of EER).

Table 4.2 presents the descriptive analyses of several covariates stratified by reporting group (under-reporters, plausible reporters and over-reporters) among adults (≥18years). Under-reporters were more likely to be older (p=0.0013) and to have higher BMIs (p<0.0001), diabetes (51.13% vs. 30.33%, p<0.0001), hypertension (36.64% vs. 30.40%, p=0.0003), heart disease (36.08% vs. 31.11%, p=0.035) and at least one chronic disease (34.53% vs. 28.92%, p=0.0031). In addition, the percentage of under-reporters was higher among residents of Prairie provinces (Manitoba (MB) and Saskatchewan (SK)) and Ontario (ON), those with secondary education or less, and daily smokers (p<0.006). Similar results were observed among adolescents (12-17 years) (Supplementary Table 4.1).

The weighted mean values of dietary determinants of obesity by reporting status are reported for different age and sex categories to examine evidence of potential "selective misreporting" (Table 4.3). Adult under-reporters reported substantially lower mean EI (1434 (±18) kcal/day in males, 1075 (±14) kcal/day in females) compared to the plausible (2611 (±20) kcal/day in males, and 1967 (±20) kcal/day in females) and over-reporters (4483 (±71) kcal/day in males, and 3267 (±77) kcal/day in females)(p-trend <0.0001). Similarly, % energy from SoFAS, total energy density, and food-only energy density were significantly higher in over-reporter males and females compared to under- and plausible reporters (p-trend<0.0001). In contrast, weighted mean fiber density and % energy from fruits and vegetables were higher in under-reporters compared to plausible- and over-reporters (p-trend<0.0064). Similar selective misreporting of dietary variables were also observed among adolescents, although the magnitude was not as large as in adults, probably due to the lower rate of misreporting in younger individuals.

4.4.2 Part B: Comparison of different methods to handle misreporting

Table 4.4 shows the odds ratio (OR) (95% confidence intervals (CI)) obtained from six different regression models for the association between overweight and obesity as outcomes and several dietary variables as exposures in adults. In the basic model (model I) adjusted for age and sex, a significant negative association was seen between EI and overweight (OR: 0.988 (0.979-0.998); p=0.0135), and obesity (OR: 0.989 (0.977-0.999); p=0.0553). A similar inverse association was observed between total energy density and overweight (OR: 0.670 (0.487-0.923); p=0.0142) and obesity (NS). More specifically, only the association between fiber density and food-based energy density with obesity were significant and in the expected direction in model I (p<0.0019). Adjusting for covariates (model II) revealed very similar ORs for all dietary exposures so that the direction and significance of none of the variables changed. The strongest relationship between overweight, obesity and dietary exposures were seen after excluding misreporters from the analyses (Model III). In this model significantly positive associations between EI and overweight (OR: 1.045 (1.021-1.070) and obesity (OR: 1.139 (1.108-1.171) were observed (p<0.0001), as well as direct positive associations between % energy from SoFAS, total energy density and food-only energy density with obesity risk (p<0.0028). Furthermore, the negative association between fiber density and % energy from fruits and vegetables with obesity were changed to be strong and significant (p<0.0205). Including all respondents and adjusting for the reporting group (IV) revealed similar results that were slightly less pronounced compared to the model excluding misreporters (model III). After adjusting for the propensity score (model V), all associations changed to be similar to the Model II (adjusted for the covariates) and no longer in the expected direction. Finally, adjustment for both the propensity score and the adjusting group (model VI) did not improve results compared to adjusting for the reporting group alone. Additional inclusion of dietary variables into the propensity score calculation did not improve the results (data not shown). The same results were confirmed among adolescents where excluding misreporters (Model III) yielded the strongest association between most dietary exposures and overweight and obesity (Supplementary Table 4.2).

In adults, when the basic model was stratified by the reporting group, only EI was significantly associated with obesity in all 3 groups (under-reporters, plausible reporters and over-reporters) (Model VII) (Table 4.5). Additional adjustment for the propensity score did not improve statistical models (Model VIII), except for slight improvement in EI associations with obesity. Generally, the association of most dietary variables with overweight and obesity was significant and in the expected direction among plausible reporters, even though the strongest association between most dietary variables and overweight and obesity was observed among under- or over-reporters (Table 4.5 and Supplementary Table 4.3). Graphical representations of the relationship between EI and BMI among under-reporters, plausible reporters and over-reporters are presented in Figures 4.1a-d.

4.4.3 Part C: Agreement of subjective and objective measures of recall validity

To test the validity of participants' self-reported usual intakes, we additionally compared the self-reported usual intake amounts with the ±1SD cut off for the agreement between EI and EER. As presented in Supplementary Figures 4.3 a and b, 58.95% (±1.04) of adults and 60.06% (±1.55) of adolescents who said they consumed "their usual amount" were actually plausible reporters and 29.99% (±1.34) and 20.23% (±1.22) of these individuals underreported their intakes. Among those who reported consuming "less than the usual" amount of food, only 42.58% (±2.13) of adults and 21.72% (±2.05) of adolescents were under-reporters and 49.75% (±2.10) and 58.62% (±3.17) reported accurately. In addition, of those who reported that they consumed "more than the usual" amount only 16.98% (±2.87) of adults and 31.11% (±4.22) of adolescents actually over-reported their intakes.

4.5 Discussion

To our knowledge this is the first study using large-scale national survey data among adolescents and adults (self-reports) to compare seven different statistical approaches to counteract attenuation of risk estimates caused by misreporting. Consistent with previous studies on differential misreporting by weight and disease status (24, 85, 94, 115), under-reporters were more likely to be obese and have higher rates of chronic diseases compared to the plausible and over-reporters. In addition, our results showed strong evidence of selective misreporting in line with others (16, 116, 117), where under-reporters reported significantly higher intakes of healthy foods, such as fiber, fruits and vegetables, and lower intakes of energy and energy-dense foods. Given the high prevalence of such systematic differential and selective misreporting, statistical models which neglected misreporting of energy intakes rendered the association of nearly all dietary exposures and obesity as insignificant or even reversed, even though the variables studied have been strongly suggested by the WHO as major determinants of overweight and obesity (102). In addition, the nature of the relationship between dietary variables and obesity was different among different reporting groups (under-reporters, plausible reporters, and over-reporters). Exclusion of misreporters, adjusting for the reporting groups and stratification resulted in risk estimates that were more consistent with the established hypotheses regarding the role of dietary variables in obesity (102, 118, 119). Particularly, adjusting for the reporting group yielded more consistent results, even when compared to those from plausible reporters in stratified analyses, and it provided the maximum sample size while maintaining biological plausibility.

In line with a previous study (36), findings of this research showed a significant disagreement between objective and subjective measures of intake validity, which suggests that although individual's self-defined "usual amount" may be within the normal range of day-to-day intake variation, this does not necessarily translates into the "habitual" amount needed to maintain current body weight (36). In addition, this inconsistency confirms that individual's self-assessment of intake amounts can not be used for identification of inaccurate recalls in nutritional surveys (36).

Thus far, only a few studies have investigated methods of dealing with implausible recalls (23, 24, 91, 94). Huang et al. in 2005 evaluated this issue and concluded that lack of exclusion of misreporters in the analyses results in non-significant, weak and misleading diet-obesity relationships (23). However, these authors did not consider the loss of statistical power that occurs as a result of excluding such large number of participants from the analyses and the fact that results would no longer be generalizable to the entire population, since misreporters have unique characteristics that are not shared by the plausible reporters (i.e., differential misreporting) (23, 115, 120), as also clearly demonstrated in our study. In addition, extreme observations and outliers usually contain valuable information about the outcome of interest and their exclusion may introduce an unknown bias (121). Even though excluding misreporters may strengthen the diet-disease relationships, as was also seen in the present study, it is not an appropriate methodology and may lead to a selection bias (24, 46, 94, 121). Generally, results from Huang et al.'s study should be interpreted with caution since all individuals were assumed to be low-active for EER calculations due to lack of data on physical activity levels (23), which could potentially lead to misclassification of additional subjects to the underreporting group.

Another study on alternative methods of dealing with inaccurate recalls was based on the National Health and Nutrition Examination Survey (NHANES) 1999-2002 data and concluded that stratification by the intake level is more representative of population nutrient intakes compared to data elimination or exclusions (91). These authors observed a significant association between EI and BMI only among plausible reporters, and not the total sample (91). This also supports our findings for the total group where no significant association was observed (model I). Nevertheless, the association of EI with BMI in our study was significant for nearly all reporting groups (under-reporters, plausible reporters, and over-reporters), which is in line with a previous study (94). Generally, the limitations of stratification (models VII and VIII in our study) are similar to those of data exclusion, since it results in reduced sample size and loss of statistical power, especially among the over-reporter group (smaller n) (94). An important limitation of the Nielsen et al.'s study (91) is the use of a modified Goldberg method for identifying misreporters, which assumes a certain habitual PAL for individuals without accounting for the error in assigning this PAL (34). In our study, on the other hand, EI was directly compared with EER using cut-off points for their agreements based on error propagation calculations (23). This is important since previous studies have noted a very low precision for assigning PALs to individuals, which may also explain the lack of sensitivity of the Goldberg cut-off point for identifying inaccurate dietary reports (122). Another limitation of the Goldberg method is that only extremely inaccurate recalls (±2SD) are identified (34), even though misreporting can occur to varying degrees.

In 2011, Mendez and colleagues concluded that adjusting for the reporting status through inclusion of a dummy variable for reporting group resulted in stronger associations between diet and obesity and yielded results similar to when misreporters were excluded from the analyses (24). Our findings corroborate these conclusions; adjustment for the reporting group maintained the statistical power and shifted the association of dietary exposures with overweight and obesity to the expected direction among Canadian adolescents and adults. Although Mendez et al.'s study was the first to systematically compare the effect of "adjusting for the reporting group" and "excluding misreporters" (24), it suffers from the same limitation as other previous studies in the field which is assumption of a habitual PAL for all participants without consideration of error in assigning this PAL.

The most recent study that explored different methods of handling misreporting was conducted in 2-9 year old children (proxy reports) and was the first to calculate and apply a propensity score for handling inaccurate recalls (94). These authors concluded that mutual adjustment for the reporting group and a propensity score is a useful tool for obtaining unbiased risk estimates in obesity research among children (94). However, their findings may have been influenced by the proxy-reported nature of diet recalls and lack of consideration of children' PAL in calculation of EER, for identifying misreporters and for developing the propensity score. Our study is the first among adolescents and adults to develop and apply the propensity score as a means of counteracting misreporting bias. We found that among adolescents and adults adjusting for the propensity score had no benefit over adjusting for the reporting group for improving the association between dietary exposures and obesity. This discrepancy may reflect higher differential and selective misreporting among adolescents and adults compared to children, which may not be simply accounted for by inclusion of a propensity score, or other calibration methods, which assume a linear (non-differential) measurement error with a constant variance (123-125).

Future studies could test the applicability of constructing calibration scores based on biomarker data in large-scale national surveys where dietary measures are also available for the same subjects. Although exclusion of misreporters strengthened diet-obesity relationships in this study, it is not an appropriate strategy due to introducing an unknown bias by exclusion of about 40% of the population (misreporters) who are systematically different than the plausible reporters (different lifestyle and higher obesity and chronic disease risk). In the absence of biomarker measurements in the Canadian national nutrition survey, our results suggest that simple adjustment for the reporting group is superior to other statistical techniques for handling the misreporting bias, retaining adequate power among adolescents and adults.

4.5.1 Strengths and limitations

This is the largest known study to compare seven different statistical approaches to address the misreporting bias among adolescents and adults in a nationally representative sample, and it provides important knowledge on the critical role of handling misreporting in obesity research. Developing specific cut-off limits for defining misreporting based on participants' PAL and McCrory et al.'s algorithm-based method was one of the strengths of this research, compared to studies that mistakenly apply the first cut-points used by Goldberg et al. in 1991 to identify misreporting(62, 85). This is problematic since cut-points should be derived based on characteristics of the population being studied to avoid subject misclassification. Including various covariates, using a large nationally-representative sample, and measured anthropometry are some of the other strengths of this study. In addition, the likelihood of misreporting due to missing items or eating occasions was minimized in this research since dietary data were collected using the USDA AMPM; therefore, some of our results may not be applicable to surveys with less comprehensive methods of dietary data collection.

One limitation of this study is day-to-day variation (random non-differential error) associated with dietary recalls which may have weakened the associations between dietary intakes and obesity. In addition, causal inference is limited owing to the cross-sectional nature of this research (91).

4.5.2 Conclusions and implications

The present study clearly demonstrated widespread prevalence of selective and differential misreporting across all age and sex groups in the Canadian national nutrition survey, which can undermine the validity of existing national dietary assessments, diet-disease relationships and public health policies that are developed based on these data, unless appropriate statistical methods are used to deal with such misreporting. Unlike some groups who concluded that national surveys have extremely limited ability for estimating energy intakes and explaining the obesity epidemic (85), we suggest that rigorous methods to control for the misreporting bias are needed and should be applied to any such analysis.

In this study, "adjusting for the reporting group" maintained the statistical power and shifted the association of dietary exposures with obesity to the expected direction. These results can help advance knowledge about the relationship between dietary variables and obesity and demonstrate to obesity researchers and nutrition policy makers the importance of adjusting for recall plausibility in obesity research. Future studies which assess the sensitivity and specificity of different statistical techniques for correcting the misreporting bias against reference biomarkers of dietary intakes will further advance our abilities to handle misreporting in epidemiological and national cross-sectional studies.

Table 4.1. Weighted mean ratio of energy intake (EI) to estimated energy requirement (EER) and disparity values (EI-EER) for Canadian adolescents (12-17 years) and adults (≥18 years) by body mass index (BMI) categories (n=16187)[*,†,‡]

Age/sex groups		BMI Categories	Weighted Mean EI/EER	SE	Weighted Mean EI-EER (Kcal)[§]	SE
Adolescents	**M**	Normal-weight	1.17[a,b,c]	0.02	363[a,b,c]	58
		Overweight	0.94[b,d]	0.03	-196[b,d]	99
		Obese	0.75[c,d]	0.03	-888[c,d,e]	110
	F	Normal-weight	1.20[a,b,c]	0.02	342[a,b,c]	35
		Overweight	0.86[b,d]	0.03	-291[b,d]	58
		Obese	0.75[c,d]	0.04	-662[c,d,e]	104
Adults	**M**	Normal-weight	1.06[a,b,c,f]	0.03	151[a,b,c,f]	72
		Overweight	0.90 [b,d]	0.02	-275[b,d]	65
		Obese	0.81[c,d]	0.02	-576[c,d,e,g]	49
	F	Normal-weight	0.98[a,b,c,f]	0.02	-59[a,b,c,f]	45
		Overweight	0.89[b,d]	0.02	-232[b,d]	38
		Obese	0.82[c,d]	0.02	-413[c,d,e,g]	36

F, Females; M, Males; SE, Standard Error.
[*]Estimates are weighted means and bootstrapped variances (Balanced Repeated Replication technique)
[†]EI was from the CCHS 2.2 24-hour dietary recalls and the EER was from the Institute of Medicine (IOM) equations (112)
[‡]For adolescents 12-17 years of age, Cole et al.'s categories were used to define obesity
[§]Negative values indicate total kcal/day of underreporting
[a]Significantly different between adolescents and adults in normal-weight individuals in each sex ($p<0.05$)
[b]Signficantly different between normal-weight and overweight in each age and sex group ($p<0.001$)
[c]Signficantly different between normal-weight and obese in each age and sex group ($p<0.001$)
[d]Signficantly different between overweight and obese in each age and sex group ($p<0.05$)
[e]Significantly different between adolescents and adults in obese individuals in each sex ($p<0.05$)
[f]Significantly different between males and females in normal weight adults ($p<0.01$)
[g]Significantly different between males and females in obese adults ($p<0.01$)

Table 4.2. Descriptive weighted analysis of covariates (row percentages) stratified by the reporting group (differential misreporting) among Canadian adults (≥18 years) (n=11748)[*]

Characteristics	Under-reporters[†]		Plausible reporters[‡]		Over-reporters[§]		P-value
	Weighted Mean/ %	SE	Weighted Mean/%	SE	Weighted Mean/%	SE	
Sex ,%							
Males	31.10	1.52	57.09	1.31	11.81	1.25	0.31
Females	31.61	1.46	58.47	1.32	9.91	0.95	
Age, yr	46.84	0.49	46.08	0.41	43.30	0.76	0.0013
Body mass index, kg/m^2	28.56	0.22	26.92	0.16	25.13	0.29	<0.0001
Self-reported diabetes ,%							
Yes	51.13	3.73	44.95	3.51	3.91	1.23	<0.0001
No	30.33	1.22	58.44	0.96	11.23	0.87	
Self-reported hypertension ,%							
Yes	36.64	1.76	56.28	1.82	7.08	1.12	0.0003
No	30.40	1.38	58.05	1.09	11.56	0.92	
Self-reported heart disease ,%							
Yes	36.08	3.18	57.25	3.36	6.67	1.31	0.035
No	31.11	1.27	57.80	0.98	11.08	0.88	
Has at least one chronic condition ,%							
Yes	34.53	1.66	55.96	1.31	9.51	1.03	0.0031
No	28.92	1.39	59.17	1.30	11.91	1.05	
Physical activity ,%							
Inactive	29.70	2.47	57.26	2.32	13.04	1.68	0.066
Moderately active	31.17	1.17	58.52	1.02	10.31	0.90	
High/very highly active	39.66	4.13	49.43	3.87	10.91	2.58	
Province of residence ,%							
NFLD,PEI,NS,NB	32.46	1.83	59.61	1.84	7.93	1.00	<0.0001
QC	24.03	1.72	60.97	2.04	15.00	1.65	
ON	35.24	1.79	56.11	1.74	8.65	1.17	
MB,SK	36.47	2.04	54.43	2.02	9.10	1.07	
AB	34.25	2.79	54.87	2.72	10.89	1.54	
BC	28.11	2.35	59.49	2.53	12.40	1.59	
Marital status ,%							
Never married	31.56	1.45	57.45	1.23	10.99	1.01	0.22
Married	34.47	2.02	56.26	2.03	9.27	1.03	
Widowed	28.81	1.67	59.67	1.71	11.53	1.45	
Highest household education ,%							
<Secondary education	34.76	1.94	54.76	1.94	10.47	1.49	0.006
Secondary education	38.39	3.50	53.68	3.19	7.93	1.26	
Some post-secondary education	32.70	2.91	58.64	2.96	8.66	1.47	
Post-secondary education	29.66	1.40	58.75	1.13	11.59	1.05	
Income adequacy ,%							
Lowest	34.12	2.83	57.30	3.43	8.58	1.95	0.22
Lower middle	34.17	2.43	56.82	2.21	9.00	1.28	
Upper middle	30.24	1.57	57.34	1.49	12.42	1.38	
Highest	30.54	1.89	59.33	1.73	10.12	1.26	
N/S	29.60	3.27	56.26	3.29	14.14	2.67	

Drank alcohol in past 12 months ,%							
Yes	30.47	1.39	58.35	1.03	11.18	0.94	0.093
No	35.29	2.03	55.22	2.10	9.49	1.35	
Self-perceived level of stress ,%							
Not at all	28.27	1.24	60.73	1.51	11.00	1.39	0.145
A bit stressful	33.35	2.03	56.25	1.77	10.40	1.05	
Quite a bit, extreme	32.50	1.84	56.05	1.97	11.45	1.28	
Immigration status ,%							
Canadian born	31.41	1.43	57.46	1.18	11.12	0.79	0.782
Immigrant	31.17	2.00	58.76	2.33	10.07	1.80	
Smoking status ,%							
Daily	33.74	2.05	54.85	1.97	11.42	1.39	0.0053
Occasional	23.73	3.15	58.83	4.45	17.44	4.71	
Former	33.13	1.63	59.05	1.63	7.82	0.88	
Never smoked	29.91	1.61	58.23	1.40	11.86	1.28	
Self-perceived health status ,%							
Poor/fair	34.78	2.39	55.74	2.55	9.49	1.31	0.068
Good	33.04	1.63	58.25	1.59	8.71	1.19	
Very good	30.98	1.71	57.34	1.54	11.68	1.29	
Excellent	27.76	2.41	58.89	2.31	13.35	1.68	
Aboriginal of North America ,%							
Yes	30.06	3.51	58.11	4.09	11.83	3.32	0.928
No	31.37	1.26	57.77	0.97	10.86	0.85	

AB, Alberta; BC, British Columbia; MB, Manitoba; NB, New Brunswick; NFLD, Newfoundland; NS, Nova Scotia; ON, Ontario; PEI, Prince Edward Island; QC, Quebec; SE, Standard Error; SK, Saskatchewan

[*]Estimates are weighted means and bootstrapped variances (Balanced Repeated Replication technique)

[†]Under-reporters: Individuals whose energy intake (EI) was less than 70% of their estimated energy requirement (EER)

[‡]Plausible reporters: Individuals whose EI was between 70% and 142% of their EER

[§]Over-reporters: Individuals whose EI was more than 142% of their EER

Table 4.3. Descriptive weighted analysis of dietary determinants of obesity as set by the World Health Organization (WHO) stratified by the reporting group (selective misreporting) among Canadian adults (≥18 years) and adolescents (12-17 years) (n=16187)[*]

Dietary variables	**Under-reporters[†]**		**Plausible reporters[‡]**		**Over-reporters[§]**		**P-trend**
	Weighted Mean	**SE**	**Weighted Mean**	**SE**	**Weighted Mean**	**SE**	
Adult Males							
Energy intake, Kcal	1434	18	2611	20	4483	71	<0.0001
Fiber density, grams per 1000 Kcal	9.18	0.40	7.83	0.13	7.24	0.29	0.0008
% Energy from Solid Fats and Added Sugars (SoFAS)[|]	25.00	0.80	30.39	0.63	32.26	1.45	<0.0001
% Energy from fruits and vegetables[¶]	4.74	0.52	3.92	0.23	2.59	0.21	<0.0001
Total energy density, kcal/g[**]	0.60	0.01	0.79	0.01	0.96	0.02	<0.0001
Food-only energy density, kcal/g[††]	1.38	0.03	1.53	0.02	1.68	0.04	<0.0001
Adult Females							
Energy intake, Kcal	1075	14	1967	20	3267	77	<0.0001
Fiber density, grams per 1000 Kcal	10.44	0.30	8.82	0.14	7.67	0.22	<0.0001
% Energy from Solid Fats and Added Sugars (SoFAS)	22.45	0.61	26.53	0.63	30.67	1.59	<0.0001
% Energy from fruits and vegetables	6.99	0.54	5.34	0.18	4.84	0.46	0.0064
Total energy density, kcal/g	0.48	0.01	0.69	0.01	0.89	0.02	<0.0001
Food-only energy density, kcal/g	1.25	0.03	1.44	0.02	1.52	0.04	<0.0001
Adolescent Males							
Energy intake, Kcal	1548	35	2727	31	4506	107	<0.0001
Fiber density, grams per 1000 Kcal	6.96	0.23	6.42	0.16	6.31	0.23	0.091
% Energy from Solid Fats and Added Sugars (SoFAS)	30.45	1.37	31.30	0.76	36.11	1.47	0.0082
% Energy from fruits and vegetables	2.96	0.38	2.60	0.23	2.90	0.38	0.626
Total energy density, kcal/g	0.82	0.04	0.96	0.02	1.10	0.02	<0.0001
Food-only energy density, kcal/g	1.84	0.06	1.84	0.03	1.93	0.06	0.356
Adolescent Females							
Energy intake, Kcal	1110	23	1954	19	3154	52	<0.0001
Fiber density, grams per 1000 Kcal	7.55	0.32	7.29	0.14	6.36	0.22	0.0007
% Energy from Solid Fats and Added Sugars (SoFAS)	30.79	1.45	30.62	0.93	33.49	1.81	0.3809
% Energy from fruits and vegetables	3.64	0.59	3.77	0.21	2.79	0.29	0.0523
Total energy density, kcal/g	0.67	0.03	0.87	0.01	1.08	0.03	<0.0001
Food-only energy density, kcal/g	0.67	0.03	1.66	0.03	1.88	0.06	0.0004

SE, Standard Error.
[*]Estimates are weighted means and bootstrapped variances (Balanced Repeated Replication technique)
[†]Under-reporters: Individuals whose energy intake (EI) was less than 70% of their estimated energy requirement (EER)
[‡]Plausible reporters: Individuals whose EI was between 70% and 142% of their EER
[§]Over-reporters: Individuals whose EI was more than 142% of their EER
[‖]SoFAS were defined by the HHS/USDA Dietary Guidelines for Americans (DGA) as high-calorie low nutrient-dense food items that need to be limited (103)
[¶]Fruits and vegetables were defined based on the WHO Global Strategy on Diet, Physical activity and Health excluding potatoes, nuts, and juices(105)
[**]Total energy density was calculated dividing the total energy intake from foods and beverages (kcal) by total food and beverages weight (grams)(106-108)
[††]Food-only energy density was calculated dividing the total energy intake from foods (kcal) by total weight of foods (grams)(107, 108)

Table 4.4. Association between overweight and obesity risk with dietary determinants of obesity as set by the World Health Organization (WHO) among Canadian adults (≥18 years)*,†,‡

Dietary Variables	Basic model (n=11748) (Model I)§		Basic model adjusted for covariates (n=11748) (Model II)ǁ		Excluding misreporters (n=6725) (Model III)¶		Adjusting for the reporting group (n=11748) (Model IV)**		Adjusting for propensity score (n=11748) (Model V)††		Adjusting for the reporting group and propensity score (n=11748) (Model VI)‡‡	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Energy intake (1 unit=100 kcal), overweight	0.988	0.979, 0.998	0.989	0.979, 0.999	1.045	1.021, 1.070	1.037	1.019, 1.055	0.989	0.980, 0.999	1.037	1.019, 1.056
Energy intake (1 unit=100 kcal), obesity	0.989	0.977, 0.999	0.995	0.983, 1.007	1.139	1.108, 1.171	1.109	1.082, 1.137	0.993	0.981, 1.005	1.110	1.083, 1.139
Fiber density, g/1000kcal, overweight	1.000	0.980, 1.021	1.002	0.981, 1.023	0.980	0.952, 1.009	0.992	0.972, 1.012	1.001	0.981, 1.021	0.993	0.973, 1.013
Fiber density, g/1000kcal, obesity	0.963	0.942, 0.985	0.973	0.951, 0.995	0.933	0.898, 0.969	0.946	0.925, 0.968	0.964	0.943, 0.986	0.948	0.927, 0.970
%E from solid fat and added sugar (SoFAS), overweight	1.001	0.996, 1.007	1.001	0.995, 1.007	1.011	1.003, 1.019	1.003	0.998, 1.009	1.001	0.995, 1.007	1.003	0.997, 1.009
%E from solid fat and added sugar (SoFAS), obesity	1.003	0.997, 1.008	1.000	0.994, 1.006	1.012	1.004, 1.020	1.007	1.001, 1.012	1.002	0.996, 1.007	1.006	1.000, 1.011
% E from fruits & vegetables, overweight	1.002	0.986, 1.018	1.003	0.986, 1.020	0.982	0.961, 1.004	0.998	0.981, 1.014	1.003	0.987, 1.019	0.998	0.982, 1.015
% E from fruits & vegetables, obesity	0.984	0.968, 1.001	0.990	0.974, 1.007	0.966	0.938, 0.995	0.977	0.961, 0.994	0.987	0.971, 1.004	0.980	0.964, 0.99)
Total energy density, kcal/g, overweight	0.670	0.487, 0.923	0.657	0.471, 0.917	1.039	0.645, 1.674	1.013	0.700, 1.464	0.685	0.496, 0.947	1.013	0.699, 1.467
Total energy density, kcal/g, obesity	0.709	0.495, 1.016	0.701	0.480, 1.023	2.453	1.385, 4.344	1.758	1.131, 2.731	0.774	0.537, 1.115	1.773	1.136, 2.769
Food-based energy density, kcal/g, overweight	1.073	0.930, 1.237	1.059	0.917, 1.222	1.314	1.064, 1.622	1.151	0.993, 1.334	1.063	0.922, 1.225	1.141	0.985, 1.321
Food-based energy density, kcal/g, obesity	1.273	1.093, 1.482	1.193	1.016, 1.399	1.727	1.360, 2.195	1.444	1.231, 1.695	1.238	1.059, 1.448	1.403	1.192, 1.650

%E, % of Energy intake; 95%CI, 95% Confidence interval; OR, Odds ratio.

*Estimates are weighted and variances are bootstrapped using the Balance Repeated Replication technique

†For the propensity score, 0.01 unit offset from mean was chosen due to its small scale and for the energy intake a 100-unit offset from mean was considered. All other continuous variables were assessed based on 1-unit offset from the mean

‡Under-reporters: Individuals whose energy intake (EI) was less than 70% of their estimated energy requirement (EER); Plausible reporters: Individuals whose EI was between 70% and 142% of their EER; Over-reporters: Individuals whose EI was more than 142% of their EER

§Model I: Weighted multinominal logistic regression adjusted for age and sex

ǁModel II: Model I additionally adjusted for physical activity, having a chronic disease, province of residence, highest household education, self-reported health, and smoking status

¶Model III: Basic model but excluding under-reporters and over-reporters

**Model IV: Basic model adjusted for the reporting groups (under-reporters, plausible reporters, over-reporters)

[††]Model V: Basic model adjusted for propensity score
[‡‡]Model VI: Basic model adjusted for both propensity score and the reporting group

Table 4.5. Association between overweight and obesity with dietary determinants of obesity as set by the World Health Organization (WHO) in different models stratified by the reporting group among Canadian adults (≥18 years)[*,†]

Dietary variables	**Stratification (Model VII)[‡]**						**Stratification and adjustment for propensity score (Model VIII)[§]**					
	Under-reporter (n=3847)		**Plausible reporter (n=6725)**		**Over-reporter (n=1176)**		**Under-reporter (n=3847)**		**Plausible reporter (n=6725)**		**Over-reporter (n=1176)**	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Energy intake (1 unit=100 kcal), overweight	1.044	0.990,1.101	1.045	1.021,1.070	1.046	1.006,1.088	1.047	0.993,1.105	1.046	1.021,1.071	1.046	1.005,1.088
Energy intake (1 unit=100 kcal), obesity	1.154	1.094,1.217	1.139	1.108,1.171	1.083	1.023,1.147	1.156	1.097,1.219	1.141	1.109,1.174	1.085	1.027,1.147
Fiber density, g/1000 kcal, overweight	0.997	0.953,1.044	0.980	0.952,1.009	1.070	0.980,1.168	1.000	0.956,1.046	0.980	0.952,1.009	1.070	0.979,1.168
Fiber density, g/1000 kcal, obesity	0.959	0.919,1.001	0.933	0.898,0.969	0.941	0.796,1.114	0.963	0.925,1.004	0.933	0.899,0.969	0.951	0.817,1.108
%E from solid fat and added sugar (SoFAS), overweight	0.991	0.982,1.001	1.011	1.003,1.019	0.992	0.977,1.007	0.991	0.981,1.000	1.011	1.003,1.019	0.992	0.977,1.008
%E from solid fat and added sugar (SoFAS), obesity	0.994	0.985,1.004	1.012	1.004,1.020	1.022	1.002,1.042	0.993	0.984,1.002	1.011	1.003,1.019	1.020	1.000,1.040
% E from fruits & vegetables, overweight	1.014	0.987,1.043	0.982	0.961,1.004	0.999	0.944,1.056	1.016	0.989,1.044	0.983	0.962,1.004	0.997	0.941,1.055
% E from fruits & vegetables, obesity	0.994	0.972,1.017	0.966	0.938,0.995	0.834	0.736,0.944	0.997	0.976,1.020	0.969	0.941,0.998	0.842	0.745,0.952
Total energy density, kcal/g, overweight	0.574	0.242,1.359	1.039	0.645,1.674	2.189	0.831,5.765	0.580	0.245,1.371	1.039	0.643,1.679	2.197	0.825,5.851
Total energy density, kcal/g, obesity	0.689	0.332,1.430	2.453	1.385,4.344	3.576	0.959,13.34	0.701	0.340,1.444	2.461	1.378,4.394	3.460)	0.949,12.613
Food-based energy density, kcal/g, overweight	0.926	0.706,1.213	1.314	1.064,1.622	1.073	0.664,1.734	0.908	0.696,1.185	1.307	1.059,1.614	1.093	0.674,1.773
Food-based energy density, kcal/g, obesity	1.062	0.829,1.361	1.727	1.360,2.195	2.206	1.423,3.418	1.032	0.809,1.317	1.679	1.314,2.146	2.023	1.300,3.148

%E, % of Energy intake; 95%CI, 95% Confidence interval; OR, Odds ratio.

[*]Estimates are weighted and variances are bootstrapped using the Balance Repeated Replication technique

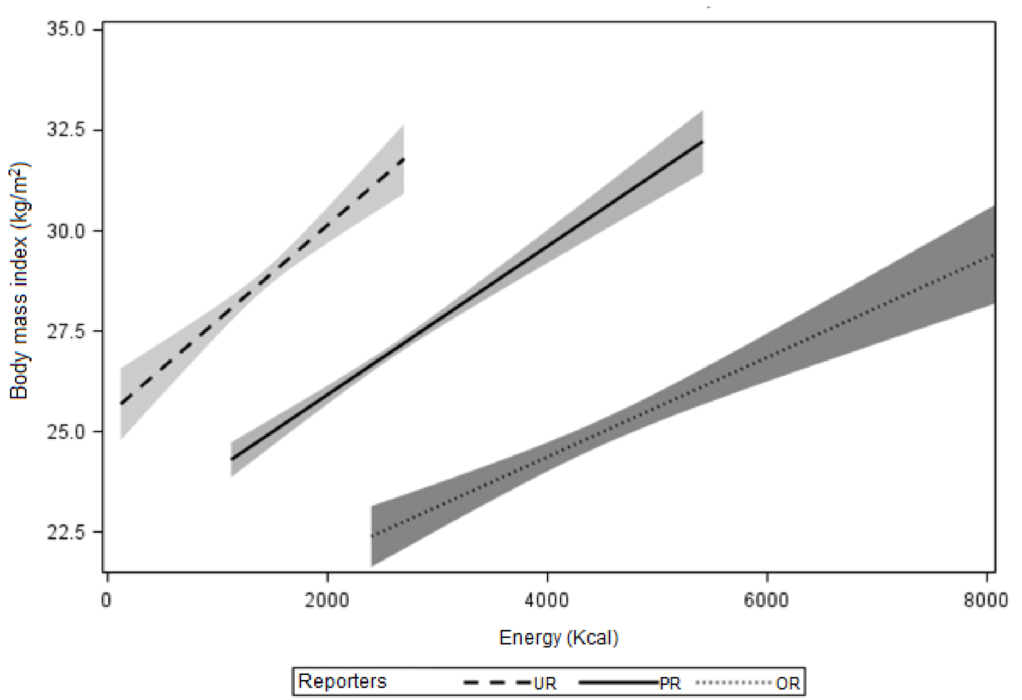
[†]Under-reporters: Individuals whose energy intake (EI) was less than 70% of their estimated energy requirement (EER); Plausible reporters: Individuals whose EI was between 70% and 142% of their EER; Over-reporters: Individuals whose EI was more than 142% of their EER

[‡]Basic model (adjusted for age and sex) stratified by underreporting, plausible reporting and over-reporting

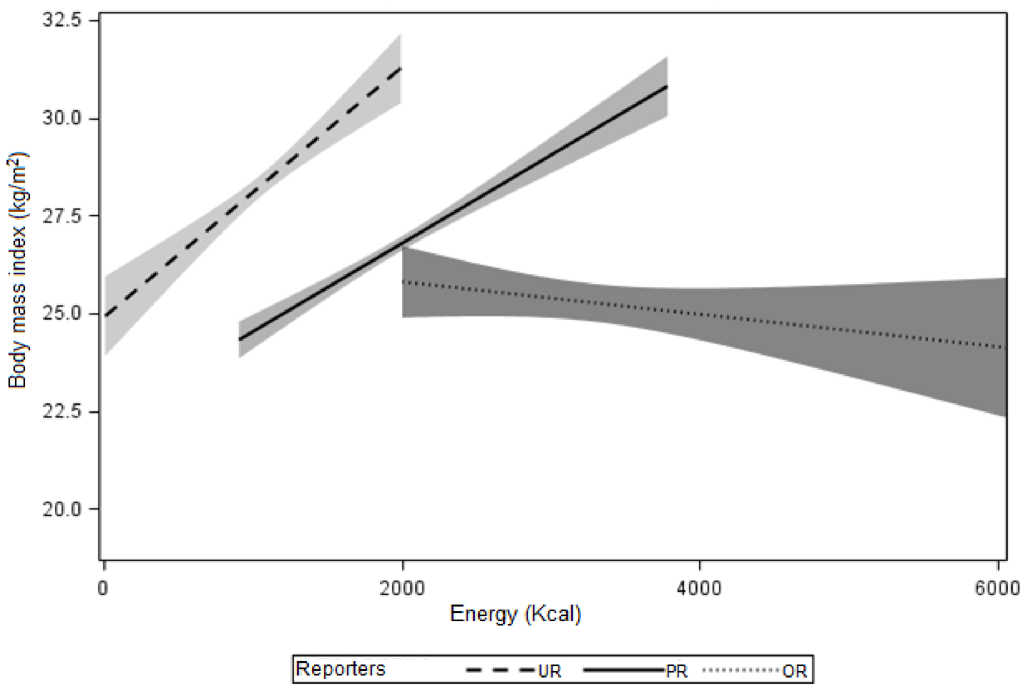
[§]Basic model (adjusted for age and sex) additionally adjusted for the propensity score and stratified by underreporting, plausible reporting and over-reporting

Figure 4.1. The relationship between energy intake (EI) and Body Mass Index (BMI) among under-reporters, plausible reporters and over-reporters Canadian adults (≥18 years) and adolescents (12-17 years)[*,†]

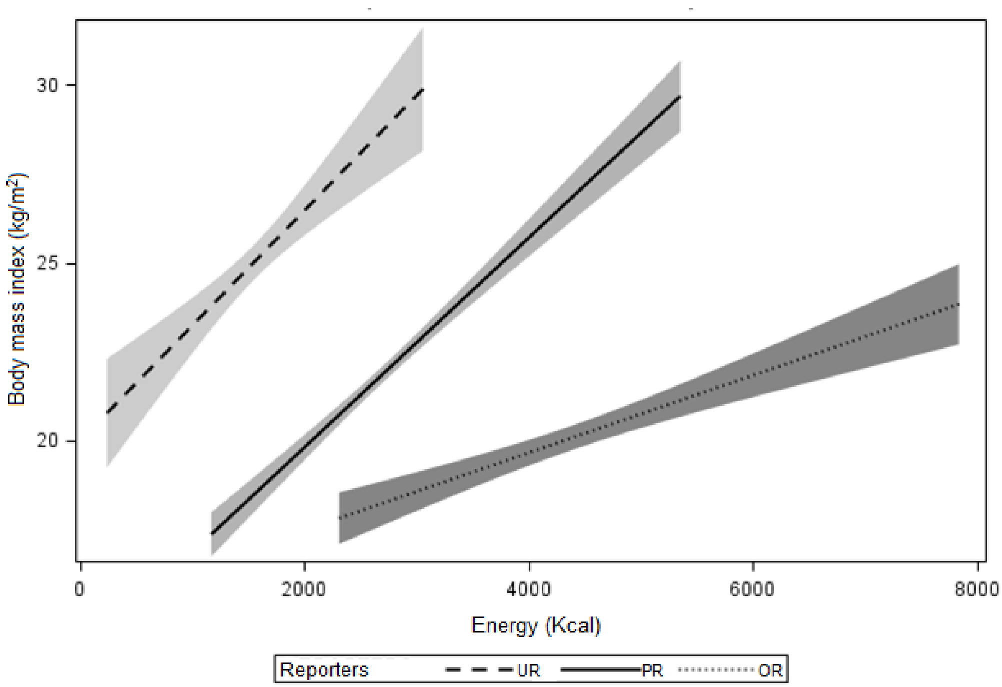
a) Adult males



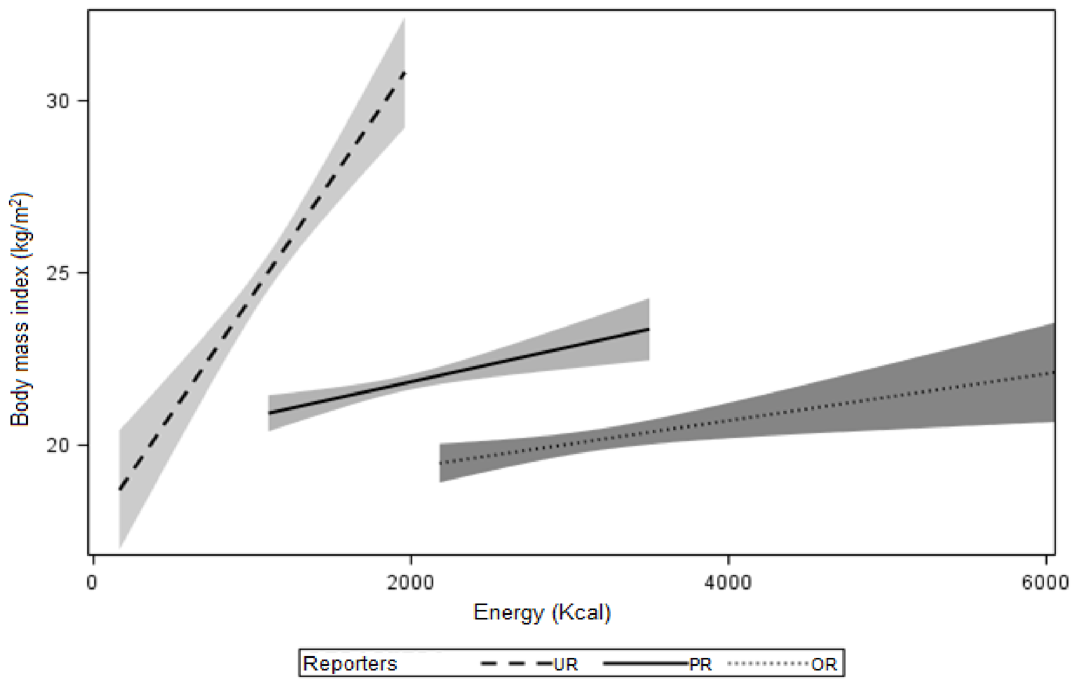
b) Adult females



c) Adolescent males

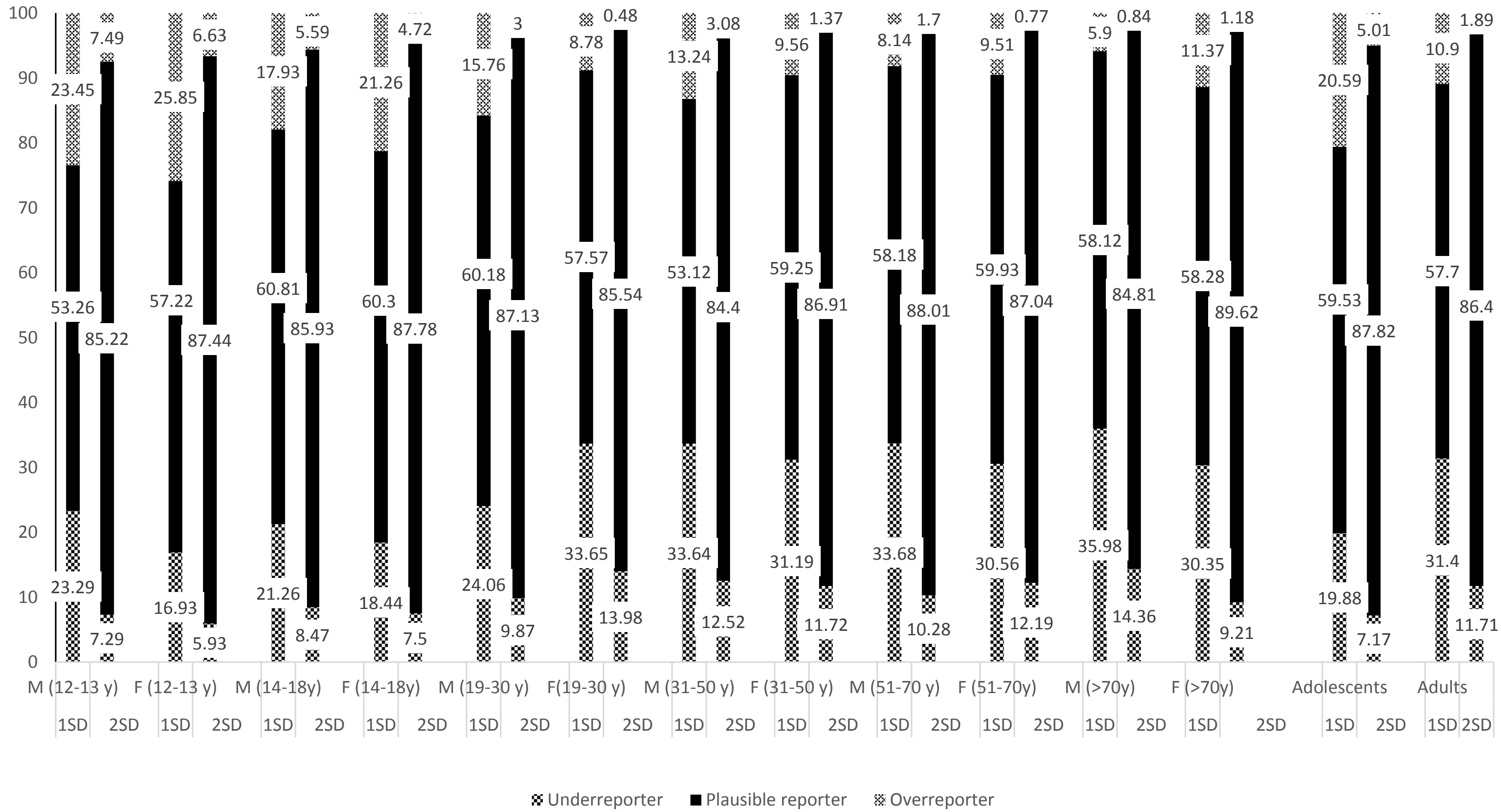


d) Adolescent females



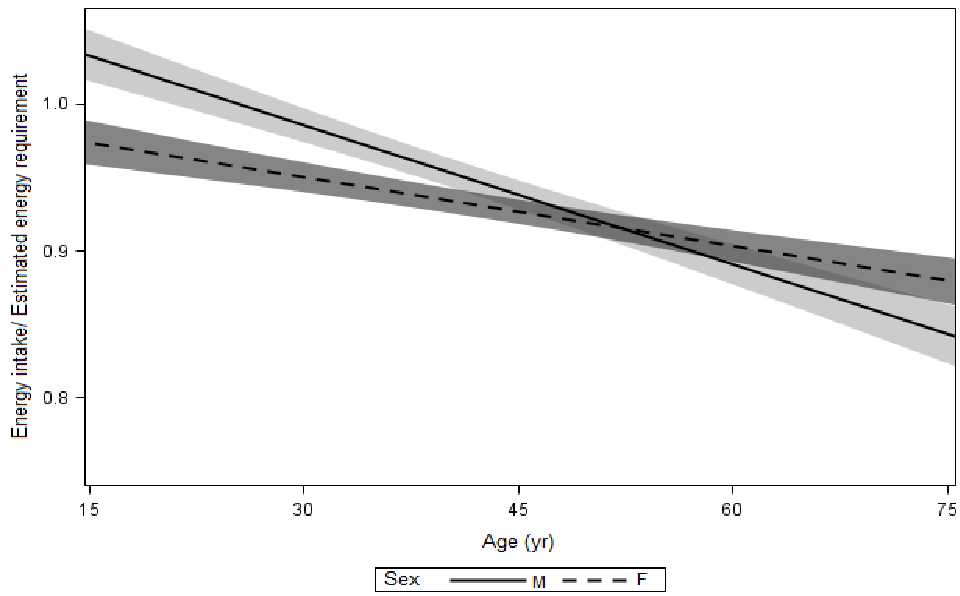
OR, over-reporter; PR, Plausible reporter; UR, Under-reporter.
*Estimates are weighted and variances are bootstrapped using the Balance Repeated Replication technique
†±1SD cut-off for plausible reporting: 0.7≤Energy Intake (EI)/Estimated Energy Requirement (EER)≤1.42

Supplementary Figure 4.1. Weighted prevalence of underreporting, plausible reporting, and over-reporting by dietary reference intake (DRI) age and sex categories using the ±1SD and ±2SD cut-off points for identifying misreporters (side-by-side comparison) among Canadians ≥12 years*



F, Females; M, Males. *±1SD cut-off for plausible reporting: 0.7≤Energy Intake (EI)/Estimated Energy Requirement (EER)≤1.42 ; ±2SD cut-off for plausible reporting: 0.5≤EI/EER≤ 1.98

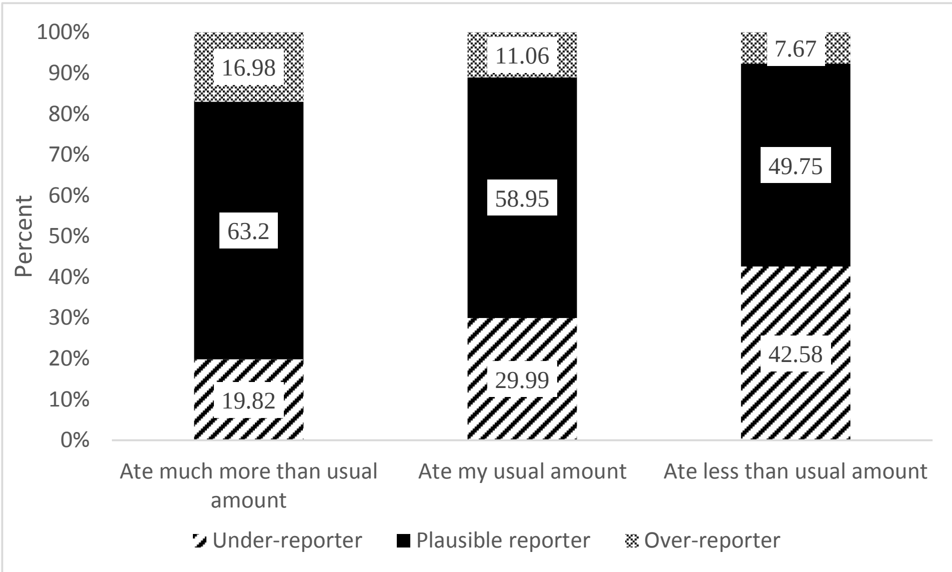
Supplementary Figure 4.2. The association of age with the ratio of Energy intake (EI) to estimated energy requirement (EER) by sex among Canadians ≥ 12 years*



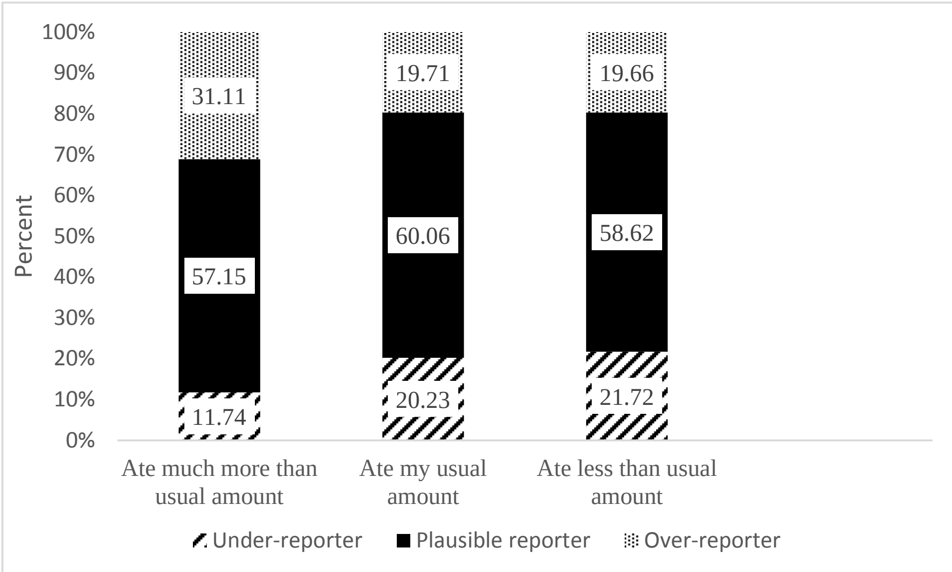
F, Females; M, Males.*Estimates are weighted and variances are bootstrapped using the Balance Repeated Replication technique

Supplementary Figure 4.3. Agreement of self-assessed validity of dietary intakes (subjective) and intakes assessed using the ±1SD cut-off point for misreporting (objective)[*,†]

a) Adults



b) Adolescents



*Estimates are weighted. †±1SD cut-off for plausible reporting: 0.7≤Energy Intake (EI)/Estimated Energy Requirement (EER)≤1.42

Supplementary Table 4.1. Descriptive weighted analysis of covariates (row percentages) stratified by the reporting group (differential misreporting) among Canadian adolescents (12-17 years) (n=3974)[*,†,‡]

Characteristics	**Under-reporters[§]**		**Plausible reporters[ǁ]**		**Over-reporters[¶]**		**P-value**
	Weighted Mean/ %	**SE**	**Weighted Mean/ %**	**SE**	**Weighted Mean/ %**	**SE**	
Sex ,%							
Males	21.68	1.52	60.06	1.80	18.25	1.47	0.078
Females	18.19	1.46	58.96	2.05	22.85	1.71	
Age, yr	14.56	0.12	14.47	0.07	14.20	0.11	0.060
Body mass index, kg/m^2	25.05	0.31	21.86	0.16	20.13	0.19	<0.0001
Physical activity ,%							
Inactive	15.88	3.58	51.20	5.49	32.92	5.64	0.0008
Moderately active	18.85	1.16	60.58	1.49	20.57	1.30	
High/very highly active	25.15	2.33	59.09	2.62	15.77	1.93	
Province of residence ,%							
NFLD,PEI,NS,NB	25.56	2.91	56.47	3.03	17.97	2.09	<0.0001
QC	12.46	2.01	55.93	3.47	31.61	3.44	
ON	21.49	1.83	60.54	2.03	17.97	1.62	
MB,SK	20.18	1.93	61.19	2.44	18.64	1.97	
AB	21.69	3.06	66.34	3.45	11.97	2.86	
BC	24.21	2.98	57.91	3.25	17.88	2.62	
Highest household education ,%							
<Secondary education	21.36	4.55	58.57	5.66	20.06	5.09	0.088
Secondary education	24.43	3.03	60.98	3.50	14.59	2.65	
Some post-secondary education	18.94	3.78	68.06	4.57	13.00	2.73	
Post-secondary education	19.41	1.21	58.42	1.52	22.17	1.34	
Income adequacy ,%							
Lowest	30.76	5.24	47.36	4.96	21.89	4.08	0.029
Lower middle	19.28	2.43	56.90	3.43	23.82	3.13	
Upper middle	20.02	1.81	58.36	2.28	21.63	2.17	
Highest	17.25	1.91	63.74	2.53	19.01	2.07	
N/S	19.82	2.17	64.06	3.03	16.12	2.48	
Drank alcohol in past 12 months ,%							
Yes	21.61	1.63	61.87	1.91	16.53	1.44	0.009
No	19.09	1.27	58.15	1.60	22.76	1.53	
Immigration status ,%							
Canadian born	20.13	1.10	59.77	1.33	20.10	1.15	0.625
Immigrant	18.93	3.94	56.90	5.38	24.17	5.06	
Smoking status ,%							

Daily	24.62	5.29	56.42	5.77	18.96	3.74	0.596
Occasional	23.62	6.02	50.41	7.49	25.97	8.16	
Former	28.95	8.08	49.39	8.61	21.67	7.22	
Never smoked	19.46	1.06	60.28	1.30	20.26	1.17	
Self-perceived health status ,%							
Poor/fair	28.85	5.21	58.02	5.61	13.13	3.98	0.003
Good	27.32	2.65	53.30	3.08	19.38	2.44	
Very good	17.29	1.39	62.23	2.00	20.48	1.87	
Excellent	16.55	2.12	60.96	2.52	22.49	2.08	
Aboriginal of North America ,%							
Yes	27.48	6.39	55.73	7.00	16.79	4.40	0.431
No	19.89	1.03	59.61	1.26	20.50	1.12	

AB, Alberta; BC, British Columbia; MB, Manitoba; NB, New Brunswick; NFLD, Newfoundland; NS, Nova Scotia; ON, Ontario; PEI, Prince Edward Island; QC, Quebec; SE, Standard Error; SK, Saskatchewan

[*]Estimates are weighted means and bootstrapped variances (Balanced Repeated Replication technique)

[†]For adolescents 12-17 years of age, Cole et al.'s categories was used to define obesity (101)

[‡]The following variables are only presented in adults due to either having small frequencies or not being applicable to adolescents: self-reported diabetes, self-reported hypertension, self-reported heart disease, having at least one chronic condition, marital status, and self-perceived level of stress.

[§]Under-reporters: Individuals whose energy intake (EI) was less than 70% of their estimated energy requirement (EER)

[‖]Plausible reporters: Individuals whose EI was between 70% and 142% of their EER

[¶]Over-reporters: Individuals whose EI was more than 142% of their EER

Supplementary Table 4.2. Association between overweight and obesity risk with dietary determinants of obesity as set by the World Health Organization (WHO) among Canadian adolescents (12-17 years)[*,†,‡,§]

Dietary Variables	Basic model (n=3974) (Model I)[ǁ]		Basic model adjusted for covariates (n=3974) (Model II)[¶]		Excluding misreporters (n=2380) (Model III)[**]		Adjusting for the reporting group (n=3974) (Model IV)[††]		Adjusting for propensity score (n=3974) (Model V)[‡‡]		Adjusting for the reporting group and propensity score (n=3974) (Model VI)[§§]	
	OR	**95%CI**	**OR**	**95%CI**	**OR**	**95%CI**	**OR**	**95%CI**	**OR**	**95%CI**	**OR**	**95%CI**
Energy intake (1 unit=100 kcal), overweight	0.979	0.964, 0.994	0.980	0.964, 0.995	1.077	1.044, 1.110	1.068	1.045, 1.092	0.982	0.967, 0.996	1.069	1.045, 1.093
Energy intake (1 unit=100 kcal), obesity	0.960	0.940, 0.980	0.964	0.944, 0.984	1.132	1.091, 1.175	1.084	1.049, 1.120	0.964	0.945, 0.984	1.084	1.049, 1.121
Fiber density, g/1000kcal, overweight	0.998	0.955, 1.043	0.999	0.954, 1.047	0.942	0.890, 0.996	0.978	0.938, 1.020	0.999	0.956, 1.044	0.980	0.939, 1.022
Fiber density, g/1000kcal, obesity	0.987	0.931, 1.046	1.004	0.950, 1.060	0.935	0.815, 1.072	0.958	0.901, 1.019	0.990	0.932, 1.051	0.961	0.903, 1.024
%E from solid fat and added sugar (SoFAS), overweight	1.002	0.996, 1.009	1.002	0.995, 1.009	1.007	0.998, 1.017	1.005	0.998, 1.012	1.002	0.995, 1.008	1.004	0.998, 1.011
%E from solid fat and added sugar (SoFAS), obesity	0.994	0.985, 1.003	0.993	0.982, 1.003	1.006	0.992, 1.021	0.998	0.988, 1.008	0.993	0.983, 1.002	0.996	0.986, 1.006
% E from fruits & vegetables, overweight	0.988	0.958, 1.020	0.988	0.957, 1.020	0.981	0.941, 1.023	0.982	0.952, 1.012	0.991	0.960, 1.022	0.983	0.954, 1.013
% E from fruits & vegetables, obesity	0.961	0.922, 1.001	0.974	0.936, 1.013	0.974	0.914, 1.039	0.955	0.919, 0.992	0.966	0.928, 1.006	0.959	0.922, 0.997
Total energy density, kcal/g, overweight	0.408	0.252, 0.661	0.416	0.248, 0.697	0.600	0.299, 1.204	0.807	0.500, 1.303	0.432	0.266, 0.701	0.817	0.506, 1.317
Total energy density, kcal/g, obesity	0.311	0.160, 0.602	0.263	0.128, 0.543	0.914	0.356, 2.347	0.892	0.502, 1.586	0.344	0.180, 0.660	0.909	0.514, 1.610
Food-based energy density, kcal/g, overweight	1.021	0.832, 1.252)	0.988	0.796, 1.227	1.218	0.935, 1.587	1.100	0.899, 1.347	1.006	0.817, 1.238	1.088	0.885, 1.338
Food-based energy density, kcal/g, obesity	0.874	0.682, 1.119	0.816	0.627, 1.061	1.223	0.838, 1.786	0.969	0.768, 1.221	0.854	0.670, 1.090	0.951	0.756, 1.195

%E, % of Energy intake; 95%CI, 95% Confidence interval; OR, Odds ratio.

[*]Estimates are weighted and variances are bootstrapped using the Balance Repeated Replication technique

[†]For adolescents 12-17 years of age, Cole et al.'s categories was used to define obesity (101)

[‡]For the propensity score, 0.01 unit offset from mean was chosen due to its small scale and for the energy intake a 100-unit offset from mean was considered. All other continuous variables were assessed based on 1-unit offset from the mean

[§]Under-reporters: Individuals whose energy intake (EI) was less than 70% of their estimated energy requirement (EER); Plausible reporters: Individuals whose EI was between 70% and 142% of their EER; Over-reporters: Individuals whose EI was more than 142% of their EER

[ǁ]Model I: Weighted multinominal logistic regression adjusted for age and sex

[¶]Model II: Model I additionally adjusted for physical activity, drinking alcohol in the past 12 months, highest household education, self-reported health, smoking status, province of residence, and income adequacy

[**]Model III: Basic model but excluding under-reporters and over-reporters
[††]Model IV: Basic model adjusted for the reporting groups (under-reporters, plausible reporters, over-reporters)
[‡‡]Model V: Basic model adjusted for propensity score
[§§]Model VI: Basic model adjusted for both propensity score and the reporting group

Supplementary Table 4.3. Association between overweight and obesity with dietary determinants of obesity as set by the World Health Organization (WHO) in different models stratified by the reporting group among Canadian adolescents (12-17 years)[*,†,‡]

Dietary variables	Stratification (Model VII)[§]						Stratification and adjustment for propensity score (Model VIII)[ǁ]					
	Under-reporter (n=861)		Plausible reporter (n=2380)		Over-reporter (n=733)		Under-reporter (n=861)		Plausible reporter (n=2380)		Over-reporter (n=733)	
	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
Energy intake (1 unit=100 kcal), overweight	1.114	1.037,1.197	1.077	1.044,1.110	1.059	1.019,1.100	1.114	1.036,1.197	1.078	1.046,1.112	1.058	1.019,1.100
Energy intake (1 unit=100 kcal), obesity	1.172	1.071,1.283	1.132	1.091,1.175	1.013	0.944,1.088	1.175	1.072,1.287	1.136	1.095,1.177	1.013	0.946,1.085
Fiber density, g/1000 kcal, overweight	1.044	0.967,1.128	0.942	0.890,0.996	0.947	0.824,1.088	1.044	0.966,1.129	0.945	0.894,0.999	0.943	0.820,1.083
Fiber density, g/1000 kcal, obesity	1.013	0.948,1.082	0.935	0.815,1.072	0.792	0.648,0.969	1.016	0.950,1.088	0.940	0.817,1.081	0.793	0.648,0.970
%E from solid fat and added sugar (SoFAS), overweight	0.994	0.983,1.007	1.007	0.998,1.017	1.016	1.000,1.033	0.995	0.982,1.007	1.006	0.997,1.016	1.017	1.001,1.033
%E from solid fat and added sugar (SoFAS), obesity	0.985	0.970,1.000	1.006	0.992,1.021	1.006	0.983,1.029	0.984	0.968,1.000	1.005	0.991,1.019	1.006	0.984,1.029
% E from fruits & vegetables, overweight	0.991	0.946,1.038	0.981	0.941,1.023	0.892	0.736,1.080	0.990	0.945,1.038	0.985	0.945,1.027	0.891	0.737,1.078
% E from fruits & vegetables, obesity	0.957	0.913,1.002	0.974	0.914,1.039	0.759	0.343,1.679	0.959	0.914,1.005	0.980	0.919,1.046	0.760	0.362,1.595
Total energy density, kcal/g, overweight	0.908	0.360,2.293	0.600	0.299,1.204	1.839	0.644,5.250	0.907	0.360,2.284	0.614	0.305,1.232	1.845	0.645,5.275
Total energy density, kcal/g, obesity	0.668	0.293,1.521	0.914	0.356,2.347	7.502	1.462,38.507	0.665	0.289,1.527	0.945	0.368,2.429	7.496	1.499,37.488
Food-based energy density, kcal/g overweight	0.736	0.506,1.071	1.218	0.935,1.587	1.926	1.159,3.203	0.737	0.503,1.082	1.194	0.917,1.556	1.918	1.127,3.261
Food-based energy density, kcal/g, obesity	0.654	0.460,0.930	1.223	0.838,1.786	1.467	0.766,2.807	0.645	0.453,0.918	1.191	0.821,1.728	1.455	0.717,2.955

%E, % of Energy intake; 95%CI, 95% Confidence interval; OR, Odds ratio.

[*]Estimates are weighted and variances are bootstrapped using the Balance Repeated Replication technique

[†]For adolescents 12-17 years of age, Cole et al.'s categories was used to define obesity (107)

[‡]Under-reporters: Individuals whose energy intake (EI) was less than 70% of their estimated energy requirement (EER); Plausible reporters: Individuals whose EI was between 70% and 142% of their EER; Over-reporters: Individuals whose EI was more than 142% of their EER

[§]Basic model (adjusted for age and sex) stratified by underreporting, plausible reporting and over-reporting

[ǁ]Basic model (adjusted for age and sex) additionally adjusted for the propensity score and stratified by underreporting, plausible reporting and over-reporting

Phase II

Dietary Pattern Analyses

Phase II project is the main focus of this thesis and was aimed at providing the first evidence-base required for informing the next Canadian food guide and nutritional policies through comprehensive dietary pattern analyses using different methods at the national population level. All analyses in Phase II were additionally adjusted for the potential misreporting bias as described in Phase I, to ensure results would not be influenced by differential systematic measurement errors.

Chapter 5

5 Study #2: Assessing the Nutritional Quality of Diets of Canadian Adults Using the 2014 Health Canada Surveillance Tool Tier System

This manuscript has been published (126): Jessri M, Nishi SK, L'Abbé MR. Assessing the Nutritional Quality of Diets of Canadian Adults Using the 2014 Health Canada Surveillance Tool Tier System. Nutrients. 2015 Dec 12;7(12):10447-68. doi: 10.3390/nu7125543. Available from: http://www.mdpi.com/2072-6643/7/12/5543

This study addressed the objective #2 of my thesis, to:

- Evaluate the associations between adherence to the only Canadian *a priori* index, Health Canada's Surveillance Tool Tier System (HCST) 2014, and diet quality and obesity risk among participants of the CCHS 2.2

Student's contribution:

I conceived and designed the original study and reviewed the idea with my supervisor, Dr. Mary L'Abbe. I performed all coding for this project, ran the analyses at the Research Data Center (RDC) of Statistics Canada, prepared data tables, and led drafting of the manuscript. I completed the original interpretation of results and revised the final manuscript based on the reviewers' comments, which was eventually published in the "*Nutrients*" journal. Due to the extensive number of analyses (for each DRI age/gender group for children, adolescents and adults), S. Nishi was hired to help with running the codes at the RDC. This allowed us to also analyze and publish the results for children and adolescents in the BMC Public Health, which is not included in this thesis on account of room (127): Jessri M, Nishi SK, L'Abbe MR. Assessing the nutritional quality of diets of Canadian children and adolescents using the 2014 Health Canada Surveillance Tool Tier System. BMC Public Health. 2016 May 10;16:381. doi: 10.1186/s12889-016-3038-5. Available from: http://www.biomedcentral.com/1471-2458/16/381/prepub

5.1 Abstract

The 2014 Health Canada Surveillance Tool (HCST) was developed to assess adherence of dietary intakes with Canada's Food Guide. HCST classifies foods into one of four Tiers based on thresholds for sodium, total fat, saturated fat and sugar, with Tier 1 representing the healthiest and Tier 4 foods being the unhealthiest. This study presents the first application of HCST to assess (a) dietary patterns of Canadians; and (b) applicability of this tool as a measure of diet quality among 19,912 adult participants of Canadian Community Health Survey 2.2. Findings indicated that even though most of processed meats and potatoes were Tier 4, the majority of reported foods in general were categorized as Tiers 2 and 3 due to the adjustable lenient criteria used in HCST. Moving from the 1st to the 4th quartile of Tier 4 and "other" foods/beverages, there was a significant trend towards increased calories (1876 kcal *vs.* 2290 kcal) and "harmful" nutrients (e.g., sodium) as well as decreased "beneficial" nutrients. Compliance with the HCST was not associated with lower body mass index. Future nutrient profiling systems need to incorporate both "positive" and "negative" nutrients, an overall score and a wider range of nutrient thresholds to better capture food product differences.

Keywords: 2014 Health Canada Surveillance Tool Tier system; nutrient profiling; nutritional quality; adults; Canadians

5.2 Introduction

The World Health Organization (WHO), as well as several other international health authorities and regulatory bodies, are developing and supporting the implementation of various "nutrient (or nutritional) profiling" approaches to assess the healthfulness of foods for a wide variety of applications, which may be associated with improved health (128-135). Nutrient profiling is designed to globally evaluate the healthfulness of food products, based on transparent nutritional composition criteria (128). Common applications of nutrient profiling include the regulation of front of pack food labeling, health and nutrition claims and food procurement for public institutions (such as schools and hospitals) (128). With the development in 2014 of Health Canada Surveillance Tool (HCST) (73), the first Canadian nutrient profiling system, there is a potential to broaden the scope of nutrient profiling to assess dietary patterns at a population level. However, this approach has yet to be applied to the dietary intakes of Canadian adults to assess its applicability and relevance.

The HCST aims to assess the food intakes of Canadians relative to the guidance provided by Eating Well with Canada's Food Guide (EWCFG) (26), based on the classification of foods in the Canadian Nutrient File (CNF) (73, 100). The HCST is the first government-developed nutrient profiling system in Canada and evaluates Canadians' adherence to EWCFG in terms of amount and type of foods (*i.e.*, number of servings from each food group, and within these, the quality of food choices) (73). Details regarding this tool have been previously reported by Health Canada (73). Generally, HCST is a categorical nutrient profiling system that classifies foods within each food group into four Tiers according to their adherence with EWCFG recommendations (73). The HCST system can then be used to assess Canadians' eating patterns, based on the proportion of food choices that fall within each Tier (73). The objectives of the present study were to: (a) assess the quantity and quality of food choices of Canadian adults relative to the HCST Tier system using the Canadian national nutrition survey, and (b) evaluate the applicability and relevance of the HCST as a dietary assessment tool on a population basis.

5.3 Experimental Section

Data from the Canadian Community Health Survey (CCHS) cycle 2.2, was used for this study, which was collected under the authority of the Statistics Act of Canada (2004/5) (96, 97). All data analyses were performed at the Research Data Center of Statistics Canada. The CCHS 2.2 is a multi-stage stratified population-based survey with cluster design, which provides the latest and most complete national nutrition data since the Nutrition Canada Survey conducted in 1972 (96). The sampling method was designed to be representative of the Canadian population (>98%) in terms of age, sex, geography, and socioeconomic status. The CCHS 2.2 includes cross-sectional nutrition and health data for 35,107 Canadians of all ages from 10 provinces (96). For the present analysis, we excluded Canadians aged <19 years, pregnant and breastfeeding women, and those with invalid/missing dietary recalls (according to Statistics Canada), leaving a final sample of 19,912 adults. Invalid/missing dietary recalls were defined by Statistics Canada as those with extreme portion sizes and nutrient amounts or with incomplete meals and interviews (30). Additionally, for evaluation of the applicability and relevance of the Tier system (Objective 2), respondents with missing energy intake, height, weight, and physical activity measures were excluded (final sample: 11,538).

5.3.1 Data collection and preparation

Detailed 24-h dietary recall data were obtained using a modified version of the 5-step US Department of Agriculture (USDA) Automated Multiple Pass Method (AMPM) (98). Energy and nutrient composition information for reported foods were derived from Health Canada's CNF (2001b supplement) (100), which is based on the USDA Nutrient Database for Standard Reference (136) modified to reflect the Canadian food supply and fortifications. Computer-assisted interviews were conducted during all months throughout the year and on all days of the week (96).

Glycemic index (GI) values were determined using the published International GI table values (137, 138), which were assigned to each of the Bureau of Nutritional Sciences (BNS) food categories (139) using the procedures proposed by Louie *et al.* and Flood *et al.* (140, 141). Following this method, a BNS group was matched with its corresponding GI; however, if there was no direct match, the GI of a closely-related category was assigned (140, 141). Glycemic load was calculated by multiplying the glycemic index value by the number of grams of carbohydrate then dividing by 100 (137, 138). Energy density of the consumed foods (excluding beverages) was calculated by dividing the total energy from foods (kilocalories) by the total food weight (in grams) (106-108). To reduce extraneous variability and confounding effects, all nutritional analyses were performed in terms of energy intake (using nutrient density approach) (142) and not the absolute amount. In the nutrient density approach, nutrients are expressed per 1000 kcal, and are determined by dividing the amount of the specific nutrient consumed by total energy intake and multiplying by 1000 (142).

As per the procedures of the CCHS 2.2, trained interviewers measured height and weight in person, and body mass index (BMI) was then calculated dividing the weight in kg by the square of height in meters (96). Respondents were asked about leisure time physical activity during the past 3 months, and socio-demographic and lifestyle behaviours, such as smoking status, and alcohol consumption (96). All descriptive analyses in this study were stratified by the Institute of Medicine (IOM) Dietary Reference Intakes (DRI) age and sex categories to allow for comparison with national recommendations (112).

5.3.2 Application of the HCST Tier System to dietary recalls

5.3.2.1 Foods recommended in the EWCFG

The HCST assesses Canadians' adherence to EWCFG in terms of amount and type of foods consumed (73). Foods in the CNF were first classified according to the four EWCFG food groups (*i.e.*, Vegetables and Fruits; Grain Products; Milk and Alternatives; Meat and

Alternatives); and "other" foods and beverages recommended in EWCFG (*i.e.*, water, and vegetable oil). The four main EWCFG food groups were additionally categorized into 21 subgroups (e.g., subgroups within the Vegetable and Fruits food group: dark green vegetables, deep yellow or orange vegetables, potatoes, other vegetables, vegetable juice and cocktail, fruits other than juice, and fruit juice) (73). Within each subgroup of the four EWCFG food groups, foods were then categorized into one of four Tiers (Supplementary Table 5.1), based on: (1) placement of foods according to EWCFG guidance on total fat, saturated fat, sugars, and sodium (Step 1); and (2) adjustments according to other EWCFG guidance (Step 2) (73). In general, foods classified as Tier 1 and Tier 2 are considered "foods in line with EWCFG guidance", Tier 3 foods are "partially in line with EWCFG guidance", while foods in Tier 4 are described as "foods that are not in line with EWCFG guidance" (Supplementary Table 5.1). A detailed description of the food groups and subgroups classified by HCST has been published previously and is briefly explained below (73).

Step 1: Tier 1 foods are those that do not exceed any of the three lower thresholds for total fat ($\leq$3 g/reference amount (RA)), sugars ($\leq$6 g/RA), and sodium ($\leq$140 mg/RA) (73). The reference amount (RA) provides a standardized basis for a specific food category, and typically is the quantity of a type of food usually eaten by an individual in one sitting (73). On the other hand, the upper threshold levels of the HCST include: total fat (>10 g/RA), sugars (>19 g/RA), sodium (>360 mg/RA) and saturated fat (>2 g/RA). Foods within Tier 4 exceed at least two upper threshold levels for total fat, sugars, sodium and saturated fat; however, higher exceptions are made for the Milk and Alternatives and Meat and Alternatives food groups which have more inherent saturated fat (73). Tier 2 and 3 foods fall in between the Tier 1 and Tier 4 foods in terms of healthfulness and nutrient content (73). Full details of the cut points and applications by food group are shown in Supplementary Table 5.1.

Step 2: Additional adjustments were made to reflect other guidance provided by EWCFG, including: consuming at least one dark green and one orange vegetable each day, and having meat alternatives such as beans, lentils and tofu often (73). Different subgroup codes for orange and green vegetables, as well as for legumes were used for this step after employing the thresholds for total fat, sodium, sugars, and saturated fat (73).

5.3.2.2 Foods not recommended in the EWCFG

Foods that were not among the four main EWCFG food groups and "other" foods and beverages recommended in the EWCFG (*i.e.*, water and vegetable oil) (26), were categorized into the "other" foods and beverages not recommended in the EWCFG, which were further grouped in one of the following subcategories (73): (a) saturated and/or trans fats and oils (e.g., butter); (b) high fat and/or high sugar foods (e.g., chocolate, candies, sauces, syrups); (c) high-calorie beverages (≥40 kcal/100 g) (e.g., sugar sweetened beverages); (d) low-calorie beverages (<40 kcal/100 g); (e) uncategorized (e.g., dehydrated and condensed soups, ingredients/seasoning and unprepared mixes); (f) meal replacements (e.g., instant breakfast) and supplements (e.g., energy bar); and (g) alcoholic beverages.

Generally, even though it is possible to estimate quantitates equivalent to the Food Guide servings for Tier 4 foods, according to the Health Canada HCST both Tier 4 foods and foods and beverages not included in EWCFG do not have "Food Guide Servings" and both are not in line with the national dietary guidance and therefore can be measured in terms of calories they contribute to the diet. As an example, most cakes, pastries, doughnuts and cookies are categorized as Tier 4 Grain Products, while chocolate and candies are categorized as "other" foods not recommended in Canada's Food Guide, both of which should be limited.

5.3.3 Definition of compliance to the HCST Tier System

Since the HCST does not provide a total sum score to represent compliance to the Tier system, we categorized individuals into quartiles based on the percentage of their energy intake from the Tier 4 foods and "other" foods/beverages that are not recommended in the EWCFG (26). We hypothesized that consumption of higher calories in form of Tier 4 foods and "other" foods and beverages would be associated with higher prevalence of overweight and obesity. Following this classification, individuals with the lowest percentage of energy from Tier 4 and “other” foods/beverages (quartile 1) were labelled as “compliers”, those in the interquartile ranges (quartiles 2 and 3) were “intermediates” and individuals with the highest percentage of energy from Tier 4 and “other” foods/beverages were defined as “non-compliers”. Lifestyle and nutritional characteristics of “compliers”, “intermediates” and “non-compliers” were then compared in order to evaluate the relevance and benefits of adhering to the HCST Tier system.

5.3.4 Identification of implausible reporters

Nutritional studies often rely on self-reported dietary intakes, which are prone to dietary under- and over-reporting (35, 91). Recently our group confirmed a widespread prevalence of energy misreporting with higher likelihood among obese individuals and those with chronic diseases (differential misreporting) among participants of the CCHS 2.2 (14). In addition, we observed higher likelihood of underreporting for foods that are socially undesirable (e.g., high in fat, added sugars and alcohol) (selective misreporting) (14). We also demonstrated that energy intake misreporting attenuates or reverses the association of dietary exposures with health outcomes; and that adjusting for the misreporting bias is an important consideration in nutritional surveys (14). In this study, each respondent was classified as under-reporter, plausible reporter or over-reporter by comparing their total Estimated Energy Requirement (EER) and reported energy intake (14, 23, 36). IOM factorial equations, established from a meta-analysis of studies measuring EER via doubly-labeled water, were used to calculate EER using participants’ age, sex, BMI, weight, height, and physical activity level (PAL) (112). Intervals for 4 different levels of physical activity were applied to the data for Canadian adults according to their reported physical activity levels (14, 23, 36). Individuals whose EI was less than 70% of their EER were categorized as under-reporters, while those whose EI was more than 142% of their EER were classified as over-reporters (±1 standard deviation) (14, 19, 23, 36). Participants whose EI was between 70% and 142% of their EER were classified as plausible reporters (14, 19). All nutrient profiling analyses in this research were additionally adjusted for the reporting status (under-reporters, plausible reporters, and over-reporters) to account for this systematic bias, as outlined and recommended in our previous study (14).

5.3.5 Statistical analyses

All statistical analyses were performed using the Statistical Analysis Software (SAS) (version 9.4; SAS Institute Inc., Cary, NC, USA). The bootstrap balanced repeated replication (BBR) method was used to account for the complex multistage survey design in estimation of all standard errors, coefficients of variation and Confidence Intervals (CI) (30, 113, 114). All analyses were adjusted for the complex CCHS 2.2 sampling design using appropriate sample weights based on respondent classes with similar socio-demographic characteristics, to maintain a nationally representative sample. Lifestyle and dietary intake characteristics were assessed within age and sex clustered categories by PROC SURVEYREG and PROC SURVEYLOGISTIC for continuous and categorical data, respectively. Group comparison with Tukey post-hoc adjustment was used to evaluate the characteristics of participants classified within DRI age and sex categories. Covariates included in the analysis were age, sex, and dietary recall misreporting status (*i.e.* under-reporter, plausible reporter, or over-reporter). Results with a two-tailed *p*-value <0.001 were considered statistically significant.

5.4 Results

5.4.1 Quantity of food consumption

Table 5.1 presents the number of servings from Tier 1 to 3 foods recommended in EWCFG based on the DRI age and sex groups, as well as total number of servings from all Tiers (*i.e.*, 1–4) for comparison, although Tier 4 foods do not have an EWCFG “Food Guide” serving according to Health Canada. Generally the pattern of food consumption choices was consistent across different age groups, even though choices among food groups ranged from healthy foods (Tier 1) to very poor food choices (Tier 4). A few differences, however, were noted.

Consumption of vegetables and fruits increased with age (except for a slight decrease among >70 years), especially among women who complied more with the EWCFG recommended number of servings. Within Milk and Alternatives, even though the mean servings were not significantly different between age groups, those over 51 years of age specifically failed to meet recommendations due to their higher requirements. This is even more concerning considering that the recent increase in vitamin D DRI recommendations has not yet been reflected in EWCFG despite Canada's more Northern latitude (27). On average, females consumed an equivalent of 0.2 servings of Meat and Alternatives from Tier 4, which is slightly lower compared to their male counterparts at approximately 0.3 servings. As illustrated in Table 5.2, calories from Tier 4 foods decreased significantly moving from the 19–30 to >70 years old in both males and females ($p < 0.001$). The mean sum of Tier 4 foods and "other" foods and beverages not recommended in EWCFG also decreased with age, comprising 31% and 29% of total calorie intakes in 19–30 year old males and females, compared to 25% and 21% of calories in >70 year old males and females, respectively ($p < 0.001$). The major contributors of "other" foods and beverages were high calorie beverages, high-fat and/or sugar foods, and saturated and/or trans fats and oils.

5.4.2 Quality of food consumption

The highest percentage of servings from Vegetables and Fruits (except for potatoes) consumed by both male and female Canadians were chosen from Tier 1 and 2 classified foods, while the majority of servings from processed meats and potatoes were contributed by Tier 4 foods (Figure 5.1a,b). The majority of servings from Grain products, Milk and Alternatives, and Meat and Alternatives subgroups were dominated by foods from Tier 2 and Tier 3. When additionally evaluated at the food product level (foods reported in the survey), 20.74% of Fruits and Vegetables, 65.97% of Grain Products, 70.01% of Milk and Alternatives, and 76.35% of Meat and Alternatives food products reported in the CCHS 2.2 were categorized as Tier 2 and 3 (Supplementary Table 5.2 and 5.3). In other words, only 24.22% and 6.52% of total food products reported in all 4 food groups met the criteria required to receive the Tier 1 or Tier 4 classification, respectively. In addition, for the products categorized as “other” foods and beverages not included in the EWCFG, the following were the most frequently reported items: ingredients/seasoning and unprepared foods, high fat and/or sugar foods, lower calorie beverages (<40 kcal/100g), and saturated and/or trans fats and oils. The percentage of calorie intake by Tier categories for each of the EWCFG food groups is presented in Figure 5.2a–h. As can be seen, within the vegetable group, potatoes (Tiers 1–4) and other vegetables Tier 1 comprised 82% of kilocalories (Figure 5.2b). About seventy percent of calories from the Grain Products group was contributed by enriched, non-whole grains, with only 16.15% coming from whole grains, which is well below the recommendation for 50% of Grain Products to be whole-grain (26) (Figure 5.2d). Considering meat products alone, (excluding alternatives), beef, game and organ meats Tier 3 (32.61%), poultry Tier 3 (15.92%), and processed meat Tier 4 (11.73%) made up 60.26% of the total calorie intake from the meat group (Figure 5.2f).

5.4.3 Diets High in Calories from Tier 4 and “Other” Foods/Beverages Are Not Associated with Obesity

As presented in Table 5.3, individuals in quartile 1 of calories from Tier 4 and “other” foods and beverages (compliers) were more likely to be older (*p*-trend < 0.0001), female (*p*-trend: 0.0175), physically active (*p*-trend: 0.0342), and non-smokers (*p*-trend < 0.0001) compared to the intermediate- and non-compliers.

However, there was no significant trend observed between more compliance to the HCST recommendations and BMI in the present study (*p*-trend: 0.3214). Additional regression analysis adjusted for age and sex did not reveal any significant associations (odds ratio for quartile 4 *vs.* quartile 1: 1.058 (0.799–1.397); quartile 3 *vs.* quartile 1: 1.047 (0.792–1.384); quartile 2 *vs.* quartile 1: 0.872 (0.646–1.176) (*p*-trend: 0.7053) (Supplementary Table 5.4).

5.4.4 Diets High in Calories from Tier 4 and "Other" Foods/Beverages Are Associated with a Lower Nutrient Dense Diet

The mean servings of EWCFG food subgroups per 1000 kcal among compliers (Q1), intermediate compliers (Q2 and Q3), and non-compliers is presented in Figure 5.3. After adjusting for age, sex and misreporting status, individuals in the highest quartile category of the percentage of energy from Tier 4 and "other" foods/beverages (non-compliers) consumed significantly higher servings of processed meat per 1000 kcal (0.18 ± 0.011) compared to those in the lowest quartile (0.12 ± 0.015) (*p*-trend < 0.0001). Similarly, mean servings per 1000 kcal of potatoes was higher among non-compliers, even though the p-trend did not reach the statistical significance level (*p*-trend: 0.1402). Generally, the mean servings of all Fruit, Vegetable (excluding potatoes), Milk and Alternatives, Grains Products (except for refined enriched grains), and Meat and Alternatives (excluding processed meats, fish, shellfish, egg) subgroups per 1000 kcal were significantly higher in the complier group compared to the non-compliers (Figure 5.3).

The nutrient intakes of compliers, intermediates and non-compliers reported in terms of energy density (142) and adjusted for age, sex and misreporting are presented in Table 5.4. Generally, compliers consumed significantly less energy (on average 415 kcal/day) compared to non-compliers (*p*-trend: <0.0001). Similarly, there was a significant trend towards increasing the percentage energy from fat, saturated fat, mono-unsaturated fat, poly-unsaturated fat, added sugars, and alcohol intake with less compliance to EWCFG guidance ($p < 0.0001$). In addition, the intakes of fiber, protein, vitamin A, vitamin D, all B-vitamins, and vitamin C decreased significantly moving from quartile 1 to 4, indicating that those consuming the most energy from Tier 4 and "other" foods and beverages (*i.e.*, non-compliers) have a less nutrient dense diet. Consumption of minerals, including calcium, phosphorus, potassium, magnesium, iron, and zinc, was significantly lower in the non-compliers compared to the intermediate and compliers

($p < 0.0001$). Similarly, glycemic index, and energy density were significantly higher in the non-complier group compared to the intermediates and compliers (p-trend <0.0001).

5.5 Discussion

The present study provides the first assessment of the 2014 HCST Tier system based upon national Canadian nutrition data. Assessment of eating habits using this nutrient profiling system revealed that the quality and quantity of Canadian adults' eating patterns are not meeting Health Canada's recommendations. Specifically, Canadian adults are not meeting Health Canada's recommended number of food group servings, and there is a high prevalence of consumption of Tier 4 classified foods among this population, especially Tier 4 processed meats and potatoes. Importantly, one-third of daily calories were consumed from Tier 4 and "other" food/beverage sources not recommended in the EWCFG. Using this nutrient profiling system, the majority of food choices of Canadians (except for vegetables and processed meats) were categorized as either Tiers 2 or 3, despite the large variation among the food items reported. This lack of specificity questions the validity of HCST and discriminative ability of its thresholds for use to evaluate national eating patterns. These findings may also justify the lack of significant associations between adherence to HCST and obesity among CCHS 2.2 participants. However, closer compliance to HCST system indicated increased probability of meeting DRI nutrient recommendations, which is expected since the HCST was developed to evaluate adherence to EWCFG, which itself is modeled based on achieving DRI recommendations (26). Similarly, since HCST is in line with EWCFG, it does not address recommendations for obesity and chronic disease prevention (27, 28), which may also explain lack of significant associations between HSCT compliance and obesity risk in this study.

In 2015, the World Health Organization (WHO) published a report developing a common nutrient profiling model for Europe based on review of existing nutrient profiling models (129), including those published by the governments of the United Kingdom, Australia and New

Zealand, and the United States (131, 135). The WHO model consists of 17 food categories with pre-defined thresholds for the contents of energy, total fat, saturated fat, total sugars, added sugars, and sodium to help authorities identify unhealthy foods (129). Compared to the HCST with 9 food categories, the WHO model consists of 17 food categories, even though both systems use pre-defined thresholds for classifying different foods (73, 129). The HCST food categories contain a large variation within each Tier subgroup due to the broad discrete definitions used for defining the thresholds for Tiers 1 and 4, and the lenient adjustable criteria used to categorize foods into Tiers 2 and 3 (73). In the present study, a consequence of HCST limitations was categorization of the majority of foods into Tiers 2 and 3, except for fruits and vegetables where the majority were classified as Tier 1 and 2 as well as processed meats, despite large product differences. As an example, foods categorized by the BNS Food Group Descriptions (139) as “jello, dessert toppings and pudding mixes-commercial” could fall within both Tier 2 and Tier 3 of the HCST. In addition, the limited range of thresholds in HCST results in a small percentage of products to be categorized as Tiers 1 or 4, especially in sub-groups such as fluid milk and fortified soy-based beverages and fruit juice, with more similarities among products. This is in contrast to the United Kingdom’s Ofcom Model, which calculates a total score for food items based on the total points for “negative” nutrients (energy, total sugar, saturated fat, and sodium) subtracted by points obtained for “positive” nutrients (fruits, vegetables and nuts, fiber, and protein) (131). Based upon the Ofcom model, the Nutrient Profiling Scoring Criterion (NPSC), developed by Food Standards Australia New Zealand (FSANZ), not only considers sodium, saturated fat, and sugar content of foods, but it also accounts for ingredients such as dietary fiber, protein and fruit and vegetables and calculates a total nutrient profiling score for a food (135).

Since 2010, the United States NuVal Nutritional Scoring System has been used on the basis of the Overall Nutritional Quality Index (ONQI) algorithm (132-134). The ONQI incorporates over 30 nutrients and food properties, in addition to weighting coefficients (energy density, glycemic load, protein quality, and fat quality) representing epidemiologic associations between nutrients and health outcomes (132). ONQI summarizes comprehensive nutritional information into a single score ranging from 1 to 100 based on their relative nutrition and healthfulness (132). Adherence to the ONQI has previously been associated with lower risk of total chronic diseases and total mortality during over 20 years of follow-up, although the lack of transparency of this tool has remained controversial (132, 143).

In the present study, the HCST was able to distinguish the diet quality of compliers, intermediate compliers, and non-compliers, which is in line with the findings of previous research using other indexes (74, 80, 144). Favorable diet quality in terms of lower consumption of Tier 4 and “other” foods/beverages was associated with higher intakes of vitamins and minerals, and lower intakes of energy, fats, added sugars, alcohol, glycemic index, and energy density, even though these nutritional components were not considered in the quartile categorization of individuals.

In addition, our results confirm previous research indicating that older, female, physically active, and non-smoker individuals have healthier dietary quality, which is also an indication of the face validity of HCST in the Canadian population (80, 145-147). In particular, lower diet quality was seen among smokers, who have been previously shown to be less physically active, and have high alcohol intakes and low consumption of fruits and vegetables (148, 149), which may be due to taste modifications, dysregulation of appetite, and unhealthy lifestyle among this group (149).

In this research, we failed to observe a significant association between adherence to a nutrient profiling system and BMI, which is in line with some previous studies (145, 150). This lack of association may be explained by the focus of the EWCFG and HCST on meeting the DRI nutrient requirements rather than disease prevention (27). Our group recently published a critical analysis of the EWCFG concluding that adherence to the EWCFG does not necessarily guarantee a reduced risk of obesity or other chronic diseases (27), since the EWCFG has been modeled to strictly meet the DRI nutrient recommendations. Even though some *a priori* diet quality indexes have been negatively associated with the risk of obesity (including healthy eating index and dietary quality index among CCHS 2.2 participants (151)), others have found neutral (150) or even inverse (152) associations. These inconsistent results may also be related to the cross-sectional nature of studies, or the observation that overweight and obese individuals are more likely to watch their nutritional intake or to be dieting (66, 153).

To our knowledge, this is the first study to investigate the application of a nutrient profiling system in characterizing the diet quality of Canadians, which is of high public health importance. Nutrient profiling systems as well as dietary quality scores aim to evaluate overall diet quality of individuals using available scientific evidence about the role of diet in health promotion (65). Considering the correlation between foods and nutrients and totality of diet are important advantages of using diet quality indexes and nutrient profiling systems (65). Strengths of our study include the use of a large nationally-representative sample, including several covariates, having measured anthropometry, and use of the USDA AMPM which minimized misreporting bias as a result of missing items or eating occasion.

This study is not without its limitations. One limitation is the day-to-day variation (random non-differential error) associated with 24-h dietary recalls. Another disadvantage common among all diet quality index analyses is the subjectivity surrounding the selection of nutritional components, threshold values, and scoring criteria (70). The major limitation of HCST is the strict focus on 4 “negative” nutrients (total fats, saturated fat, sodium, and sugars) and lack of calculation of a total dietary score, which prevents direct comparisons across groups. Finally, owing to the cross-sectional design of the national Canadian nutrition survey, the causal inference is limited.

5.6 Conclusions

The 2014 HCST Tier system proves to have good validity for characterizing dietary intakes of Canadian adults and therefore could be used for public health initiatives to ensure adherence to EWCFG recommendations. However, it must be noted that this system was not a good indicator of obesity, which is in line with previous studies that have criticized the overly focus of the EWCFG on meeting DRI nutrient requirements, rather than chronic disease prevention (27). In light of recent improvements and updates in dietary guideline (e.g., Scientific Report of the Dietary Guidelines for Americans 2015 (25)) and strong evidence for the role of nutrition in the prevention of chronic diseases, revising the EWCFG model to reflect these may form a more appropriate platform for development of future Canadian nutrient profiling systems (27). Future Canadian nutrient profiling systems should also take an approach similar to that taken by the United Kingdom Ofcom model, FSANZ, and/or the ONQI, to include a more complex algorithm that incorporates several “positive” and “negative” nutrients, provide a total summative score, and consider associations with chronic diseases risk.

Table 5.1. Weighted analysis of number of servings from Health Canada's Eating Well with Canada's Food Guide (EWCFG) (26) presented based on the 2014 Health Canada's Surveillance Tool (HCST) Tier system (73) among Canadians ≥19 years*[,†].

	Men, 19–30 Year	Women, 19–30 Year	Men, 31–50 Year	Women, 31–50 Year	Men, 51–70 Year	Women, 51–70 Year	Men, >70 Year	Women, >70 Year
Food Groups (Servings/Day)	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**
Vegetables and Fruits								
Tiers 1–3	4.35(0.26)	4.76(0.19)	4.64(0.23)	5.12(0.18)	5.56(0.21)	5.70(0.14)	5.37(0.20)	5.52(0.15)
Tiers 1–4	4.57(0.26)	5.01(0.18)	4.86(0.23)	5.33(0.18)	5.71(0.21)	5.88(0.14)	5.49(0.19)	5.67(0.15)
EWCFG Rec.	8–10	7–8	8–10	7–8	7	7	7	7
Grain Products								
Tiers 1–3	5.37(0.23)	5.03(0.16)	5.06(0.17)	4.83(0.14)	4.98(0.16)	4.99(0.13)	5.23(0.19)	5.00(0.12)
Tiers 1–4	5.99(0.23)	5.81(0.17)	5.70(0.18)	5.64(0.14)	5.55(0.16)	5.66(0.13)	5.99(0.21)	5.82(0.12)
EWCFG Rec.	8	6–7	8	6–7	7	6	7	6
Milk and Alternatives								
Tiers 1–3	1.34(0.10)	1.62(0.08)	1.17(0.08)[b]	1.58(0.07)[b]	1.23(0.08)	1.46(0.06)	1.55(0.13)	1.59(0.06)
Tiers 1–4	1.51(0.10)	1.79(0.08)	1.34(0.08)[b]	1.75(0.07)[b]	1.37(0.08)	1.59(0.06)	1.64(0.13)	1.72(0.06)
EWCFG Rec.	2	2	2	2	3	3	3	3
Meat and Alternatives								
Tiers 1–3	1.86(0.15)	1.70(0.10)	2.35(0.11)	2.01(0.09)	2.40(0.11)	2.19(0.09)	2.10(0.11)	2.01(0.08)
Tiers 1–4	2.12(0.14)[a]	1.88(0.09)[a]	2.60(0.10)[b]	2.20(0.09)[b]	2.65(0.10)	2.40(0.09)	2.36(0.10)	2.21(0.08)
EWCFG Rec.	3	2	3	2	3	2	3	2

Rec.: Recommendation; SEM: Standard Error of Mean; * Energy adjusted; † Tiers are based on Health Canada's Surveillance Tool and defined generally as follows: Tier 1–3 foods are compliant with EWCFG and Tier 4 foods are not recommended by the EWCFG. Tier 1 foods are foods that do not exceed lower thresholds for total fat, sugars, and sodium; Tier 2 foods do not exceed up to 2 lower thresholds for total fat, sugars or sodium, without exceeding any upper thresholds; for the Vegetables and Fruit and Grain Products food groups Tier 3 are foods that exceed all 3 lower thresholds without exceeding any upper thresholds or exceed only one upper threshold, while Tier 4 foods exceed at least 2 upper thresholds for total fat, saturated fat, sugars, or sodium. Within the Milk and Alternatives and Meat and Alternatives food groups, Tier 3 foods exceed all 3 lower thresholds without exceeding any upper thresholds for total fat, sugars, or sodium (irrespective of saturated fat) or exceed only one of these 3 thresholds or foods that only exceed the upper saturated fat threshold; within these 2 food groups foods that exceed at least 2 upper thresholds for total fat, sugars, or sodium were classified as Tier 4. Where lower thresholds entail: total fat ≤3 g/RA, sugars ≤6 g/RA, and sodium ≤140 mg/RA; and upper thresholds are: total fat >10 g/RA, sugars >19 g/RA, sodium >360 mg/RA, and saturated fat >2 g/RA. Full details are shown in Supplementary Table 5.1; [a] Comparison significantly different between 19–30 year old males and females, based on Tukey multiple comparison test ($p < 0.001$); [b] Comparison significantly different between 31–50 year old males and females, based on Tukey's multiple comparison test ($p < 0.001$).

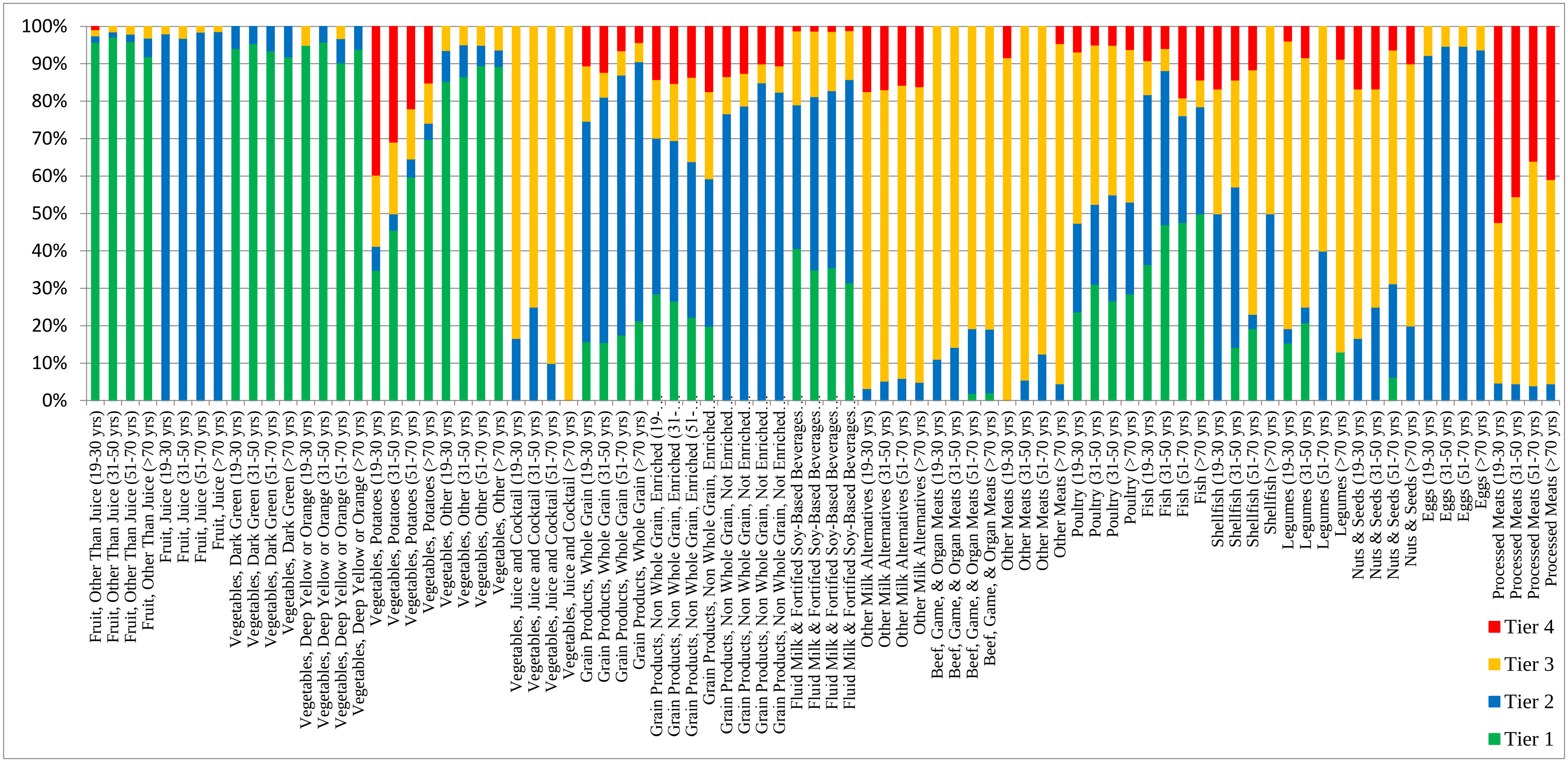
Table 5.2. Weighted analysis of energy contribution from Tiers 1–3 foods (compliant with Eating Well with Canada's Food Guide (EWCFG)) (73) and Tier 4 and "other" foods and beverages not included in the EWCFG among Canadian adults (≥19 years)*.

	Men, 19–30 y	Women, 19–30 y	Men, 31–50 y	Women, 31–50 y	Men, 51–70 y	Women, 51–70 y	Men, >70 y	Women, >70 y
Variable (kcal/day)	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**
Tiers 1 + 2 + 3	1539 (34)	1089 (24)	1468 (29)	1103 (16)	1353 (20)	1086 (17)	1217 (23)	1014 (16)
Tier 4	269 (15)	175 (10)	240 (12)	161 (9)	178 (10)	125 (7)	164 (10)	114 (6)
Other Foods/Beverages								
Alcoholic beverages	155 (12)	63 (9)	127 (8)	63 (6)	124 (8)	42 (3)	62 (6)	22 (2)
Beverages, higher calorie (≥40 kcal/100g)	171 (8)	103 (6)	108 (6)	61 (4)	58 (4)	42 (4)	30 (3)	26 (2)
Beverages, lower calorie (<40 kcal/100g)	30 (3)	26 (2)	29 (2)	26 (2)	23 (2)	19 (1)	16 (1)	15 (1)
High fat and/or sugar foods	153 (8)	130 (7)	167 (9)	124 (7)	123 (5)	105 (5)	121 (7)	87 (5)
Meal replacements	7 (2)	6 (2)	4 (1)	5 (1)	2 (1)	4 (1)	0 (0)	1 (0)
Saturated and/or trans fats and oils	74 (5)	54 (4)	80 (5)	59 (3)	87 (4)	62 (3)	78 (4)	64 (4)
Supplements	4 (2)	1 (0)	3 (2)	1 (0)	1 (0)	2 (1)	2 (1)	3 (1)
Uncategorized (ingredients/seasonings and unprepared foods)	22 (3)	15 (1)	20 (2)	17 (1)	18 (1)	16 (1)	15 (1)	14 (1)
Unsaturated fats and oils	83 (5)	57 (5)	71 (4)	62 (3)	70 (4)	55 (2)	51 (3)	47 (3)
Total energy from Tier 4 and "other" foods/beverages (kcal/day)	874 (27)	567 (19)	771 (21)	510 (16)	611 (17)	411 (11)	487 (18)	342 (11)
Total energy from Tier 4 and "other" foods/beverages (%)	31 (1)	29 (1)	30 (1)	27 (1)	27 (1)	23 (0)	25 (1)	21 (0)

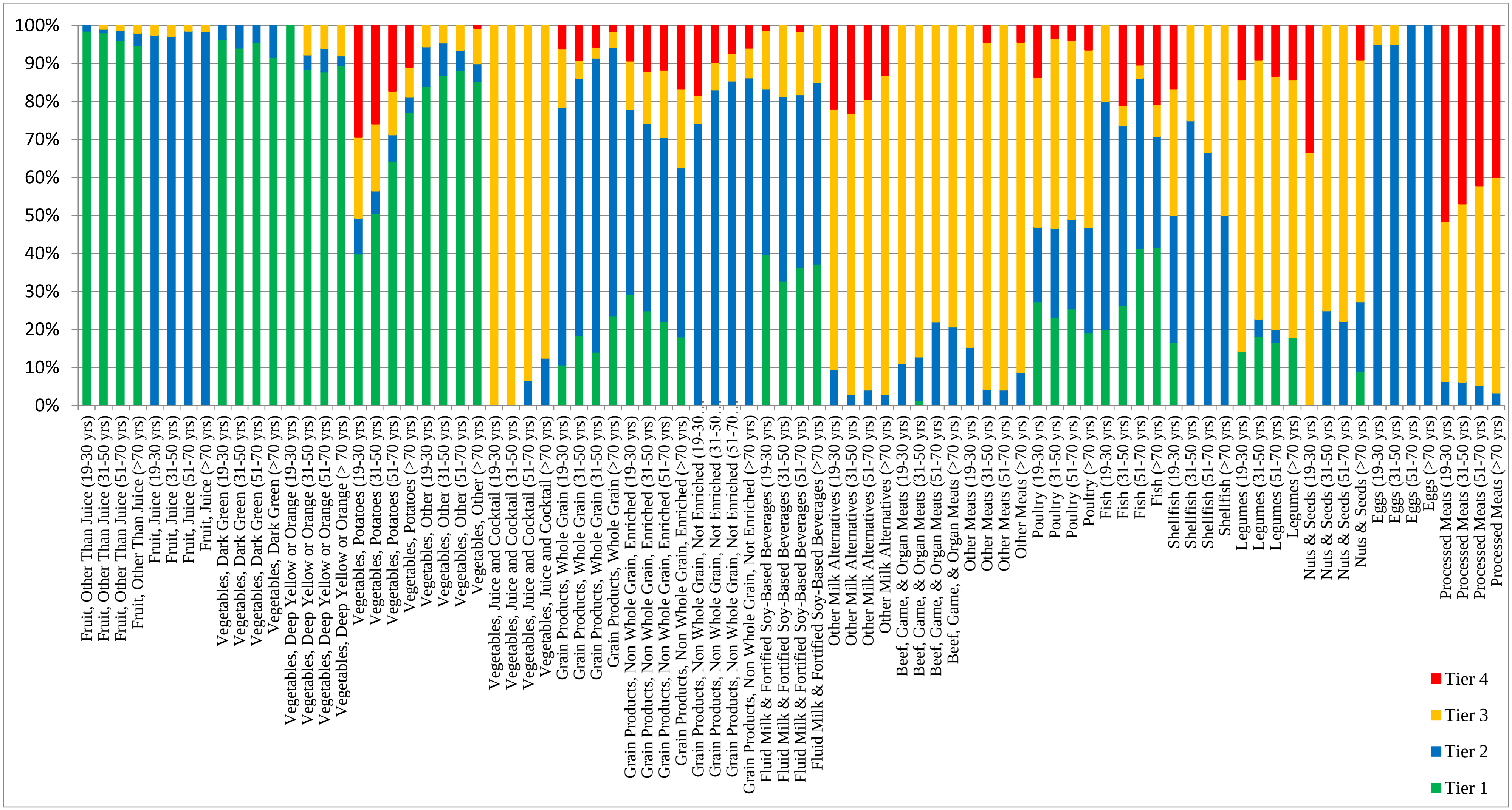
SEM: Standard Error of Mean; * "Other" foods/beverages are not part of the Tier system and include "other" food and beverages not in the groups of Eating Well with Canada's Food Guide (73).

Figure 5.1. Weighted age-stratified analysis of classification of foods as a percentage of servings based on the 2014 Health Canada Surveillance Tool Tier system among individuals ≥19 years *,† in (**a**) Women and (**b**) Men.

(**a**) **Women**



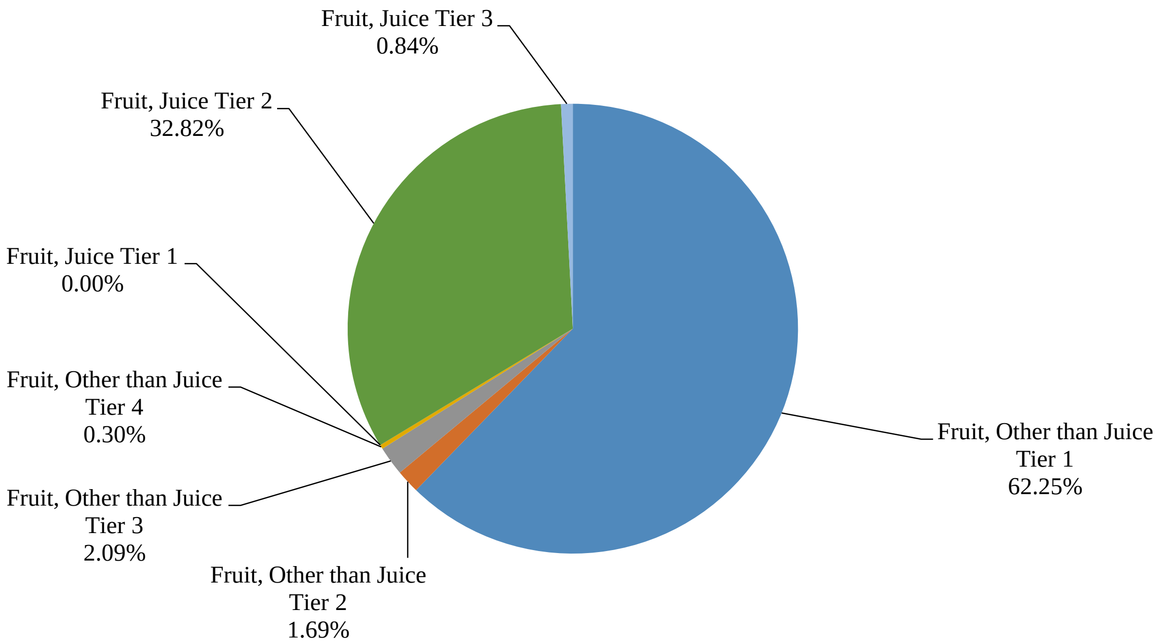
(b) Men



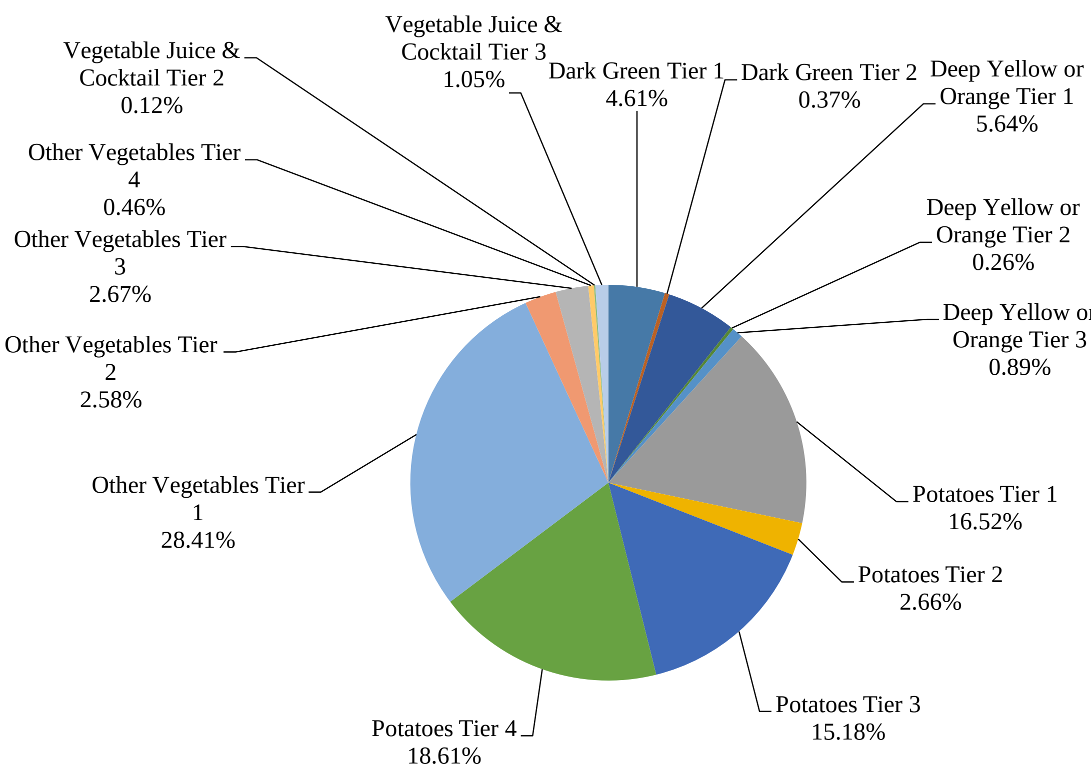
*Energy adjusted. † Tiers are based on Health Canada's Surveillance Tool (73) and defined generally as follows: Tier 1–3 foods are compliant with EWCFG and Tier 4 foods are not recommended by the EWCFG. Tier 1 foods are foods that do not exceed lower thresholds for total fat, sugars, and sodium; Tier 2 foods do not exceed up to 2 lower thresholds for total fat, sugars or sodium, without exceeding any upper thresholds; for the Vegetables and Fruit and Grain Products food groups Tier 3 are foods that exceed all 3 lower thresholds without exceeding any upper thresholds or exceed only one upper threshold, while Tier 4 foods exceed at least 2 upper thresholds for total fat, saturated fat, sugars, or sodium. Within the Milk and Alternatives and Meat and Alternatives food groups, Tier 3 foods exceed all 3 lower thresholds without exceeding any upper thresholds for total fat, sugars, or sodium (irrespective of saturated fat) or exceed only one of these 3 thresholds or foods that only exceed the upper saturated fat threshold; within these 2 food groups foods that exceed at least 2 upper thresholds for total fat, sugars, or sodium were classified as Tier 4. Where lower thresholds entail: total fat ≤3 g/RA, sugars ≤6 g/RA, and sodium ≤140 mg/RA; and upper thresholds are: total fat >10 g/RA, sugars >19 g/RA, sodium >360 mg/RA, and saturated fat >2 g/RA. Full details are shown in Supplementary Table 5.1.

Figure 5.2. Weighted analysis of percentage of energy intake (kcal) within the (**a**) Fruit Group, (**b**)Vegetable Group; (**c**)Vegetable and Fruit Group; (**d**) Grain Products; (**e**) Milk and Alternatives; (**f**) Meat Group; (**g**) Meat Alternatives Group; (**h**) Meat and Alternatives Group, using the Health Canada Surveillance Tool Tier system among Canadians ≥19 years *.

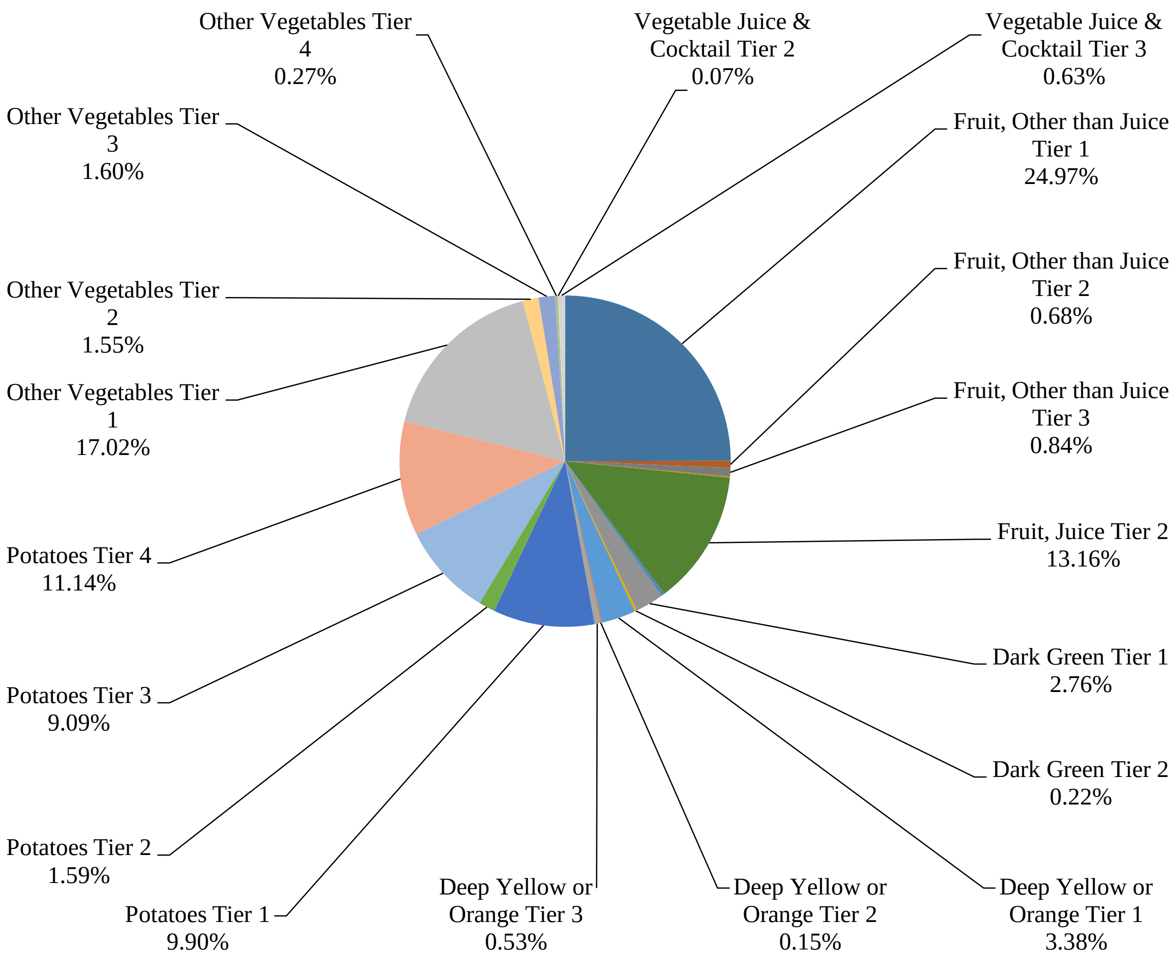
(**a**)



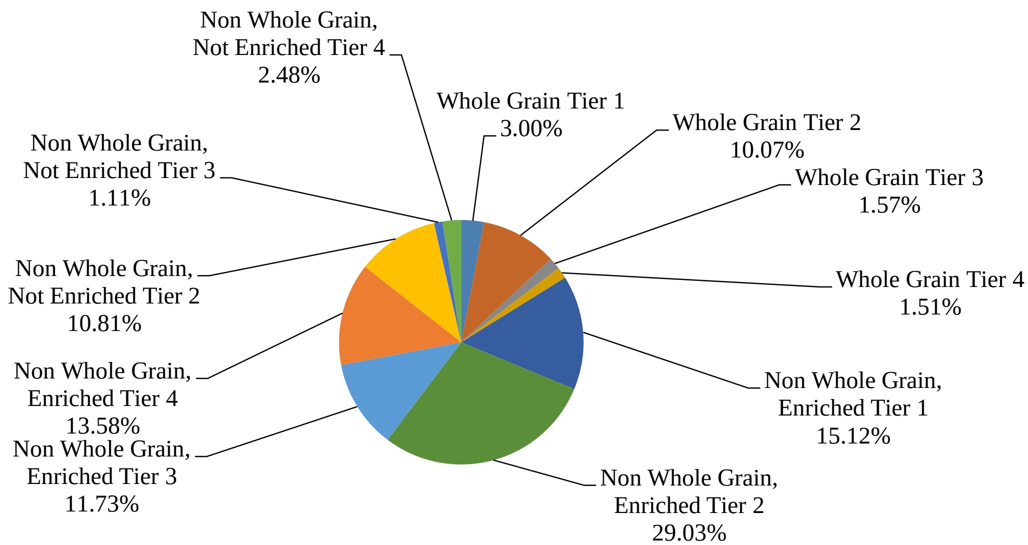
(**b**)



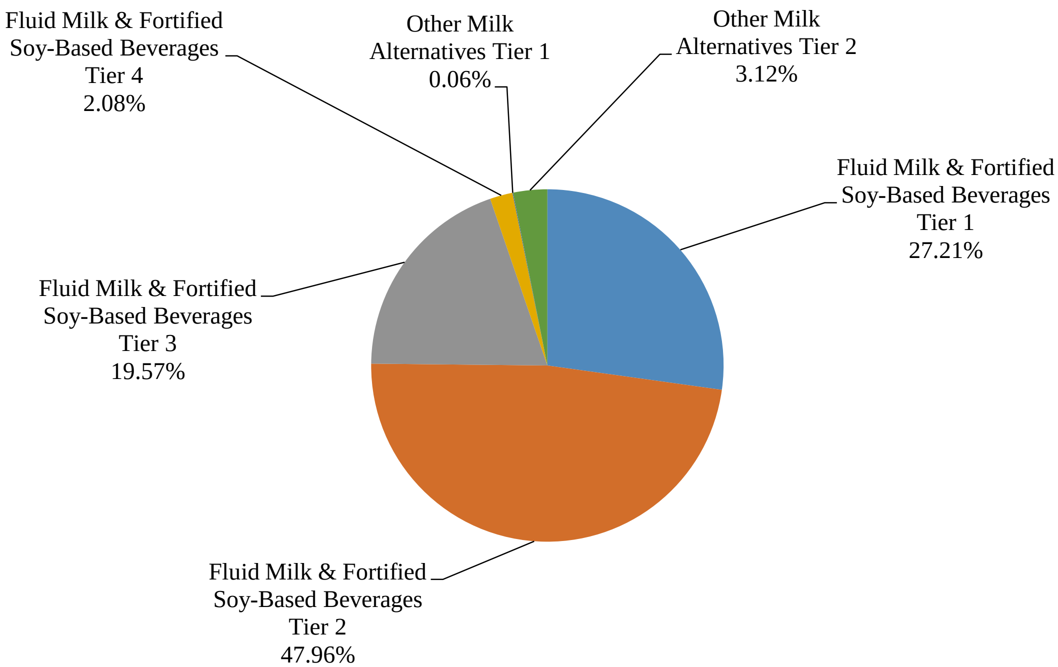
(c)


Other Vegetables Tier 4 0.27%
Vegetable Juice & Cocktail Tier 2 0.07%
Vegetable Juice & Cocktail Tier 3 0.63%
Other Vegetables Tier 3 1.60%
Fruit, Other than Juice Tier 1 24.97%
Fruit, Other than Juice Tier 2 0.68%
Other Vegetables Tier 2 1.55%
Other Vegetables Tier 1 17.02%
Fruit, Other than Juice Tier 3 0.84%
Fruit, Juice Tier 2 13.16%
Potatoes Tier 4 11.14%
Dark Green Tier 1 2.76%
Potatoes Tier 3 9.09%
Dark Green Tier 2 0.22%
Potatoes Tier 2 1.59%
Potatoes Tier 1 9.90%
Deep Yellow or Orange Tier 3 0.53%
Deep Yellow or Orange Tier 2 0.15%
Deep Yellow or Orange Tier 1 3.38%

(d)

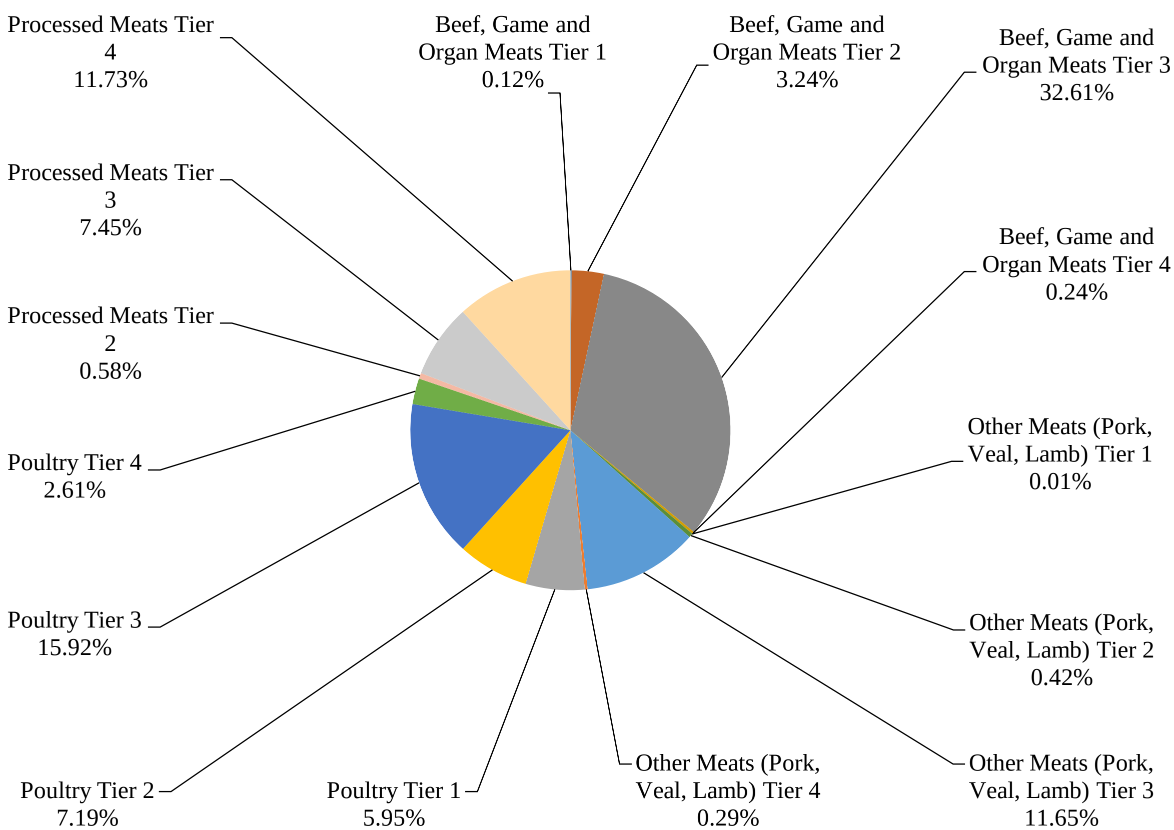

Non Whole Grain, Not Enriched Tier 4 2.48%
Whole Grain Tier 1 3.00%
Whole Grain Tier 2 10.07%
Non Whole Grain, Not Enriched Tier 3 1.11%
Whole Grain Tier 3 1.57%
Non Whole Grain, Not Enriched Tier 2 10.81%
Whole Grain Tier 4 1.51%
Non Whole Grain, Enriched Tier 4 13.58%
Non Whole Grain, Enriched Tier 1 15.12%
Non Whole Grain, Enriched Tier 3 11.73%
Non Whole Grain, Enriched Tier 2 29.03%

(e)



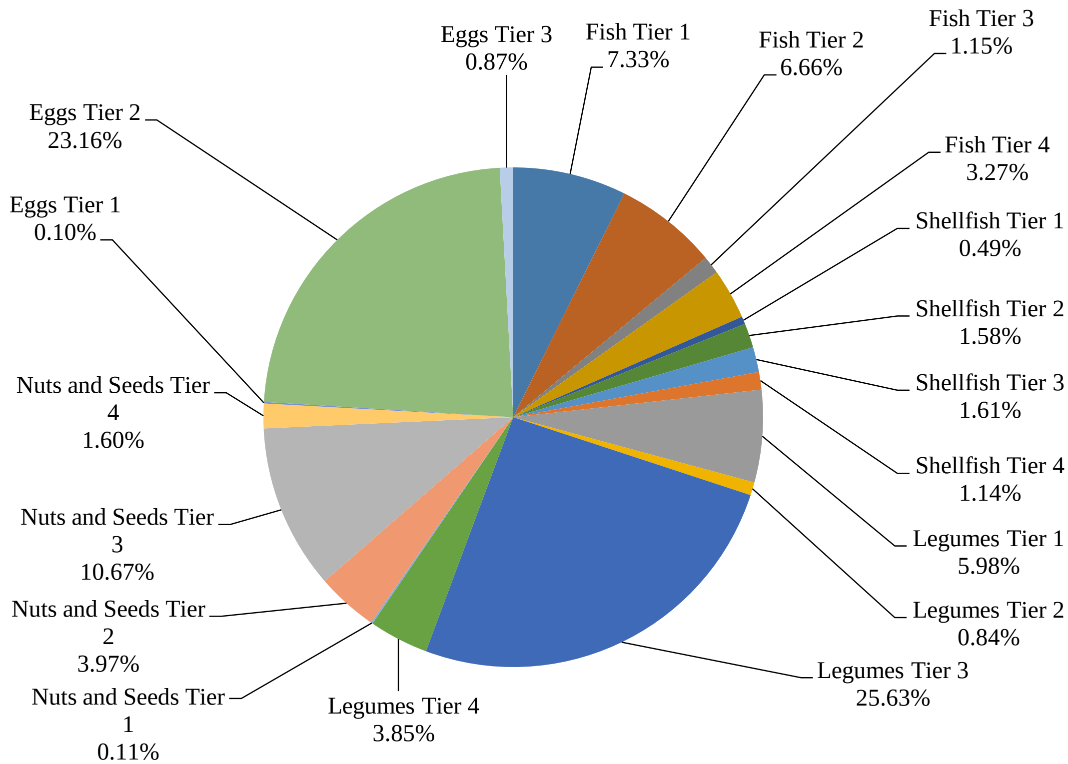
Fluid Milk & Fortified Soy-Based Beverages Tier 4 2.08%
Other Milk Alternatives Tier 1 0.06%
Other Milk Alternatives Tier 2 3.12%
Fluid Milk & Fortified Soy-Based Beverages Tier 1 27.21%
Fluid Milk & Fortified Soy-Based Beverages Tier 3 19.57%
Fluid Milk & Fortified Soy-Based Beverages Tier 2 47.96%

(f)



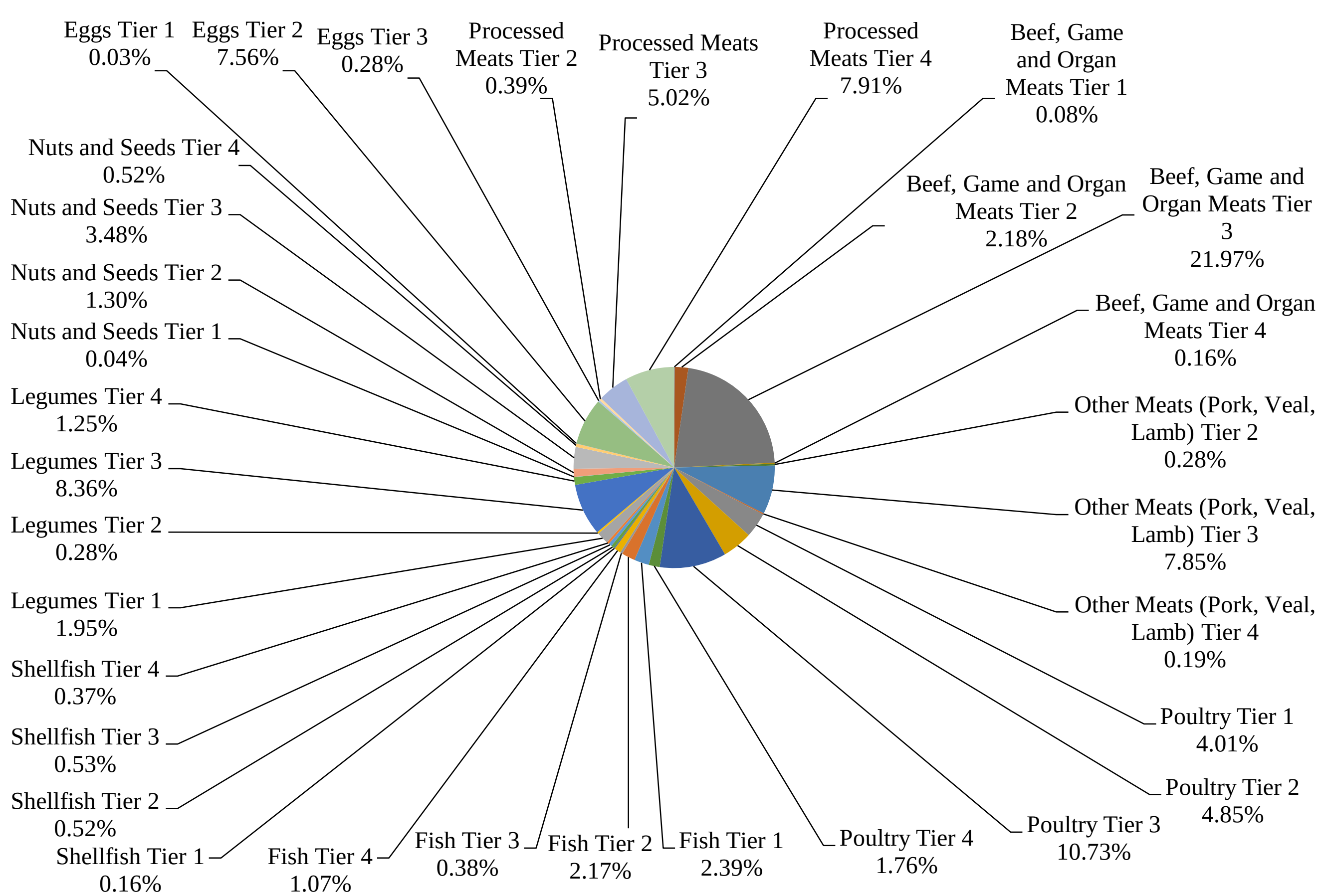
Processed Meats Tier 4 11.73%
Beef, Game and Organ Meats Tier 1 0.12%
Beef, Game and Organ Meats Tier 2 3.24%
Beef, Game and Organ Meats Tier 3 32.61%
Processed Meats Tier 3 7.45%
Beef, Game and Organ Meats Tier 4 0.24%
Processed Meats Tier 2 0.58%
Other Meats (Pork, Veal, Lamb) Tier 1 0.01%
Poultry Tier 4 2.61%
Poultry Tier 3 15.92%
Other Meats (Pork, Veal, Lamb) Tier 2 0.42%
Poultry Tier 2 7.19%
Poultry Tier 1 5.95%
Other Meats (Pork, Veal, Lamb) Tier 4 0.29%
Other Meats (Pork, Veal, Lamb) Tier 3 11.65%

(g)



Eggs Tier 3 0.87%
Fish Tier 1 7.33%
Fish Tier 2 6.66%
Fish Tier 3 1.15%
Fish Tier 4 3.27%
Shellfish Tier 1 0.49%
Shellfish Tier 2 1.58%
Shellfish Tier 3 1.61%
Shellfish Tier 4 1.14%
Legumes Tier 1 5.98%
Legumes Tier 2 0.84%
Legumes Tier 3 25.63%
Legumes Tier 4 3.85%
Nuts and Seeds Tier 1 0.11%
Nuts and Seeds Tier 2 3.97%
Nuts and Seeds Tier 3 10.67%
Nuts and Seeds Tier 4 1.60%
Eggs Tier 1 0.10%
Eggs Tier 2 23.16%

(h)



Eggs Tier 1 0.03%
Eggs Tier 2 7.56%
Eggs Tier 3 0.28%
Processed Meats Tier 2 0.39%
Processed Meats Tier 3 5.02%
Processed Meats Tier 4 7.91%
Beef, Game and Organ Meats Tier 1 0.08%
Beef, Game and Organ Meats Tier 2 2.18%
Beef, Game and Organ Meats Tier 3 21.97%
Beef, Game and Organ Meats Tier 4 0.16%
Other Meats (Pork, Veal, Lamb) Tier 2 0.28%
Other Meats (Pork, Veal, Lamb) Tier 3 7.85%
Other Meats (Pork, Veal, Lamb) Tier 4 0.19%
Poultry Tier 1 4.01%
Poultry Tier 2 4.85%
Poultry Tier 3 10.73%
Poultry Tier 4 1.76%
Fish Tier 1 2.39%
Fish Tier 2 2.17%
Fish Tier 3 0.38%
Fish Tier 4 1.07%
Shellfish Tier 1 0.16%
Shellfish Tier 2 0.52%
Shellfish Tier 3 0.53%
Shellfish Tier 4 0.37%
Legumes Tier 1 1.95%
Legumes Tier 2 0.28%
Legumes Tier 3 8.36%
Legumes Tier 4 1.25%
Nuts and Seeds Tier 1 0.04%
Nuts and Seeds Tier 2 1.30%
Nuts and Seeds Tier 3 3.48%
Nuts and Seeds Tier 4 0.52%

*Tiers are based on Health Canada's Surveillance Tool (73) and defined generally as follows: Tier 1–3 foods are compliant with EWCFG and Tier 4 foods are not recommended by the EWCFG. Tier 1 foods are foods that do not exceed lower thresholds for total fat, sugars, and sodium; Tier 2 foods do not exceed up to 2 lower thresholds for total fat, sugars or sodium, without exceeding any upper thresholds; for the Vegetables and Fruit and Grain Products food groups. Tier 3 are foods that exceed all 3 lower thresholds without exceeding any upper thresholds or exceed only one upper threshold, while Tier 4 foods exceed at least 2 upper thresholds for total fat, saturated fat, sugars, or sodium. Within the Milk and Alternatives and Meat and Alternatives food groups, Tier 3 foods exceed all 3 lower thresholds without exceeding any upper thresholds for total fat, sugars, or sodium (irrespective of saturated fat) or exceed only one of these 3 thresholds or foods that only exceed the upper saturated fat threshold; within these 2 food groups foods that exceed at least 2 upper thresholds for total fat, sugars, or sodium were classified as Tier 4. Where lower thresholds entail: total fat $\leq$3 g/RA, sugars $\leq$6 g/RA, and sodium $\leq$140 mg/RA; and upper thresholds are: total fat >10 g/RA, sugars >19 g/RA, sodium >360 mg/RA, and saturated fat >2 g/RA. Full details are shown in Supplementary Table 5.1.

Table 5.3. Weighted analysis of characteristics of compliers, intermediates, and non-compliers based on the percentage of energy from Tier 4 foods and "other" foods/beverages among Canadian adults (≥19 years) *,†.

	Compliers (Q1) ‡ ≤19.42% Energy	**Intermediates (Q2) § 19.42%–31.78% Energy**	**Intermediates (Q3) § 31.78%–45.73% Energy**	**Non–compliers (Q4) ǀ >45.73% Energy**	
Characteristics	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	***p*-Trend**
Age (years)	49.82 (0.57)	47.38 (0.72)	46.05 (0.54)	42.57 (0.49)	<0.0001
Sex (%)					
Males	44.10 (3.57)	48.84 (3.73)	51.76 (2.47)	53.48 (2.24)	
Females	55.90 (3.57)	51.16 (3.73)	48.24 (2.47)	46.52 (2.24)	0.0175
BMI (kg/m^2)	27.62 (0.28)	27.18 (0.19)	27.42 (0.19)	27.69 (0.21)	0.3214
Misreporting Status (%)					
Under Reporters	42.87 (2.03)	34.35 (2.54)	26.87 (1.52)	22.66 (1.64)	
Over Reporters	9.02 (1.39)	7.97 (1.05)	9.94 (1.21)	14.29 (1.49)	<0.0001
Physical Activity (%)					
Inactive	55.86 (2.48)	56.83 (1.96)	57.54 (1.85)	62.93 (1.84)	
Active	18.97 (1.53)	18.86 (1.41)	15.80 (1.24)	15.87 (1.28)	0.0342
Smoking Status (%)					
Daily Smoker	13.07 (1.32)	14.56 (1.17)	24.61 (1.76)	30.33 (1.68)	
Never Smoked	57.68 (1.97)	48.33 (2.07)	41.89 (1.88)	34.10 (1.53)	<0.0001

SEM: Standard Error of Mean; * Adjusted for age and sex; † Quartiles are based upon percentage of energy from all Tier 4 foods based on 2014 Health Canada's Surveillance Tool Tier system plus "other" foods and beverages not recommended in the Eating Well with Canada's Food Guide; ‡ The 25% of individuals with the lowest percentage of energy from Tier 4 and "other" foods and beverages; § The individuals in the interquartile range for energy intakes from Tier 4 and "other" foods and beverages; ǀ The 25% of individuals with the highest percentage of energy from Tier 4 and "other" foods and beverages.

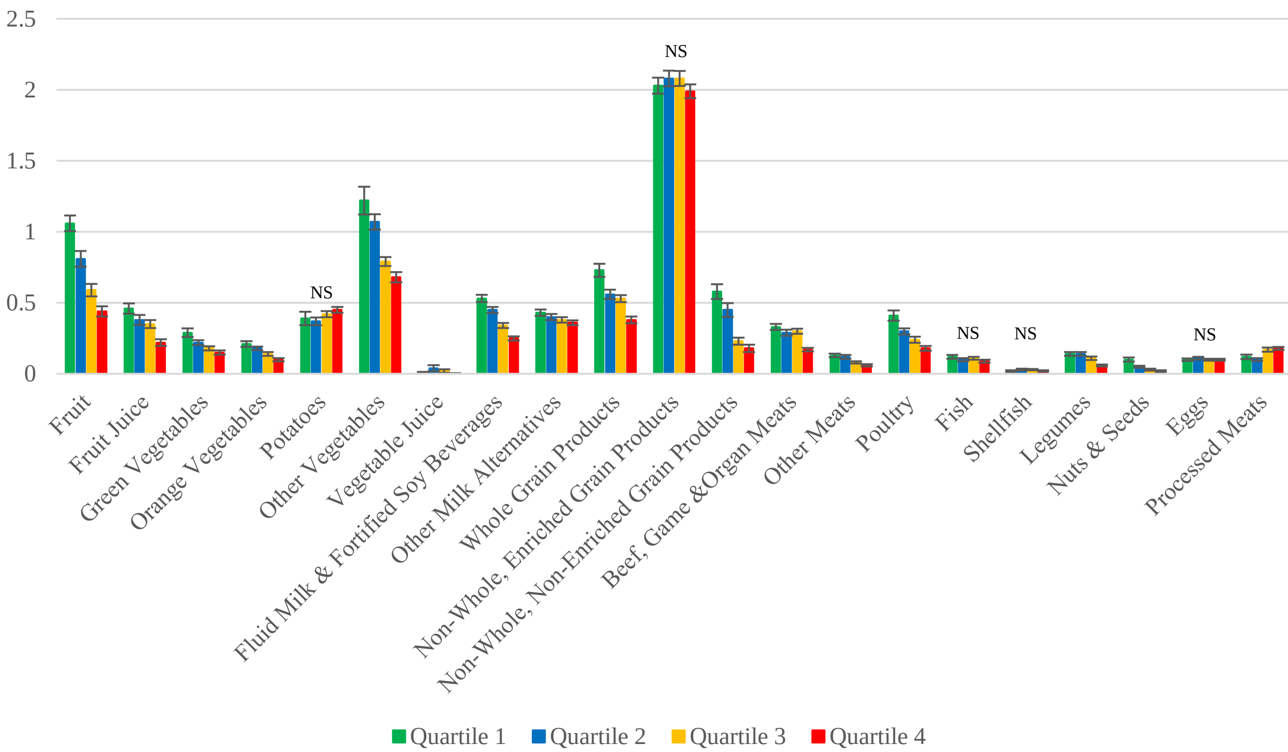
Table 5.4. Weighted analysis of nutrient intakes (density approach) by compliers, intermediates, and non-compliers based on the percentage of energy consumed from Tier 4 foods and "other" foods/beverages among Canadian adults (≥19 years), adjusted for age, sex, and misreporting status (under-reporter, plausible-,and over-reporters)*.

	Compliers (Q1) † ≤19.42% Energy	**Intermediates (Q2) ‡ 19.42–31.78% Energy**	**Intermediates (Q3) ‡ 31.78–45.73% Energy**	**Non–compliers (Q4) § >45.73% Energy**	***p*-Trend**
Nutrients	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**	
Energy (kcal/day)	2355 (28)	2426 (24)	2427 (22)	2478 (30)	<0.0001
Fat (%Energy)	28.90 (0.43)	31.70 (0.34)	33.91 (0.32)	33.73 (0.39)	<0.0001
Saturated fat (%Energy)	9.02 (0.15)	10.02 (0.16)	11.23 (0.18)	11.29 (0.19)	<0.0001
Monounsaturated fat (%Energy)	11.37 (0.22)	12.74 (0.18)	13.59 (0.15)	13.64 (0.19)	<0.0001
Polyunsaturated fat (%Energy)	5.35 (0.13)	5.76 (0.10)	5.96 (0.10)	5.91 (0.11)	0.00
Carbohydrates (%Energy)	50.83 (0.56)	48.77 (0.55)	47.13 (0.46)	47.29 (0.47)	<0.0001
Added sugar (%Energy)	5.45 (0.23)	7.71 (0.31)	10.40 (0.29)	14.00 (0.36)	<0.0001
Dietary fiber (g/1000 kcal)	10.99 (0.30)	9.37 (0.16)	7.99 (0.13)	6.86 (0.11)	<0.0001
Protein (%Energy)	19.63 (0.32)	17.46 (0.30)	15.78 (0.22)	12.82 (0.16)	<0.0001
Alcohol (%Energy)	0.64 (0.13)	2.07 (0.13)	3.17 (0.24)	6.16 (0.41)	<0.0001
Vitamin A (RE/1000 kcal)	454.94 (37.78)	377.34 (37.78)	339.23 (11.48)	287.96 (10.65)	<0.0001
Vitamin D (ug/1000 kcal)	3.23 (0.16)	3.18 (0.15)	2.84 (0.19)	2.45 (0.16)	<0.0001
Thiamin (mg/1000 kcal)	1.01 (0.02)	0.91 (0.01)	0.81 (0.01)	0.66 (0.01)	<0.0001
Riboflavin (mg/1000 kcal)	1.09 (0.02)	0.99 (0.01)	0.90 (0.01)	0.80 (0.01)	<0.0001
Niacin (NE/1000 kcal)	23.09 (0.40)	20.45 (0.27)	18.66 (0.26)	16.03 (0.31)	<0.0001
Vitamin B6 (ug/1000 kcal)	1.18 (0.02)	0.98 (0.01)	0.86 (0.02)	0.71 (0.01)	<0.0001
Folate (ug/1000 kcal)	140.90 (4.18)	126.67 (2.72)	111.50 (2.16)	94.84 (1.86)	<0.0001
Vitamin B12 (ug/1000 kcal)	2.60 (0.17)	2.44 (0.16)	2.03 (0.06)	1.69 (0.06)	<0.0001
Vitamin C (mg/1000 kcal)	77.08 (2.35)	67.80 (2.22)	59.87 (1.90)	45.63 (1.76)	<0.0001
Calcium (mg/1000 kcal)	480.37 (9.83)	437.20 (8.22)	392.96 (6.56)	349.48 (6.24)	<0.0001
Phosphorous (mg/1000 kcal)	772.27 (8.81)	691.04 (7.52)	622.08 (7.17)	547.76 (6.62)	<0.0001
Potassium (mg/1000 kcal)	1855.09 (27.90)	1644.51 (16.61)	1477.51 (16.16)	1295.64 (18.68)	<0.0001

Sodium (mg/1000 kcal)	1536.45 (30.10)	1523.69 (25.57)	1584.82 (24.92)	1510.05 (35.78)	0.11
Magnesium (mg/1000 kcal)	194.68 (3.53)	173.05 (1.99)	152.38 (1.57)	140.98 (4.48)	<.0001
Iron (mg/1000 kcal)	8.04 (0.12)	7.38 (0.10)	6.75 (0.08)	5.75 (0.07)	<.0001
Zinc (mg/1000 kcal)	6.63 (0.10)	5.89 (0.13)	5.37 (0.09)	4.33 (0.07)	<0.0001
Glycemic Index	51.03 (0.40)	52.40 (0.32)	53.61 (0.32)	53.56 (0.35)	<0.0001
Glycemic Load	151.26 (3.12)	156.99 (2.72)	154.48 (2.48)	159.37 (2.94)	0.07
Energy Density (kcal/g)	1.55 (0.02)	1.71 (0.02)	1.91 (0.02)	2.15 (0.02)	<0.0001

* Quartiles are based upon percentage of energy from all Tier 4 foods based on 2014 Health Canada's Surveillance Tool Tier system plus "other" foods and beverages not recommended in the Eating Well with Canada's Food Guide; † The 25% of individuals with the lowest percentage of energy from Tier 4 and "other" foods and beverages; ‡ The individuals in the interquartile range for energy intakes from Tier 4 and "other" foods and beverages; § The 25% of individuals with the highest percentage of energy from Tier 4 and "other" foods and beverages.

Figure 5.3. Implementation of 2014 Health Canada Surveillance Tool Tier system to the dietary intakes of Canadian adults (≥19 years) in a weighted analysis to assess the number of serving from each of the Eating Well with Canada's Food Guide subgroups per 1000 kcal (142). Dietary profiles of compliers (Quartile 1) *, intermediates (Quartiles 2 and 3) †, and non-compliers (Quartile 4) ‡ are compared[§,ǀ]



NS, Not significant; *The 25% of individuals with the lowest percentage of energy from Tier 4 and "other" foods and beverages; † The individuals in the interquartile range for energy intakes from Tier 4 and "other" foods and beverages; ‡ The 25% of individuals with the highest percentage of energy from Tier 4 and "other" foods and beverages; § Adjusted for age, sex, and misreporting status (under-reporters, plausible-, and over-reporters); ǀ Quartiles are based upon percentage of energy from all Tier 4 foods based on 2014 Health Canada's Surveillance Tool Tier system plus "other" foods and beverages not recommended in the Eating Well with Canada's Food Guide.

Supplementary Table 5.1. Initial placement of foods in Tiers using thresholds for fats, sodium and sugars.

<table>
<tr><th>Tiers</th><th colspan="2">Fats, Sugars and Sodium Content of Foods</th><th>Thresholds</th></tr>
<tr><td>1</td><td colspan="2">Foods that do not exceed any of the three lower thresholds for total fat, sugars and sodium *</td><td rowspan="2">Lower thresholds: Total Fat: ≤3 g/RA
Sugars: ≤6 g/RA Sodium: ≤140 mg/RA</td></tr>
<tr><td>2</td><td colspan="2">Foods that exceed one or two lower thresholds for total fat, sugars or sodium, without exceeding any upper thresholds</td></tr>
<tr><td rowspan="2">3</td><td>Vegetables and Fruit and Grain Products</td><td>Milk and Alternatives and Meat and Alternatives</td><td rowspan="2"></td></tr>
<tr><td>Foods that exceed all three lower thresholds without exceeding any upper thresholds for total fat, saturated fat, sugars or sodium
OR
Foods that exceed only one upper threshold for total fat, saturated fat, sugars or sodium</td><td>Foods that exceed all three lower thresholds without exceeding any upper thresholds for total fat, sugars or sodium †
OR
Foods that exceed only one upper threshold for total fat, sugars or sodium †
OR
Foods that only exceed the upper saturated fat threshold</td></tr>
<tr><td rowspan="2">4</td><td>Vegetables and Fruit and Grain Products</td><td>Milk and Alternatives and Meat and Alternatives</td><td rowspan="2">Upper thresholds:
Total fat: >10 g/RA Sugars: >19 g/RA Sodium: >360 mg/RA Saturated fat: >2 g/RA</td></tr>
<tr><td>Foods that exceed at least two upper thresholds for total fat, saturated fat, sugars or sodium</td><td>Foods that exceed at least two upper thresholds for total fat, sugars or sodium †</td></tr>
</table>

Source: ©All Rights Reserved. The Development and Use of a Surveillance Tool: The Classification of Foods in the Canadian Nutrient File According to Eating Well with Canada's Food Guide. Health Canada, 2014. Reproduced with permission from the Minister of Health, 2015.

RA: Reference amount; * Can't exceed the upper threshold for saturated fat; † Irrespective of saturated fat content (value may be above or below upper saturated fat threshold).

Supplementary Table 5.2. Overview of food products reported in the Canadian Community Health Survey 2.2 based on the 2014 Health Canada's Surveillance Tool Tier system (73) by food group.

Food Group by Tier	% within Corresponding Food Group/Category	% of Total Reported Food Products
Tier 1 Foods		
Fruits & Vegetables Tier 1	76.11	18.57
Grain Products Tier 1	19.09	2.99
Milk & Alternatives Tier 1	15.56	1.89
Meat & Alternatives Tier 1	7.52	0.77
Total Tier 1		**24.22**
Tier 2 Foods		
Fruits & Vegetables Tier 2	14.60	3.56
Grain Products Tier 2	47.10	7.37
Milk & Alternatives Tier 2	30.80	3.74
Meat & Alternatives Tier 2	25.24	2.60
Total Tier 2		**17.28**
Tier 3 Foods		
Fruits & Vegetables Tier 3	6.14	1.50
Grain Products Tier 3	18.87	2.95
Milk & Alternatives Tier 3	39.21	4.76
Meat & Alternatives Tier 3	51.11	5.26
Total Tier 3		**14.48**
Tier 4 Foods		
Fruits & Vegetables Tier 4	3.14	0.77
Grain Products Tier 4	14.93	2.34
Milk & Alternatives Tier 4	14.43	1.75
Meat & Alternatives Tier 4	16.12	1.66
Total Tier 4		**6.52**
"Other" Foods and Beverages		
Unsaturated Fats and Oils	10.1	3.75
Saturated and/or Trans Fats and Oils	11.20	4.20
Beverages, Higher Calorie (>40 kcal/100 g)	7.00	2.63
Beverages, Lower Calorie (<40 kcal/100 g)	13.36	5.01
Uncategorized (Ingredients/ seasonings, unprepared foods)	31.26	11.73
Alcoholic Beverages	2.10	0.79
High Fat and/or Sugar Foods	23.77	8.92
Meal Replacements	0.16	0.06
Supplements	0.08	0.03
Recipes	0.22	0.08

Foods and Beverages that are Not Classified	0.83	0.31
Total "Other" Foods		**37.50**

Supplementary Table 5.3. Overview of food products reported in the Canadian Community Health Survey 2.2 based on the 2014 Health Canada's Surveillance Tool Tier system (73) by food sub-group*.

Food Sub-Group	Tier *	Absolute of Reported Food Products	% of Total Reported Products	% within Total Food Group
Fruit, other than juice	1	51,291	7.51	19.24
	2	1441	0.21	0.54
	3	1006	0.15	0.38
	4	31	0	0.01
Fruit, juice	1	NA	NA	NA
	2	22,283	3.26	8.36
	3	555	0.08	0.21
	4	NA	NA	0.00
Total Fruit		**76,607**	**11.22**	**28.74**
Vegetables, dark green	1	21,141	3.10	7.93
	2	1476	0.22	0.55
	3	27	0.00	0.01
	4	NA	NA	0.00
Vegetables, deep yellow or orange	1	17,217	2.52	6.46
	2	300	0.04	0.11
	3	204	0.03	0.08
	4	NA	NA	NA
Vegetables, potatoes	1	12,731	1.86	4.78
	2	2607	0.38	0.98
	3	5361	0.79	2.01
	4	8132	1.19	3.05
Vegetables, other	1	100,533	14.72	37.71
	2	10,739	1.57	4.03
	3	7883	1.15	2.96
	4	220	0.03	0.08
Vegetables, juice and cocktail	1	NA	NA	0.00
	2	89	0.01	0.03
	3	1324	0.19	0.50
	4	NA	NA	NA
Total Vegetable		**189,984**	**27.82**	**71.26**
Total Fruits & Vegetables		**266,591**	**39.04**	**100**
Grain products, whole grain	1	4396	0.64	2.57
	2	19,397	2.84	11.34
	3	3591	0.53	2.10
	4	2350	0.34	1.37
Grain products, non whole grain, enriched	1	28,269	4.14	16.52
	2	50,192	7.35	29.34
	3	25,612	3.75	14.97
	4	19,930	2.92	11.65
Grain products, non whole grain, not enriched	1	NA	NA	0.00
	2	10,992	1.61	6.43
	3	3085	0.45	1.80
	4	3261	0.48	1.91

Food Sub-Group	Tier *	Absolute of Reported Food Products	% of Total Reported Products	% within Total Food Group
Total Grain Products		**171,075**	**25.05**	**100.00**
Fluid milk and fortified soy-based beverages	1	20,521	3.00	15.46
	2	39,377	5.77	29.67
	3	13,908	2.04	10.48
	4	428	0.06	0.32
Other milk alternatives (cheese, yogourt)	1	128	0.02	0.10
	2	1503	0.22	1.13
	3	38,130	5.58	28.73
	4	18,721	2.74	14.11
Total Milk & Alternatives		**132,716**	**19.43**	**100.00**
Beef, game and organ meats	1	186	0.03	0.17
	2	1924	0.28	1.71
	3	19,644	2.88	17.45
	4	149	0.02	0.13
Other meats (pork, veal, lamb)	1	10	0	0.01
	2	282	0.04	0.25
	3	7523	1.10	6.68
	4	49	0.01	0.04
Poultry	1	4341	0.64	3.86
	2	4974	0.73	4.42
	3	6592	0.97	5.86
	4	2197	0.32	1.95
Processed Meats	1	NA	NA	NA
	2	754	0.11	0.67
	3	9259	1.36	8.23
	4	13,981	2.05	12.42

Food Sub-Group	Tier *	Absolute of Reported Food Products	% of Total Reported Products	% within Total Food Group
Total Meats		**71,865**	**10.52**	**63.85**
Fish	1	1891	0.28	1.68
	2	2563	0.38	2.28
	3	460	0.07	0.41
	4	540	0.08	0.48
Shellfish	1	380	0.06	0.34
	2	874	0.13	0.78
	3	461	0.07	0.41
	4	164	0.02	0.15
Legumes	1	1295	0.19	1.15
	2	216	0.03	0.19
	3	8895	1.30	7.90
	4	881	0.13	0.78
Nuts and seeds	1	20	0.00	0.02
	2	1070	0.16	0.95
	3	3897	0.57	3.46
	4	184	0.03	0.16
Eggs	1	344	0.05	0.31
	2	15,750	2.31	13.99
	3	796	0.12	0.71
	4	NA	NA	0.00
Total Meat Alternatives		**40,681**	**5.96**	**36.15**
Total Meat & Alternatives		**112,546**	**16.48**	**100**

*Tiers are based on Health Canada's Surveillance Tool and defined generally as follows: Tier 1–3 foods are compliant with EWCFG and Tier 4 foods are not recommended by the EWCFG. Tier 1 foods are foods that do not exceed lower thresholds for total fat, sugars, and sodium; Tier 2 foods do not exceed up to 2 lower thresholds for total fat, sugars or sodium, without exceeding any upper thresholds; for the Vegetables and Fruit and Grain Products food groups Tier 3 are foods that exceed all 3 lower thresholds without exceeding any upper thresholds or exceed only one upper threshold, while Tier 4 foods exceed at least 2 upper thresholds for total fat, saturated fat, sugars, or sodium. Within the Milk and Alternatives and Meat and Alternatives food groups, Tier 3 foods exceed all 3 lower thresholds without exceeding any upper thresholds for total fat, sugars, or sodium (irrespective of saturated fat) or exceed only one of these 3 thresholds or foods that only exceed the upper saturated fat threshold; within these 2 food groups foods that exceed at least 2 upper thresholds for total fat, sugars, or sodium were classified as Tier 4. Where lower thresholds entail: total fat < 3 g/RA, sugars < 6 g/RA, and sodium <140 mg/RA; and upper thresholds are: total fat >10 g/RA, sugars >19 g/RA, sodium >360 mg/RA, and saturated fat >2 g/RA. Full details are shown in Supplementary Table 5.1.

Supplementary Table 5.4. Weighted regression analysis of the association between quartiles of the percent energy from Tier 4 and “other” foods/beverages and risk of obesity in Canadian adults (≥19 years)*.

	Compliers (Q1) [†] ≤19.42% Energy	Intermediates (Q2) [‡] 19.42%–31.78% Energy	Intermediates (Q3) [‡] 31.78%–45.73% Energy	Non-Compliers (Q4) [§] >45.73% Energy	
Characteristics	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI))**	**OR (95%CI)**	***p*-Trend**
Obesity, (BMI ≥30 kg/m^2)					
Model 1 [ǀ]	1.0	0.872 (0.646–1.176)	1.047 (0.792–1.384)	1.058 (0.799–1.397)	0.7053
Model 2 [¶]	1.0	0.912 (0.675–1.233)	1.815 (0.894–1.571)	1.294 (0.971–1.724)	0.0657

95% CI: 95% Confidence Interval; BMI, Body Mass Index; OR, Odds Ratio; *Quartiles are based upon percentage of energy from all Tier 4 foods based on 2014 Health Canada’s Surveillance Tool Tier system (73) plus “other” foods and beverages not recommended in the Eating Well with Canada’s Food Guide; [†] The 25% of individuals with the lowest percentage of energy from Tier 4 and “other” foods and beverages; [‡] The individuals in the interquartile range for energy intakes from Tier 4 and “other” foods and beverages; [§] The 25% of individuals with the highest percentage of energy from Tier 4 and “other” foods and beverages; [ǀ] Adjusted for age and sex; [¶] Adjusted for age and sex and misreporting status (under-reporter, plausible-, and over-reporters).

As demonstrated in Chapter 5, the HCST 2014 which is developed based on the EWCFG 2007 was not associated with risk of obesity among Canadians. To be able to explain this lack of significant relationship, the limitations of the EWCFG 2007 were systematically evaluated in Chapter 6 and recommendations for the next revision are provided accordingly.

Chapter 6

6 Study #3: The time for an updated Canadian Food Guide has arrived

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This study addressed the objective #3 of my thesis, to:

- Systematically evaluate the limitations of current Eating Well with Canada's Food Guide (EWCFG) released in 2007, which is the basis for HCST 2014, and provide suggestions for its future improvement

Student's contribution:

I conceptualized and designed this critical review with my supervisor, Dr. Mary L'Abbe. I also independently reviewed the current evidence in the field and other dietary guidelines developed worldwide, and systematically analysed the process undertaken for developing the current Canadian food guide. I independently drafted the manuscript and revised the manuscript according to the reviewers' recommendations before publication in the "*Applied Physiology, Nutrition and Metabolism"* journal.

6.1 Abstract

Canada has published food guides since 1942 and the latest version, Eating Well with Canada's Food Guide (EWCFG), was released in 2007. The EWCFG is largely based on meeting nutrient requirements, while we are now in need of a food guide with strong guidance on the role of diet in the prevention of chronic diseases. This article systematically analyses the process and assumptions behind the EWCFG and presents suggestions for needed revisions to the next food guide.

Keywords:

Eating Well with Canada's Food Guide 2007; critical evaluation; food-based dietary guidelines

6.2 Introduction

Since 2007, Eating Well with Canada's Food Guide (EWCFG 2007) has been the foundation for federal nutrition policy and programs to translate current nutritional science into a practical food-based dietary guidance for enhancing the overall health of Canadians (26). The EWCFG 2007 is highly accessible to all Canadians and was developed to help consumers make healthy food choices. However, since its release, EWCFG 2007 has received mixed reviews and harsh criticisms by some researchers calling it "obesogenic" (28, 29). Given a number of limitations in its development, recent advances in dietary guideline development methodology, availability of Canadian national nutrition surveys, and changes in food supply, this key fundamental piece of Canadian nutrition policy is in need of updating. This paper analyses each of the steps in the development process, and directional statements used in the EWCFG 2007, and makes recommendations for updating the food guide based on the latest methodology and science.

6.3 Development of the EWCFG 2007

In this paper, each step in the development of the EWCFG 2007 (26) was reviewed for strengths and weaknesses. Briefly, a 2-step modelling process was used for development of the EWCFG 2007 to create a food intake pattern (Supplementary Figure. 6.1). In the first step, food composites were developed and manipulated until a food intake pattern with satisfactory nutrient levels was identified for each of the age and sex groups. In the second step, 500 simulated diets were created for each of these age and sex groups from the food intake patterns of the first step. Nutrient distributions from the simulated diets were then compared against the Dietary Reference Intake (DRI) values. The modelling was cycled between steps 1 and 2 to yield food intake patterns that met the target DRI nutrient requirements. The final food intake pattern was then adjust received during consultations and review of diet–disease relationships (cardiovascular disease, cancer, and osteoporosis) (26).

6.4 Limitations

6.4.1 Development process

This section analyses each stage in development of EWCFG 2007 as outlined in Supplementary Figure. 6.1

Phase 1: Food grouping

As a starting point, the 1992 food guide groups (4 main groups) and directional statements were used to categorize foods for food intake pattern development. Additional food subgroups were also developed to evaluate the impact of recommending different foods on nutrient content of diets.

Phase 2: Data sources and choice of foods

In phases 1 and 2 of the modelling process, the following 2 datasets were used: 2001 Food Expenditure Survey (FoodEx), which provides estimated quantities of purchased foods, and Provincial Nutrition Surveys conducted in the 1990s, as they were the only sources of information on Canadians' diets at the time (26). For estimating energy and nutrient values of foods, the Canadian Nutrient File (CNF) 1997 was used. The approach taken in EWCFG 2007 modelling was to use composite foods based on food choices of Canadians (Provincial Nutrition Surveys) and food popularity (FoodEx), which can have advantages in terms of being practical, realistic, and easy to adopt (33). However, Canadians' eating habits deviate significantly from a healthy diet, with the mean Healthy Eating Index-Canada (HEI-C) score being 58.8/100 (154). This, in essence, sets dietary recommendations based on the then current food choices, which may not be ideal when compared to the scientific graded evidence regarding the role of diet in chronic diseases. One further limitation of using the then current food choices is the age and methodological shortcomings of datasets used. Health Canada is now better positioned for developing a revised EWCFG, given the availability of national nutrition datasets (Canadian

Community Health Survey – Nutrition (CCHS) 2.2) and the upcoming CCHS 2015 (155). In addition, significant updates have been made in the CNF 2010 Health Canada 2010 (serving sizes, calories, and nutrient values) as a result of changes in food supply and database updates, which provides the opportunity for more accurate estimation of energy and nutrients for the next EWCFG. However, it is important to note that Canada is still in need of a national multiethnic nutrition survey to be able to capture the different eating habits of ethnic minorities and reflect them in development of culturally-relevant food patterns. In doing so, a similar approach to that taken in Australian Dietary Guidelines (ADG) and the Dietary Guidelines for Americans (DGA) can be adopted where several alternative food patterns (e.g., omnivore, rice-based, pasta-based, lacto-ovo-vegetarian, and Mediterranean) are recommended to accommodate cultural preferences of multiethnic groups (33, 67). This approach supports the growing evidence that there is more than 1 strategy for healthy eating and foods can be combined in different ways to achieve healthy dietary patterns (156). This is especially important in Canada since in 2011, 1 in every 5 Canadians was a visible minority, which is higher than any other G8 country (157).

Phase 3: Food composites/popularity

For each modelling group, food composites were created based on the relative importance of each FoodEx food in the modelling group and this information was used to identify the relative nutrient content of foods. For instance, if 50% of total purchased fruits was oranges and 25% was apples, then 50% of the nutrient content of the fruit composite was based on the nutrients in 1 serving of oranges and 25% was based on nutrients in 1 serving of apples (26). The limitation of this step is that the food composites created for modelling groups were based on a probability sampling that reflected the popularity of particular foods for a given age and sex group. This approach resulted in potatoes (which have a lower nutrient density) to represent the majority of vegetables modelled because of their high consumption among Canadians. This problem has been addressed by guidelines such as the DGA and the ADG, which categorize potatoes as starchy vegetables and set a weekly limit for their consumption (25, 33, 67). In addition, only 1 representative food composite was created in EWCFG for each age and sex group, neglecting the variability due to individual food selection.

Phase 4: Modelling

In this phase, the amounts of food composites were determined to develop a food intake pattern for each DRI age and sex group. For each group, the number of food guide servings was manipulated to reach a satisfactory average nutrient intake level (26). This food pattern was then used for developing simulated diets in step 2. Unfortunately, only selected nutrients available in the CNF 1997 database were modelled during the EWCFG 2007 development process. Notably absent were added sugars and trans fat. Another limitation of this step is lack of consideration of physical activity levels and energy requirements for estimating the required number of servings for different groups (see below).

Phase 5: DRI modelling targets used

In step 2 of the modelling, food intake patterns in step 1 were used to create 500 simulated diets for each age and sex group to estimate nutrient distributions. As mentioned above, individual foods were selected from the modelling groups with a selection probability based on the relative popularity of foods in FoodEx and Provincial Nutrition Surveys, and were revised based on review of diet–disease relationships. Distribution of energy and nutrients of simulated diets were compared with the DRIs to inform further adjustments to food intake patterns (26). The major limitation of this stage is that many deviations from DRI recommendations were accepted so that in over 10% of simulated diets, magnesium among males aged >71 years, vitamin A among females aged 14–18 years, and zinc in females aged 9–13 years were below the Estimated Average Requirements (26). Most importantly, the median sodium content of all final simulated diets exceeded the tolerable upper intake level (UL) for those >8 years of age. In addition, vitamin D in the simulated diets of individuals over 50 years of age did not meet the Adequate Intakes at the time, which was addressed by Health Canada through inclusion of a recommendation for this age group to take a daily supplement of 400 IU vitamin D (26). This deficit is now even larger since the Recommended Daily Allowances for individuals aged 1–70 years and >70 years recently increased to 600 IU/day and 800 IU/day, respectively (158). These changes in vitamin D recommendations have been reflected in the DGA 2015 and the MyPlate, which recommend 3 cups/day of milk and alternatives (including fortified soy beverages) for individuals ≥9 years of age and 2.5 cups for those 4–8 years of age, which is higher than the EWCFG recommendations, despite Canada's more northern latitude (25, 159). Other nutrients with inadequacies in the final simulated diets included fibre (especially in children), potassium, and linoleic acid (26).

Most importantly, simulated diets for females of all age groups and males of all age groups except for those aged 4–8 years and 31–50 years had higher calories than the estimated energy requirements (EER), even though only low-fat varieties of meat and milk and alternatives were modelled in an attempt to stay within the calorie limits. As a result, following the EWCFG 2007 can lead to overconsumption of energy intakes. Compounding this calorie excess, calories from "other foods" (e.g., high-fat and sugary products) were not considered in the final food patterns, since the sum of calories from recommended amounts of 4 food groups and oils ("essential calories") was higher than the EER for the simulated diets, leaving no room for assigning the remaining calories to solid fats and added sugars. This is in contrast with the DGA 2015 and the ADG, which derived dietary patterns with adequate nutrient levels and minimal calories, allowing them to allocate the remaining calories up to the calorie limit (EER) to set a limit for calories from solid fats and added sugars for each age and sex group (25, 33). Neglecting other foods is especially problematic as they contribute over 25% of total calories and fat intakes in the Canadian diet (600–800 kcal) (154) and could result in even higher overconsumption of calories when consumed.

Phase 6: Consultation

Stakeholders were consulted several times during the revision process and were consistently updated about the proposed directions of the EWCFG. Health Canada also presented the draft version of EWCFG 2007 to stakeholders for their feedback (26). The main concern about these consultations is that one-third of all stakeholders were from the food industry. Concerns have been raised by some groups that this provided industry with opportunities for lobbying and cobranding with Health Canada (160).

6.4.2 Directional statements

Directional statements are included in EWCFG 2007 beside the recommendations for each food group and are statements that guide food selection (e.g., choose lower fat meat). Limitations regarding the directional statements are presented below.

Grain products

The EWCFG 2007 recommends at least 50% of grain products to be whole (26). The justification for this recommendation was that only white flour in Canada is fortified with folate (150 g/100 g) for neural tube defect prevention. Considering the low dietary fibre intake in Canada, more emphasis on whole grains intake is necessary, such as the earlier proposal by Health Canada to permit folic acid fortification of whole grains (161). However, with the recent decision to not approve a health claim for whole grains (162), further changes would seem unlikely.

Vegetables and fruits

The EWCFG 2007 recommends consumption of 1 green and 1 orange vegetable daily but does not set limits for juice intake, despite its potential for overconsumption and limited fibre contribution. In addition, the EWCFG 2007 does not set limits for starchy vegetables (e.g., potatoes, corn). However, when Health Canada approved the health claim for fruits and vegetables in reducing the risk of some cancers, starchy vegetables, including “potatoes, yams, cassava, plantain, corn, mushrooms, mature legumes, and their juices”, were explicitly excluded from carrying this health claim (163).

Meat and alternatives

Directional statements do not specify how often meats versus alternatives (e.g., legumes, nuts, and seeds) should be consumed, and do not differentiate between red, white, and processed meats, which may imply the nutritional equivalency of these foods to consumers (28). This is inconsistent with the World Cancer Research Fund report, which suggests a strong role for processed meat in the etiology of colorectal cancer (164).

Fats and oils

The EWCFG 2007 does not recommend avoiding trans fat and only advises that individuals limit their intakes, yet Health Canada’s Trans-Fat Task Force recommended elimination of trans fats (165) and the IOM Macronutrients report did not set a UL for trans fat, as increased risk exists at levels above zero (112). Most importantly, EWCFG 2007 recommends 2–3 tablespoons per day of oils and fats for all age and sex groups (240–360 additional calories), which is higher than the energy-based recommended amounts in DGA 2015, except for those who require over 2400 kcal/day

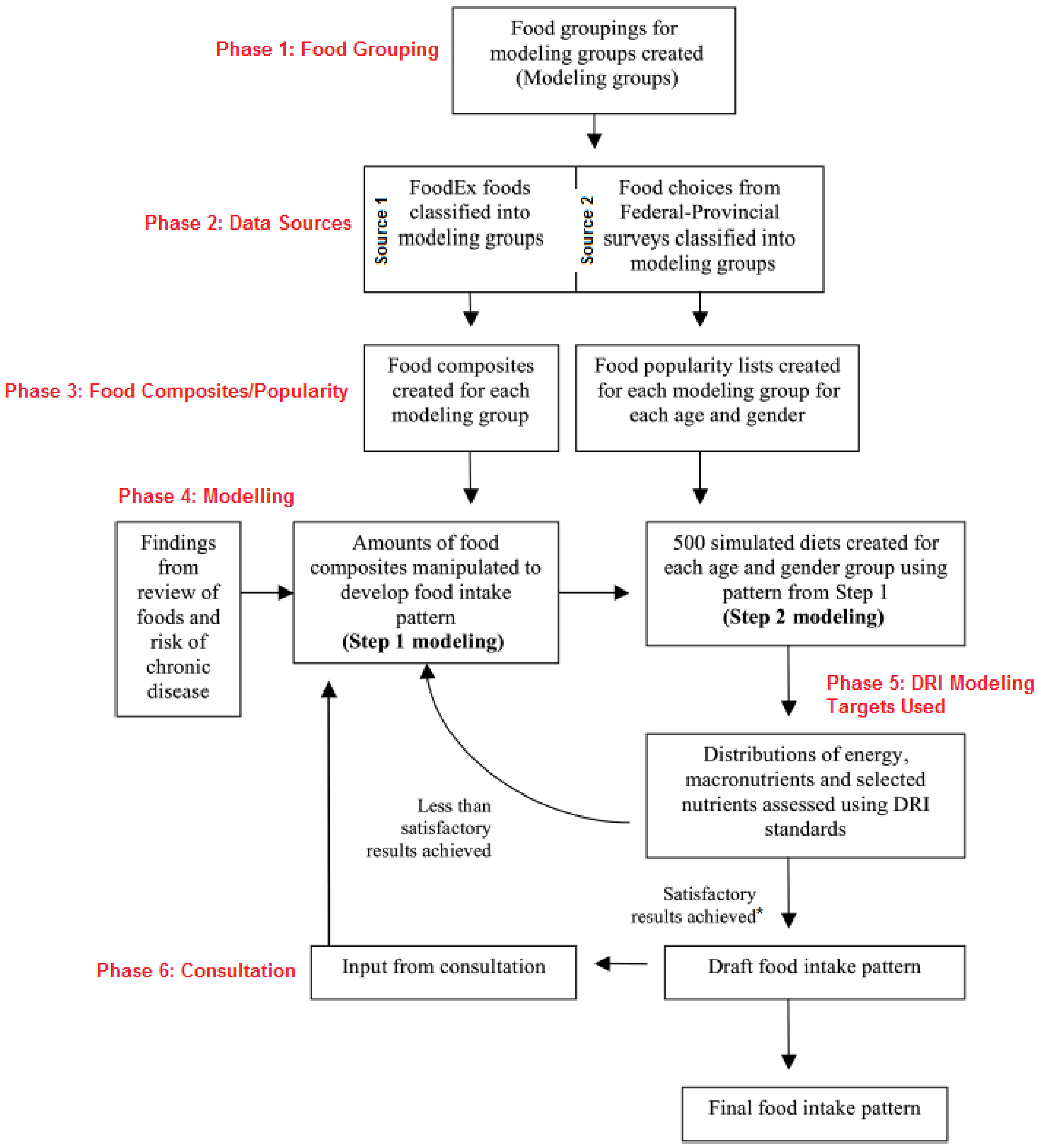
Energy

No directional statements were provided to target calorie intakes, with the underlying assumption that “healthy diets” are equivalent to “low-calorie” diets. A major limitation of the EWCFG 2007 with respect to energy is that eating patterns are recommended for different age and sex groups, without consideration of the differing energy requirements based on physical activity levels. More recent dietary guideline methodology, such as that used in the DGA 2015, sets 12 different dietary patterns for 12 different levels of energy requirements based on age, sex, and physical activity levels (25, 67).

6.5 Summary

EWCFG has evolved significantly over the past 70 years. Although current at the time, one of the main problems with the EWCFG 2007 is its primary focus on meeting nutrient DRI requirements rather than ensuring energy balance and focusing on the types of foods associated with maintaining a healthy body weight and preventing chronic diseases. This is concerning since inadequate micronutrient intakes are only seen for a few nutrients, yet 5 in 10 women and 7 in 10 men over-consume calories and 25% of males and 23% of females consume fat above the Adequate Macronutrient Distribution Range (166). In the next revision, it would also be essential to model food intake patterns based on foods associated with decreased chronic disease risk and less on nutrient deficiencies, focusing on foods to encourage (e.g., fruits, vegetables, legumes, fish, and nuts) and foods to limit (e.g., added sugar, refined grains, red and processed meats, and unhealthy oils), to be able to reorient the modelling steps based on "healthy food" selections in each food group. In addition, elimination of other foods and discretionary calories from the modelling phases suggests that the "real-world" application of EWCFG recommendations, in which the population consumes a further one-quarter of energy intake as other foods, is likely to be obesogenic. Focusing on development of "total diets" rather than a "foundation diet" (156) for Canadian population would encompass goals for moderation and can help shape appropriate educational messages for healthy weight. In addition, the next revision should acknowledge the dynamic interplay among individual lifestyle behaviours and environmental contexts by taking a socioecological evidence-based approach, such as that taken in the DGA 2015 (25, 67). Furthermore, advancing evidence-based nutrition for developing dietary guidelines requires nutrition research that goes beyond randomized controlled trials due to the complexity of nutrient interactions and eating patterns (167). Dietary pattern modelling and linkage with health outcomes offer great potential for development of evidence-based comprehensive dietary guidelines for decreasing the risk of obesity and other chronic diseases in Canada.

Supplementary Figure 6.1. Development process for the Eating Well with Canada's Food Guide 2007[1]



Satisfactory: Meeting the target nutrient requirement for pre-specified nutrients

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Chapters 5 and 6 clearly demonstrated the limitations of the Canadian EWCFG 2007 and the *a priori* index developed based on this guideline (i.e., HCST 2014). In Chapter 7, the validity and reliability of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI), developed based on the most recent US Dietary Guidelines for Americans (DGA), were evaluated. This *a priori* index was then applied to the Canadian national nutrition survey to examine its relationship with obesity risk among Canadians.

Chapter 7

7 Study # 4: Following the 2015 Dietary Guidelines for Americans (DGA) Leads to a More Nutrient-Dense Diet and Lower Risk of Obesity

This manuscript has been re-submitted to the *"American Journal of Clinical Nutrition"* after revision for publication: Jessri M, Lou WY, L'Abbé MR. Following the 2015 Dietary Guidelines for Americans (DGA) Leads to a More Nutrient-Dense Diet and Lower Risk of Obesity. American Journal of Clinical Nutrition (Under-review and revisions submitted).

This study addressed the objective #4 of my thesis, to:

- Examine the validity and reliability of the 2015 DGAI for measuring diet quality of Canadians and test its relationship with diet quality and risk of obesity with and without an accompanying chronic disease (unhealthy and healthy obesity) among participants of the CCHS 2.2

Student's contribution:

I conceptualized and designed the original study, independently performed all coding of this project, ran the analyses at the Research Data Center of Statistics Canada, prepared data tables, and interpreted the results. I also independently drafted the final manuscript and submitted the revised version to the "*American Journal of Clinical Nutrition".*

7.1 Abstract

Background: Dietary pattern analysis represents a departure from the traditional focus on single foods and nutrients and provides a comprehensive understanding of the role of diet in chronic disease prevention and etiology. Dietary patterns of Canadians have not been evaluated comprehensively using an updated *a priori* dietary quality index.

Objective: The aims of this research were to update the Dietary Guidelines for Americans Adherence Index (DGAI) based on the 2015 DGA, evaluate its construct validity and reliability, and examine whether closer adherence to this index is associated with lower risk of obesity with/without an accompanying chronic disease.

Design: Data from 11,748 participants (≥18 years) in the cross-sectional Canadian Community Health Survey 2.2 were used in weighted multivariate analyses. Multinomial logistic regression was used to test the association between diet quality and obesity risk.

Results: Principal Component Analysis confirmed multidimensionality of the 2015 DGAI and high Cronbach's Alpha (0.75) demonstrated its reliability. Moving from the first to the fourth (healthiest) quartile of the 2015 DGAI score, there was a trend towards decreased energy (2492±26 vs. 2403±22 kcal) and nutrients of concern (e.g., sodium), while intakes of beneficial nutrients increased ($p<0.0001$). In the age- and sex-adjusted model, lack of adherence to the 2015 DGA recommendations increased the odds ratio (OR) of being unhealthy obese from (OR: 1.42 (CI: 1.02,1.99)) in quartile 3, to 2.08 (1.49,2.90) in quartile 2, and 2.31 (1.65,3.23) in the first quartile of the 2015 DGAI score, compared to the fourth quartile (healthiest) (p-trend<0.0001). The odds of being obese without a chronic disease (healthy obese) and having a chronic disease without being obese also increased in the lowest DGAI quartile compared to the highest, albeit not as much as the unhealthy obese group.

Conclusions: The 2015 DGAI provides a valid and reliable measure of diet quality among Canadians.

Key words: Dietary pattern, Dietary Guidelines for Americans Adherence Index (DGAI), validity and reliability, obesity, chronic diseases, Canada

7.2 Introduction

The prevalence of obesity and other chronic diseases increase drastically every year worldwide, and some researchers attribute the failure in halting these epidemics to the extensive focus of preventive nutrition research on single foods and nutrients (168). Examining dietary patterns is increasingly recognized as an approach for informing public health recommendations, especially as methods for assessing dietary patterns are improved and the evidence-base is strengthened. A recent example is the U.S. Department of Health and Human Services (HHS) and the U.S. Department of Agriculture (USDA) 2015-2020 Dietary Guidelines for Americans (DGA), which is largely informed by the evidence reviews of healthful dietary patterns, rather than single foods or nutrients (67). Using a dietary pattern approach is also at the core of the conceptual models adopted by the Australian Dietary Guidelines committee (33).

The first *a priori* dietary guidelines-related dietary quality index (13) was proposed by Kennedy and colleagues to measure the degree of adherence to the 1995 DGA dietary recommendations (78). *A priori* methods measure the degree of adherence to national/ international dietary guidelines and are therefore reproducible tools suitable for comparison (11).

To address the limitations of previous dietary indexes, Fogli-Cawley et al. developed the 20-score 2005 Dietary Guidelines for Americans Adherence Index (DGAI), which is the only dietary guidelines-related index focused on both energy overconsumption and energy density (80). Instead of the *"one size fits all"* approach of other dietary quality indexes, the DGAI evaluates diet quality in terms of adherence to the 12 USDA Food Patterns based on individuals' energy needs (80). One of the advantages of DGAI compared to other indexes is penalizing individuals for overconsumption of energy-dense foods (i.e., starchy vegetables, grains, meat, and dairy) in order to limit the likelihood of receiving higher scores solely due to excessive food intakes (80). Adherence to the 2005 DGAI has been associated with reduced risk of several diseases, even though the validity and reliability of this index has not been confirmed systematically (169-173).

To date, the dietary patterns of Canadians have not been comprehensively examined using an *a priori* dietary guidelines-related dietary quality index, mainly due to the lack of a "total diet" approach and energy-based dietary guidelines in Canada (27). The purpose of this study was to update the 2005 DGAI to reflect changes in the 2015 DGA, and to evaluate its validity and reliability using the Canadian national nutrition survey. This updated index was then used to evaluate whether closer adherence to the 2015 DGAI is associated with lower risk of obesity with and without an accompanying chronic disease (unhealthy and healthy obese), the underlying premise of the 2015 DGA. Although the scientific community has recognized the importance of differentiating obesity phenotypes, less attention has been given to this issue in nutritional epidemiology (174).

7.3 Subjects and methods

7.3.1 Study population

Data used in this research were from the Canadian Community Health Survey (CCHS) cycle 2.2 (2004/5), which provides the most complete nutritional data on Canadian dietary intakes and is the only available national nutrition survey in >30 years (96). Data were collected under the authority of the Statistics Act of Canada and all analyses were conducted at the Statistics Canada's Research Data Center. CCHS 2.2 is a complex multistage cross-sectional survey, including 35,107 Canadians from 10 provinces representing >98% of the Canadian population (96). More details on the CCHS 2.2 sampling framework and survey procedures have been previously published (96). For the purpose of this study, all pregnant and lactating women, those under 18 years of age, individuals with invalid dietary recalls (as defined by Statistics Canada), or with missing values for physical activity, energy intakes and measured weight and height were excluded. To be able to evaluate the face-validity of the 2015 DGAI through its association with lifestyle and socio-economic characteristics, individuals with missing values for these variables were additionally removed, leaving a total of 11,748 Canadian adults for these analyses.

The final sample represented the Canadian population homogenously, as the general socio-economic and lifestyle characteristics of participants who were included in the final analyses were similar to those who were excluded due to missing variables (data not shown).

7.3.2 Exposure and outcome ascertainment

A modified version of the USDA Automated Multiple Pass Method (AMPM) was used to collect two 24-hour dietary recalls (98, 99). Since the second recall was only collected from 30% of total population, only the first dietary recall was used in all analyses (96). Respondents reported all foods and beverages consumed in the past 24 hours (midnight to midnight) and nutrient composition of reported foods was analysed using Health Canada's Canadian Nutrient File (CNF) (2001b Supplement) (100). Since added sugars are not included in the CNF, the method proposed by Brisbois et al. was used to derive estimates of added sugars (175). Dietary energy density was calculated by dividing the total energy from foods (Kcal) by total weight of foods (in grams) (excluding beverages)(108).

Data on socio-demographic characteristics and lifestyle behaviours were collected using interviewer-administered questionnaires (96). Data collection interviews and anthropometric measurements took place in person at participants' homes (96). Height and weight were measured according to the standard protocols and body mass index (BMI) was calculated. Overweight and obesity were defined as BMI ≥25-29.99 kg/m^2 and ≥30 kg/m^2, respectively. Presence of diabetes, hypertension, cardiovascular diseases, and cancer was determined using self-report of a medical diagnosis and/or presence of any chronic diseases.

7.3.3 Dietary Guidelines for Americans Adherence Index (DGAI)

The DGAI is an *a priori* diet quality index that assesses adherence of dietary intakes to 20 main dietary recommendations of the 2005 DGA and USDA Food Patterns (80). In the present study, we revised the 2005 DGAI based on the 2015 USDA Food Patterns and evaluated the construct validity and reliability of the revised index. The DGAI distinguishes between energy-specific dietary recommendations and healthy choice nutrient recommendations. Of the 20 total DGAI components, 11 evaluate energy-specific "food intake" recommendations (based on the 12 energy-based USDA Food Patterns), while 9 evaluate universal "healthy choice" nutrient recommendations (80). The "food intake" recommendations are specific to the energy needs of each individual, while "healthy choice" recommendations are presented in absolute amounts or percentage of energy and are the same for all individuals (80).

In the present study, only 19 DGAI components were available since one component of the "healthy choice" recommendations (i.e., *trans* fat) was not attainable due to lack of data on *trans* fat values of Canadian foods in the CNF (100). Each of the 19 components had a maximum score of 1.0, therefore, the maximum possible 2015 DGAI score was 19 points. The scoring scheme proposed by Imamura et al. in 2009 was adopted in this research so that instead of discrete scores of 0, 0.5 or 1 for each DGAI component, individuals were given a continuous score from 0 (total non-adherence) to 1 (complete adherence) proportional to their intake amounts (170). This is important since dichotomized scoring may conceal the true variability in dietary intakes and diminish the score range. More details regarding the calculation of the DGAI is published previously (80, 170). An example based on the 2000 Kcal Food Pattern is presented in the Supplementary Table 7.1, providing full details of the scoring scheme for the 2015 DGAI.

a) "Food Intake" Subscore

To calculate the "food intake" subscore, individuals' estimated energy requirements (EER) were first calculated using Institute of Medicine (IOM) factorial equations based on participants' measured height, weight, physical activity level (PAL) (sedentary, low active, moderately active, highly active), age, and sex (112). Based on their calculated EER rounded to the nearest 200 kcal, individuals were assigned to one of the corresponding USDA Food Patterns, which includes recommendations for 5 vegetable subgroups (dark green vegetables, red/orange vegetables, other vegetables, starchy vegetables and legumes), fruits, variety of fruits and vegetables, grains, meat and beans, dairy and added sugar. For each of these 11 “food intake” recommendations, individuals were scored proportionally from 0 to 1, with zero representing total non-adherence and 1 reflecting total adherence to the recommended food intakes. Zero intakes of food groups recommended in the 2015 DGA also received zero scores (170). The total sum of 11 scores was defined as “food intake” sub-score and reflected adherence to energy-specific USDA Food Pattern recommendations.

Legumes were counted towards the meat and beans group if participants needed to meet the recommended meat and beans score (i.e., as a lean meat alternative) (80). The legume servings not needed for attaining the recommended meat and beans servings were counted towards the legumes recommendations to avoid penalizing participants for over-consuming the meat group (80). Variety component gave credit to individuals who ate a variety of fruits and vegetables, even if they did not meet the serving recommendations for each of the 6 vegetables and fruit components. Variety score was calculated by summing the scores of all 6 vegetables and fruit components.

Starchy vegetables, grains, meat and dairy were considered energy-dense as their energy per serving was on average >50 calories based on the distribution of values for the different food groups (80). A penalty was imposed for overconsumption of these four food groups by reducing the component score proportional to the amount of overconsumption up to intakes 1.25 times higher than the recommended (170). Participants were penalized by maximum 0.5 points for overconsumption amounts ≥1.25 times the recommendations (truncation) (170). For example, an individual requiring 2000 Kcal is recommended to consume 3 cups/day of dairy to receive the full 1.0 score for this food group (Supplementary Table 7.1). If the individual consumes 3.5 cups/day, then a penalty of 0.17 points (0.5 cups over-consumption/3 cups recommendation) is imposed, leaving him/her with 0.83 score (1.0-0.17) for dairy. However, if the individual consumes any amount of dairy above 3.75 cups/day (1.25 times higher than the recommended 3 cups), he/she will only be penalized by a maximum of 0.5 points (1-0.5).

b) "Healthy Choice" Subscore

The 8 components of "healthy choice" subscore measured compliance with nutrient intake recommendations based on predetermined cut-off points, regardless of participants' EER. The following "healthy choice" index components were assessed: percentage of grains as whole, fiber intake, 4 recommendations related to fat (total fat, saturated fat, cholesterol, low-fat products), sodium intake and alcohol consumption. Adherence to each of the above-mentioned components was scored proportionally by a value that ranged from 0 to 1, with components such as fat, sodium and alcohol being reverse-coded (the higher intakes received lower scores within a recommended threshold).

7.3.4 Identification of implausible reporters

Previously, our group demonstrated widespread prevalence of misreporting among CCHS 2.2 participants (14). In this research, each participant was classified as under-reporter, plausible reporter or over-reporter according to the comparison of their reported energy intake and their calculated EER as described by our group previously (14). Since the IOM factorial equations used in this research require individuals' PAL (ratio of total energy expenditure to basal energy expenditure), the Metabolic Equivalents (MET) (Kcal/kg/day) (intensity of an activity compared to the resting metabolic rate) values available in the CCHS 2.2 were converted using the IOM method (112). McCrory et al.'s method (36) (and its updated versions (23, 63)) for four different levels of physical activity was then used to directly compare the energy intake (EI) and EER using cut-offs for their agreements based on error propagation calculations (36). All confidence intervals (CI) were constructed in the Log scale and cut-offs exponentiated to account for the skewed EI distribution in CCHS 2.2 (14, 19). Based on our dataset, participants whose EI was <70% of their EER were categorized as under-reporters, and those with EI >142% of their EER were classified as over-reporters (±1SD). Equations used for this calculations have been published previously (14, 19, 23, 36).

7.3.5 Statistical analyses

All analyses were conducted using SAS software (version 9.4; SAS Institute Inc., Cary, NC) and a two-tailed p-value <0.05 was used to define statistical significance. To account for the CCHS 2.2 complex multistage sampling framework, variance estimation was performed using bootstrap balanced repeated replication (BRR) technique (114). Briefly, a replicate weight was generated by randomly selecting a sample (with replacement) from the original sample and applying all the adjustments to the selected sample. This exercise was repeated 500 times to develop 500 sample survey weights which were used for estimating the variance. To ensure a nationally-representative sample, all analyses were weighted using the specific sample survey weight calculated by Statistics Canada. Survey weighting is an adjustment technique that considers the complex sampling design and non-response bias of national surveys to ensure that final estimates are representative of the target population (96).

The population distributions of total 2015 DGAI score and the "food intake" and "healthy choice" subscores were examined. The 2015 DGAI was distributed normally and was divided into quartile categories based on the population distribution (Quartile 1: 2.34-7.41; Quartile 2: 7.42-8.82; Quartile 3: 8.83-10.29; and Quartile 4: 10.30-15.60), consistent with previous studies (80, 169, 170, 176). Covariate-adjusted associations between 2015 DGAI score and continuous and categorical variables were determined using the weighted multivariable linear regression and the least-squares means, respectively. The p-value for linear trend across the quartiles of the 2015 DGAI was calculated using the DGAI variable entered as continuous. P-trend then represented the p-value related to the linear regression coefficient (continuous dependent variables) (PROC SURVEYREG) or the logistic regression coefficient (categorical dependent variable) (PROC SURVEYLOGISTIC) in relation to the 2015 DGAI score.

7.3.5.1 Validity and reliability of the 2015 Dietary Guidelines for Americans Adherence Index

a) Construct Validity

1) In the first step, the concurrent-criterion validity and face validity were evaluated to test whether the 2015 DGAI could distinguish between population subgroups with known differences in dietary habits. Since previous studies have consistently shown that females, older adults and non-smokers have better quality diets, we assessed the ability of the 2015 DGAI to identify diet quality differences of these groups using weighted analysis of covariance (ANCOVA) adjusted for age and sex (sex only adjusted for age, and age only adjusted for sex) (Supplementary Table 7.2). Face validity of the 2015 DGAI was also examined by evaluating whether it relates to the participants' characteristics and nutrient intakes in the expected direction based on prior knowledge (177, 178). Weighted ANCOVA was used to compare socio-demographic, lifestyle and dietary characteristics of participants across the quartile categories of the 2015 DGAI, with adjustment for age, gender and energy intake (for food groups only) (Tables 7.1-7.3). All analyses pertaining to nutrient intakes were reported in either nutrient density (per 1000 kcal) (142) or percentage energy to control for confounding and reduce extraneous measurement error and variability (110).

2) To ensure that the 2015 DGAI could evaluate diet quality of Canadians independent of their diet quantity (energy intake), weighted Pearson correlation coefficients of the total 2015 DGAI score and its components with energy intakes were assessed (Table 7.4). Since food and nutrient intakes are positively correlated with energy intakes, individuals with higher energy intakes are more likely to receive higher diet quality scores, unless the index is uncoupled from energy intakes. This indicates that individuals should not receive higher diet quality scores solely due to consuming higher energy and hence meeting the minimum dietary intake requirements for food groups and nutrients (179). Low correlations of diet quality scores and energy intake would reflect independence of diet quality scores from diet quantity.

3) Weighted Principal Component Analysis (PCA) (PROC PRINCOMP) was applied to the data to examine the underlying structure of the 2015 DGAI and to assess the number of dimensions accounting for the systematic variations in the data (Supplementary Figure 7.1). PCA determined the correlations among index items and identified the number of underling independent dimensions within the index.

b) Reliability

The relationships among individual index items (inter-component) were assessed using the weighted Pearson correlation analysis (Table 7.4). To determine the components with most influence on the total score, the correlations of each component with the total score (minus that component score) was examined. Internal consistency of the 2015 DGAI was assessed using Cronbach's coefficient α, which examines the degree of components' association within the 2015 DGAI. Nunnally and Bernstein (1994) have indicated reliability coefficients >0.7 as acceptable for group-level comparisons, which was used in this study (180).

7.3.5.2 Adherence to the 2015 Dietary Guidelines for Americans Adherence Index and risk of obesity

To examine the relationship between adherence to the 2015 DGAI and risk of overweight/obesity, multinomial logistic regression- generalized logit model (PROC SURVEYLOGISTIC) was conducted using a classification variable indicating overweight and obesity as outcomes of interest and quartiles of 2015 DGAI as exposure measures. Linearity assumption of the relationship between 2015 DGAI score and BMI in its continuous form was closely examined by weighted PROC LOESS. Quartile 4 was chosen *a priori* as the reference category in all regression analyses since we hypothesized that our outcome of interest (obesity) would be higher in the lowest quartile of 2015 DGAI score, compared to the highest. Potential confounders were selected from the literature and were further examined in a weighted back-ward regression model. Covariates with the least influence on the information criteria and regression coefficient were excluded. Potential confounders were then tested in the following four successive models: Model 1 (basic model) was adjusted for age and sex only; Model 2 was adjusted for Model 1 variables in addition to the misreporting status (under-reporting, plausible reporting and over-reporting); Model 3 was adjusted for Model 2 variables in addition to energy intake and PAL (inactive, moderately active and active); and Model 4 was adjusted for Model 3 variables as well as smoking status (daily, occasional, former, never).

To compare the predictive and discriminative value of different statistical models relating 2015 DGAI adherence and obesity risk, area under the receiver operating curve (ROC AUC) was used (c-statistic). AUC appraised the ability of 2015 DGAI score (in its continuous form) to accurately classify obese and non-obese subjects (181). Covariate-adjusted models (stated above) were compared for statistical difference according to the Janes et al.'s recommendation (182). Model selection results were consistent with the Akaike information criterion (AIC) and Bayesian information criterion (BIC) results.

Finally, regression analysis models were stratified to investigate the association of 2015 DGAI and risk of obesity with and without at least one chronic disease (e.g., diabetes, hypertension, heart disease, or cancer) ("unhealthy" and "healthy obese"), as well as risk of having at least one chronic disease without being obese. Recently, there has been suggestions that there is a subgroup within the obese population who lack the clustering of metabolic risk factors and are therefore "metabolically healthy" but obese (183, 184). The definition of metabolically unhealthy individual for this research was self-reported medical diagnosis of any of the chronic diseases among Canadians in national survey. The presence of all chronic diseases were pooled consistent with previous research (185), since the 2015 DGA is also aimed at reducing the overall risk of chronic diseases.

7.4 Results

7.4.1 Validity and reliability of the 2015 Dietary Guidelines for Americans Adherence Index

a) Construct Validity

The distribution of the 2015 DGAI score followed a normal distribution and was wide enough to detect meaningful differences (Figure 7.1). The mean 2015 DGAI score and its two subscores ("food intake" and "healthy choice") were 8.82 (±0.05), 3.92 (±0.04) and 4.90 (±0.03), respectively, which indicates that the Canadian population was adherent to less than 50% of 2015 DGA recommendations. Face validity of the 2015 DGAI was confirmed as the total DGAI score was associated as expected with several socioeconomic and lifestyle characteristics (Table 7.1). Participants in the highest DGAI quartile (healthiest diet quality) were more likely to be female (61.95 vs. 37.7%; p-trend<0.0001), older (51.19 vs. 41.87 years; p-trend<0.0001), multi-vitamin supplement user (47.27 vs. 39.37%; p-trend:0.0069), married (62.62 vs. 53.86%; p-trend<0.0001), and urban resident (84.06 vs. 79.48%; p-trend:0.0047) with higher educational attainment (56.31 vs. 42.86%; p-trend<0.0001), compared to those in the lowest quartile category (mean, p-trend). In addition, they had lower BMIs (26.57 vs. 28.07 kg/m^2; p-trend<0.0001) and were less likely to drink alcohol (77.74 vs. 87.03%; p-trend<0.0001), be low-active (51.68 vs. 64.58%; p-trend<0.0001), daily smoker (13.29 vs. 32.57%; p-trend<0.0001) and to skip breakfast (5.12 vs. 14.78%; p-trend<0.0001).

Concurrent criterion validity tests revealed that the mean 2015 DGAI score was significantly higher in women compared to men (9.28±0.05 vs. 8.56±0.06) and in older adults compared to younger adults in the age- and sex-adjusted models (p-trend <0.0001) (Supplementary Table 7.2). Similarly, the mean 2015 DGAI score was higher in the never-smoker group (9.28±0.05) compared to the occasional, former and daily smokers (8.11±0.08) (p-trend <0.0001).

After adjusting for age and sex, all nutrients examined (except for percentage of energy from polyunsaturated fatty acids (PUFA), linoleic acid, linolenic acid, and vitamin B12 density) were significantly associated with the 2015 DGAI score (Table 7.2). Specifically, there was a significant positive trend for association of the DGAI score and %energy from carbohydrates and densities of protein, calcium, vitamin A, vitamin D, vitamin C, thiamin, riboflavin, niacin, vitamin B_6, folate, folacin, phosphorus, magnesium, iron, zinc and potassium. On the other hand, energy intake, percentage of energy from monounsaturated fatty acid (MUFA) and alcohol as well as cholesterol, sodium, caffeine, glycemic index and energy density showed inverse linear trend with the 2015 DGAI score (p-trend <0.01). Similarly, when the "food intake" and "healthy choice" subscores were examined, individuals in the highest quartile category of the 2015 DGAI had lower mean intakes of added sugars (%energy), total fat (%energy), saturated fat (%energy), cholesterol (mg), sodium (mg), and alcohol (drink), while their intakes of fruits and vegetable subgroups were higher with significant linear trends (p-trend<0.0001) (Table 7.3). Further adjustment for misreporting status did not have any effect on the direction and significance of any of these trends (Model b in Tables 7.2 and 7.3).

Multidimensional radar plots were built to represent the percentage of compliers and intermediate compliers as well as under- and over-consumers for each of the 2015 DGAI components (Figure 7.2). Each spoke of the radar plots shows an individual DGAI component and each line colour represents a different category of compliance. The largest outer circle represents 100% prevalence and the smallest circle represents 0%. None of the participants adhered to all 2015 DGAI recommendations. Only 4.7%, 22%, 4.9%, 36.2%, and 7.7% of participants scored >0.9 (possible maximum score: 1.0 point) for each of the 5 vegetable subgroup recommendations, including starchy vegetables, dark green vegetables, red/orange vegetables, other vegetables, and legumes, respectively. The low scores for meat and beans and grains were mainly caused by overconsumption of these food groups, rather than underconsumption (Figure 7.2A). In addition, 60.5% and 43.46% of Canadians overconsumed added sugars and sodium, respectively.

To ensure that the total DGAI score measures diet quality independent of energy, the correlation of energy intake with the DGAI score was determined (Table 7.4). The total DGAI score had a negative correlation with energy intake (r=-0.16), and the correlation coefficients between each index component and energy were also small for all index components, except for sodium recommendation (r=-0.61).

To explore the dimensionality of the 2015 DGAI and the number of principal components to retain, the weighted PCA scree plot and the criterion of eigenvalues>1 were used. The scree plot curve levelled off at around five dimensions explaining 45.58% of total 2015 DGAI variation (Supplementary Figure 7.1). Using the criterion of eigenvalues exceeding 1, eight principal components were retained explaining 61.73% of total variation in the 2015 DGAI score. These results confirm the multidimensionality of 2015 DGAI score and show that none of the individual 2015 DGAI components account for the majority of variation in the key guidance that makes up the total score.

b) Reliability

The standardized Cronbach's coefficient α for the 2015 DGAI components was 0.75 (unstandardized: 0.74) and it did not change significantly after removing a variable from the constructs (data not shown). The correlations between the 2015 DGAI score and the "food intake" (r=0.73) and "healthy choice" (r=0.71) subscores were high, while the subscores were not intercorrelated (r=0.03) (Table 7.4). The correlation coefficients of total 2015 DGAI score with individual component scores were all significant and positive, ranging from r=0.10 for dairy and r=0.11 for grain scores, to r=0.69 for variety of fruits and vegetables and r=0.64 for fiber density scores. Similarly, the "food intake" subscore was strongly correlated with variety score (r=0.90) and most weakly correlated with alcohol score (r=-0.05). The "healthy choice subscore”, on the other hand, was most strongly correlated with total saturated fat score (r=0.60) while grains contributed the lowest correlation coefficient (r=0.01).

7.4.2 Adherence to the 2015 Dietary Guidelines for Americans Adherence Index and Risk of Obesity

Moving from the highest quartile of the 2015 DGAI score (healthiest, reference quartile) to the lowest (unhealthiest), the age- and sex- adjusted odds ratio (OR) of obesity increased monotonically, from 1.42 (95% CI: 1.1,1.84) in quartile 3 to 1.81 (1.39,2.36) in quartile 2, and 1.92 (1.5,2.45) in quartile 1 (p-trend<0.0001) (Figure 7.3). Further adjustment for the misreporting status (Model 2) strengthened all associations across the quartiles, with participants in quartile 1 vs. quartile 4 showing 2 times higher risk of obesity (p-trend<0.0001). The direction and significance of the association persisted after mutual adjustment for all potential confounders including energy intake, physical activity level, and smoking status, even though the magnitude was attenuated (Models 3 and 4) (p-trend<0.0001). The ROC AUC ranged from 0.57 in Model 1 to 0.61 in Model 2 and 0.66 in Model 3 and model 4, which confirms predictive accuracy of 2015 DGAI score for discriminating the obese and non-obese subjects in this study (Supplementary Figure 7.2).

Finally, participants were jointly classified by their weight and chronic disease status. Lack of adherence to the 2015 DGAI recommendations increased the odds of being unhealthy obese from 1.42 (1.02,1.99) in quartile 3, to 2.08 (1.49,2.9) in quartile 2 and 2.31 (1.65,3.23) in the first quartile of the 2015 DGAI score (Model 1) (p-trend<0.0001) (Figure 7.4). Even though the probability of being obese without having a chronic disease (healthy obese) [2.17 (1.4,3.38), p-trend<0.0001], and risk of having a chronic disease without obesity [1.41 (1.02,1.94), p-trend:0.0054] also increased in the lowest quartile of the 2015 DGAI score compared to the highest, the magnitude of these associations was slightly smaller. Additional adjustment for misreporting status in Model 2 strengthened the associations. In the multivariate adjusted model (Model 4), lack of adherence to the DGA guidance (quartile 1) was still positively associated with the risk of being unhealthy obese (OR: 2.17 (95%CI: 1.53,3.08)), healthy obese (2.04 (1.30,3.19)) and unhealthy non-obese (1.37 (0.98,1.93)), compared to the highest quartile category (p-trend<0.0001).

7.5 Discussion

To our knowledge this is the first examination of population compliance to the HHS/USDA 2015 DGA in relation to several dietary and chronic disease risk factors. In addition, this is the first evaluation of dietary patterns of Canadians using a multidimensional *a priori* dietary quality index (DGAI) which is based on 12 different levels of energy requirement. Our results demonstrated strong and consistent evidence of validity and reliability of the 2015 DGAI for measuring diet quality of Canadian adults. Face validity and concurrent criterion validity of the 2015 DGAI were confirmed through its robust association with various socioeconomic, lifestyle and dietary characteristics in the expected direction. The 2015 DGAI score was higher among females, older individuals, and those who were physically active, non-smoker, urban resident, leaner and vitamin supplement user. We also noted that because the total DGAI score simultaneously represents many diet quality aspects, intakes of several macro- and micronutrients not explicitly built into the index were also higher with closer adherence to the 2015 DGAI recommendations. However, none of the participants reported complete adherence to the 2015 DGA recommendations, especially for energy-based recommendations of starchy vegetables, grains, meat and dairy, which were over-consumed, as also shown previously among Canadians (126, 127). Importantly, lack of compliance to the 2015 DGAI guidance in this study was associated with 2.31 and 2.17 times higher risk of obesity with and without an accompanying chronic disease and 1.41 times higher risk of having a chronic disease without obesity.

The 2015 DGAI score was able to uncouple the quantity and quality of food consumption, since it has been developed to ensure individuals would not receive higher scores solely by energy overconsumption (80). This is in contrast to other indexes (e.g., Alternative Healthy Eating Index, alternate Mediterranean diet, and Dietary Approaches to Stop Hypertension) which have shown positive associations with energy intakes (185-188). This may be explained by the underlying scoring scheme of the DGAI which is based on 12 levels of energy requirement with an overconsumption penalty, as opposed to having absolute cut-points or using the density approach.

When individual component scores were investigated separately, none of them were driving the associations, confirming that components work synergistically to form the total index score (80, 169, 170, 176). The PCA results confirmed multidimensionality of 2015 DGAI and found no evidence of a single systematic underlying structure among the 19 components of the DGAI that would explain much of the variation in data. This finding is in line with those evaluating the Healthy Eating Index (HEI) (179), and suggests that each of the 19 components provide additional important and valuable information regarding Canadian adults' diet quality, in addition to the total sum score. The reliability (internal consistency) of the 2015 DGAI was also confirmed by high Cronbach's α which indicates that the overall score captures the construct of "diet quality" among Canadian adults with adequate confidence. Total variation in the 2015 DGAI score directly reflected variation in individual components that had high correlations with the total score (i.e., variety of fruits and vegetables, and fiber density). Index items such as dairy and grains, which had the least correlation with total 2015 DGAI score, similar to the 2010 HEI score (179), did not necessarily add variation to the total score, but rather provided important independent information about diet quality (179).

The significant gains seen in obesity risk with each quartile of the 2015 DGAI score suggests that even small improvements in diet quality may have meaningful health benefits. Assessment of different subgroups within the obese and non-obese population is essential, since recent studies suggest that the "metabolically healthy" obese phenotype may not present the same range of metabolic disorders as the "metabolically unhealthy" obese (189). In the present study, lack of adherence to the 2015 DGAI recommendations was consistently associated with higher risk of unhealthy obesity closely followed by healthy obesity and being unhealthy non-obese. Since confidence intervals for healthy and unhealthy obese estimates were overlapping, these findings highlight the potential benefits of adhering to the 2015 DGA recommendations for preventing obesity, regardless of the chronic disease status. Additional adjustment for the misreporting bias slightly strengthened diet-disease relationships in line with previous studies (14, 190). These results are consistent with those of previous research which showed inverse associations between adherence to the DGA and risk of obesity, metabolic syndrome, insulin resistance, and coronary artery atherosclerosis (80, 169-173, 176). A prospective cohort study in France compared how the 2005 DGAI, Diet Quality Index-International, French Guideline Score, Mediterranean Diet Scale, relative Mediterranean Diet Score and the Mediterranean Style Dietary Pattern Score (MSDPS) were associated with weight change over 13 years of follow-up (191). Even though scores for all indexes (except for MSDPS (192)) were significantly associated with reduced risk of becoming obese after 13 years in men, adherence to the 2005 DGAI provided the highest benefit (191). The predictive validity of the DGAI was confirmed in another prospective study where 1SD difference in weighted DGAI score was associated with 0.049-mm less coronary artery narrowing over a 3-year period (170).

In our study, even those in the highest quartile category of the DGAI (healthiest) still had significant room for improvement (median DGAI score: 11.29/19). Future research needs to examine the benefits that could be achieved by attaining more optimal dietary quality scores.

7.5.1 Strengths and limitations

This is the first and the largest study to examine the validity and reliability of the 2015 DGAI and to evaluate the benefits of following the 2015 USDA Food Patterns in relation to the risk of obesity with and without other chronic diseases. Accounting for the misreporting bias using McCrory et al.'s algorithm-based method (36), using the measured anthropometry and collecting comprehensive dietary and lifestyle data were important strengths of this research. To minimize floor and ceiling effects, we used a proportional scoring scheme (170), instead of the original DGAI dichotomous scoring system with fixed binary cut-off levels (80).

Despite our study's potential public health impacts, findings should be considered in light of few limitations. Random non-differential error associated with use of dietary recalls and calculation of EERs may have led to conservative estimates (92). In addition, the cross-sectional design of this study limits the causal inference. The third limitation is that self-reported measures were used to classify subjects with and without chronic diseases; however, the magnitude and direction of our results were consistent and robust. Another limitation is that we were unable to calculate the *trans fat* component score due to lack of data in the CNF (100). Finally, since the CCHS 2.2 was conducted in 2004/5, it may not reflect current consumption trends, even though it is the only available national nutrition survey in Canada.

7.5.2 Conclusions and implications

This study provides the first evidence that compliance to the 2015 DGA recommendations is associated with higher diet quality and lower risk of obesity with and without chronic diseases. Our findings also demonstrated the validity and reliability of the 2015 DGAI as a measure of diet quality. Longitudinal studies will be needed to prospectively examine the relationship between following the 2015 DGA recommendations and weight gain in presence and absence of metabolic disorders over long periods of time, to be able to provide insights into causal effects of following the 2015 USDA Food Patterns.

Table 7.1. Weighted socio-demographic and lifestyle characteristics by quartile category of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) among Canadian adults (≥18 years) (n=11,748)[1,2]

	2015 DGAI Quartile Category				P-trend[3]
	1 (unhealthy)	2	3	4 (healthiest)	
DGAI range	2.34-7.41	7.42-8.82	8.83-10.29	10.30-15.60	
DGAI Score, *median*[4]	6.49±0.04	8.14±0.03	9.51±0.03	11.29±0.04	
Food intake subscore, *median*[5]	2.7±0.07	3.38±0.05	4.16±0.04	5.29±0.07	
Healthy choice subscore, *median*[6]	3.51±0.07	4.8±0.04	5.33±0.06	6.2±0.04	
Female, *%*	37.7±3.4	46.56±3.23	54.4±2.33	61.95±2.86	<0.0001
Age, *yr*	41.87±0.44	44.08±0.51	47.21±0.53	51.19±0.65	<0.0001
BMI, *kg/m²*	28.07±0.21	27.84±0.22	27.27±0.24	26.57±0.21	<0.0001
Obesity, *%*	27.6±1.61	27.46±1.38	23.39±1.37	20.95±1.23	<0.0001
Obese with at least one chronic disease, *%*	17.16±0.01	16.67±0.01	13.07±0.01	10.42±0.01	<0.0001
Low-active participants, *%*	64.58±2.04	58.08±1.80	56.72±2.04	51.68±2.03	<0.0001
Having at least one chronic disease, *%*	52.3±2.23	51.86±2.46	45.66±2.15	43.27±2.47	0.0022
Current daily smokers, *%*	32.57±1.66	22.15±1.33	16.49±1.00	13.29±0.95	<0.0001
Multivitamin users, *%*	39.37±2.05	43.25±1.99	46.5±1.99	47.27±1.97	0.0069
Drank alcohol in the past 12 months, *%*	87.03±1.05	81.16±1.54	79.71±1.62	77.74±1.90	<0.0001
Highest household education, *%*					<0.0001
<Secondary school	14.03±1.14	12.13±0.89	10.27±0.73	7.72±0.80	
Post-secondary education	62.7±1.87	66.52±1.94	70.55±1.67	76.62±1.50	
Highest respondent education, *%*					<0.0001
<Secondary school	24.97±1.57	21.06±1.32	19.22±1.03	16.23±1.22	
Post-secondary education	42.86±1.93	48.34±1.93	51.2±1.74	56.31±1.93	
Married, *%*	53.86±0.02	56.64±0.02	59.83±0.02	62.62±0.02	<0.0001
Single/Never married, *%*	20.09±0.01	18.34±0.01	16.46±0.01	14.9±0.01	<0.0001
Immigrant, *%*[7]	16.76±1.57	24.32±2.14	26.44±2.24	30.96±3.73	<0.0001
Aboriginal, *%*	1.78±0.28	1.51±0.34	0.73±0.17	0.78±0.22	
Caucasian, *%*	92.28±0.88	86.71±1.67	86.99±1.33	77.92±2.82	<0.0001
<5 times/day vegetables & fruits consumed, *%*	82.8±1.30	74.14±1.83	62.54±1.97	51.53±2.17	<0.0001
Excellent self-perceived health, *%*	17.54±1.17	18.65±1.35	22.26±1.25	23.92±1.40	<0.0001
Low stress level, *%*	35.29±1.85	36.64±1.92	35.04±1.81	40.58±1.93	0.0768
Highest income group, *%*	36.49±2.51	38.61±2.32	37.03±2.18	38.04±1.97	0.6674
Urban residents, *%*	79.48±1.40	79.32±1.78	82.29±1.46	84.06±1.52	0.0047
Breakfast skippers, *%*	14.78±1.67	8.75±0.91	5.94±0.78	5.12±0.83	<0.0001

BMI: Body mass index

[1]Estimates are weighted means/percentages and bootstrapped variances (Balanced Repeated Replication technique). Covariate-adjusted associations between 2015 DGAI score and continuous and categorical variables were determined using the weighted multivariable linear regression and the least-squares means, respectively.

[2]Values are adjusted for age and sex, unless otherwise noted. Age is adjusted for sex only and gender is adjusted for age only.

[3]The p-trend was estimated using the 2015 DGAI in its continuous form and represents the p-value associated with linear regression coefficient for continuous variables and the logistic regression coefficient for the categorical variables.
[4]Possible scores for the 2015 DGAI ranged from 0-19, with higher scores indicating more healthful and varied dietary patterns.
[5]Scores ranged from 0-11 possible points and are evaluated based on energy level
[6]Scores ranged from 0-8 possible points and are evaluated on the same energy level for all participants.
[7]"Immigrant Status" was defined by Statistics Canada in response to the following question: "In what year did you first come to Canada to live? (Possible responses: 1) Year: Immigrant flag; 2) NA: Non-immigrant; 3) Don't know/Refused to Say/Not Stated: Not-Stated)". Please note that this question was asked from respondents who indicated that "they were not Canadian citizen by birth". Participants also answered another question: "In what country were you born?". A derived variable was then created based on collective responses to these 3 questions that indicated "Immigrant Status".

Table 7.2. Weighted mean daily intakes of macro- and micronutrients reported as percentage of energy or per 1000 kcal (nutrient density) by quartile category of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) among Canadian adults (≥18 years) (n=11,748)[1,2]

	Model	**2015 DGAI Quartile Category**				**P-trend**[3]
		1 (unhealthy)	**2**	**3**	**4 (healthiest)**	
DGAI range[4]		2.34-7.41	7.42-8.82	8.83-10.29	10.30-15.60	
Energy intake,	*a*	2206±54	2074±68	2058±34	2029±35	0.0079
Kcal/day	*b*	2492±26	2439±32	2432±24	2403±22	0.0182
Carbohydrate, *% Energy*	*a*	43.35±0.45	48.53±0.46	50.76±0.41	53.25±0.38	<0.0001
	b	43.11±0.46	48.17±0.50	50.4±0.45	52.91±0.44	<0.0001
Monounsaturated fatty acid, *% Energy*	*a*	14.42±0.18	12.88±0.23	12.06±0.16	11.17±0.18	<0.0001
	b	14.53±0.19	13.08±0.20	12.25±0.18	11.34±0.20	<0.0001
Polyunsaturated fatty	*a*	5.6±0.09	5.64±0.12	5.73±0.11	5.63±0.11	0.8299
acid, *% Energy*	*b*	5.67±0.10	5.74±0.11	5.83±0.11	5.72±0.12	0.7165
Linoleic acid, *%*	*a*	4.41±0.08	4.55±0.09	4.57±0.10	4.46±0.09	0.4618
Energy	*b*	4.46±0.09	4.64±0.10	4.66±0.10	4.54±0.10	0.2783
Linolenic acid, *%*	*a*	0.8±0.02	0.8±0.03	0.83±0.02	0.81±0.03	0.8609
Energy	*b*	0.81±0.02	0.81±0.03	0.84±0.02	0.82±0.03	0.8318
Protein, *% Energy*	*a*	15.52±0.25	15.95±0.29	16.78±0.27	17.36±0.22	<0.0001
	b	15.56±0.25	15.91±0.29	16.77±0.28	17.38±0.23	<0.0001
Alcohol, *% Energy*	*a*	4.64±0.31	3.39±0.31	2.32±0.18	1.56±0.14	<0.0001
	b	4.64±0.31	3.42±0.36	2.34±0.21	1.57±0.18	<0.0001
Cholesterol density,	*a*	174.58±4.85	146.81±5.58	129.48±4.01	108.68±2.92	<0.0001
mg/1000 kcal	*b*	173.97±4.80	145.13±5.43	128.09±4.09	107.52±3.69	<0.0001
Calcium density,	*a*	405.39±6.91	402.13±7.69	438.06±8.34	453.49±8.41	<0.0001
mg/1000 kcal	*b*	400.18±7.19	394.94±8.13	430.88±8.78	446.44±8.62	<0.0001
Vitamin A density in	*a*	286.18±10.12	310.1±10.55	412.73±36.34	457.95±15.81	<0.0001
retinol activity equiv., *µg/1000 kcal*	*b*	284.47±9.80	305.61±11.20	408.97±33.27	454.8±15.45	<0.0001
Vitamin D density,	*a*	2.5±0.10	2.67±0.13	2.87±0.11	3.3±0.18	0.0004
µg/1000 kcal	*b*	2.56±0.13	2.74±0.17	2.95±0.13	3.38±0.22	0.0003
Vitamin C density,	*a*	38.91±2.28	57.34±1.92	73.64±2.22	90.16±2.02	<0.0001
mg/1000 kcal	*b*	37.76±2.14	55.41±1.93	71.83±2.12	88.47±1.95	<0.0001
Sodium density,	*a*	1652.58±41.19	1520.73±23.85	1566.32±23.27	1458.16±32.01	0.0114
gr/1000 kcal	*b*	1647.19±42.22	1504.15±29.44	1552.85±24.56	1447.28±30.88	0.0061
Thiamin density,	*a*	0.72±0.01	0.84±0.01	0.91±0.01	0.96±0.02	<0.0001
mg/1000 kcal	*b*	0.72±0.01	0.83±0.01	0.9±0.014	0.95±0.02	<0.0001
Riboflavin density,	*a*	0.9±0.01	0.93±0.01	0.99±0.02	1.01±0.02	<0.0001
mg/1000 kcal	*b*	0.89±0.01	0.91±0.01	0.98±0.02	1±0.02	<0.0001
	a	17.97±0.38	18.68±0.27	20.51±0.35	21.1±0.32	<0.0001

Niacin density in niacin equivalent, *mg/1000 kcal*	*b*	17.99±0.38	18.59±0.29	20.46±0.34	21.08±0.32	<0.0001
Vitamin B_6 density,	*a*	0.7±0.01	0.86±0.02	1.02±0.02	1.17±0.02	<0.0001
mg/1000 kcal	*b*	0.7±0.01	0.85±0.02	1.01±0.02	1.16±0.02	<0.0001
Vitamin B_{12} density,	*a*	2.14±0.09	2.04±0.09	2.31±0.16	2.2±0.13	0.5109
µg/1000 kcal	*b*	2.16±0.09	2.05±0.09	2.32±0.17	2.22±0.14	0.4901
Naturally occurring	*a*	89.6±1.96	108.29±2.65	134.56±3.37	150.79±4.04	<0.0001
folate density, *µg/1000 kcal*[5]	*b*	88.33±1.94	105.77±2.20	132.3±3.25	148.77±3.99	<0.0001
Folacin density from food sources, *µg/1000*	*a*	143.12±2.49	170.72±3.44	199.14±3.47	209.63±3.93	<0.0001
kcal[6]	*b*	142±2.43	168.42±3.06	197.1±3.42	207.83±4.17	<0.0001
Phosphorus density,	*a*	601.19±6.63	627.31±7.43	684.48±8.23	732.18±7.97	<0.0001
mg/1000 kcal	*b*	601.52±6.92	624.79±8.00	682.97±8.41	731.46±8.50	<0.0001
Magnesium density,	*a*	135.61±3.98	152.7±1.83	178.19±2.98	201.81±2.32	<0.0001
mg/1000 kcal	*b*	134.73±3.80	150.26±1.67	176.17±2.96	200.13±2.19	<0.0001
Iron density, *mg/1000*	*a*	6.11±0.08	6.84±0.09	7.42±0.10	7.81±0.10	<0.0001
kcal	*b*	6.06±0.08	6.76±0.08	7.34±0.10	7.75±0.10	<0.0001
Zinc density, *mg/1000*	*a*	5.16±0.09	5.34±0.12	5.66±0.08	6.06±0.07	<0.0001
kcal	*b*	5.16±0.10	5.31±0.12	5.64±0.08	6.04±0.08	<0.0001
Potassium density,	*a*	1238.73±17.28	1465.95±20.81	1694.55±20.38	1926.54±24.53	<0.0001
mg/1000 kcal	*b*	1231.92±16.64	1444.58±16.32	1677.24±20.06	1912.61±22.84	<0.0001
Caffeine density,	*a*	158.23±9.92	138.55±7.64	125.48±5.01	105.96±4.60	<0.0001
mg/1000 kcal	*b*	154.26±9.73	130.07±6.04	118.02±5.14	99.41±4.44	<0.0001
Moisture density,	*a*	1423.37±45.27	1487.35±40.16	1534.59±32.27	1632.65±35.79	0.0067
gr/1000 kcal[7]	*b*	1386.36±39.50	1409.28±34.45	1465.72±27.84	1571.96±30.76	0.0014
Glycemic index	*a*	34.46±1.97	33±1.11	30.83±0.56	28.71±0.57	0.0031
density, *per 1000 kcal*	*b*	33.24±1.90	30.59±0.48	28.67±0.38	26.78±0.39	<0.0001
Energy density, *per*	*a*	1.41±0.10	1.14±0.04	0.96±0.02	0.77±0.02	<0.0001
1000 kcal	*b*	1.37±0.11	1.06±0.02	0.88±0.02	0.7±0.02	<0.0001

[1]Estimates are weighted means and bootstrapped variances (Balanced Repeated Replication technique). Covariate-adjusted associations were determined using the weighted multivariable linear regression.
[2]Values are adjusted for age and sex (Model a) plus misreporting status (Model b)
[3]The p-trend was estimated using the 2015 DGAI in its continuous form and represents the p-value associated with linear regression coefficient.
[4]Possible scores for the 2015 DGAI ranged from 0-19, with higher scores indicating more healthful and varied dietary patterns.
[5]Naturally-occurring folate included various forms of folate found naturally in food.
[6]Sum of quantities of "naturally-occurring folate" in addition to "folic acid" without considering their differing bioavailability
[7]The water content in foods which is abundant in fruits and vegetables like tomatoes, romaine lettuce, and grapefruit.

Table 7.3. Weighted mean of components used to calculate the total 2015 Dietary Guidelines for Americans Adherence Index (DGAI) score presented across quartile categories of the DGAI among Canadian adults (≥18 years) (n=11,748)[1-3]

	Model	2015 DGAI Quartile Category				P-trend[4]
		1 (unhealthy)	2	3	4 (healthiest)	
DGAI range[5]		2.34-7.41	7.42- 8.82	8.83- 10.29	10.30-15.60	
Food intake subscore	*a*	2.62±0.04	3.40±0.04	4.22±0.03	5.41±0.04	<0.0001
	b	2.61±0.04	3.39±0.04	4.20±0.04	5.39±0.04	<0.0001
Dark green vegetable *(cups/week)*	*a*	0.24±0.08	0.76±0.16	1.52±0.11	3.06±0.24	<0.0001
	b	0.27±0.09	0.79±0.22	1.55±0.15	3.09±0.32	<0.0001
Red/orange vegetables *(cup/week)*	*a*	0.32±0.11	0.62±0.07	1.04±0.08	2.02±0.13	<0.0001
	b	0.38±0.09	0.68±0.10	1.1±0.12	2.09±0.14	<0.0001
Legumes *(cup/week)*[6]	*a*	0.21±0.10	0.46±0.10	0.92±0.15	1.36±0.13	<0.0001
	b	0.11±0.04	0.45±0.14	0.92±0.18	1.37±0.19	<0.0001
Starchy vegetables *(cup/week)*	*a*	2.5±0.18	3.12±0.20	3.34±0.17	3.75±0.16	<0.0001
	b	2.38±0.23	3±0.21	3.23±0.22	3.65±0.21	<0.0001
Other vegetables *(cup/week)*	*a*	2.41±0.24	3.69±0.23	4.9±0.21	7.32±0.26	<0.0001
	b	2.66±0.28	3.93±0.31	5.16±0.26	7.59±0.33	<0.0001
Fruits *(cup/day)*	*a*	0.42±0.04	0.93±0.07	1.25±0.05	1.56±0.06	<0.0001
	b	0.45±0.05	0.96±0.07	1.27±0.06	1.59±0.06	<0.0001
Variety of fruits and vegetables	*a*	0.89±0.03	1.38±0.03	1.96±0.03	2.77±0.03	<0.0001
(number of components)	*b*	0.93±0.03	1.41±0.03	1.99±0.03	2.8±0.04	<0.0001
Grains *(oz-equivalent/day)*	*a*	5.27±0.12	6.17±0.13	6.27±0.12	6.08±0.12	<0.0001
	b	5.38±0.16	6.28±0.15	6.38±0.18	6.18±0.18	<0.0001
Meat and beans *(oz-equivalent/day)*[6]	*a*	5.56±0.18	5.1±0.17	5.36±0.17	5.58±0.15	0.1492
	b	5.56±0.23	5.1±0.23	5.37±0.18	5.6±0.22	0.1301
Dairy *(cup/day)*	*a*	1.36±0.07	1.34±0.05	1.4±0.05	1.5±0.04	0.0769
	b	1.33±0.08	1.31±0.07	1.36±0.07	1.47±0.06	0.089
Added sugar (*% Energy)*[7]	*a*	12.04±0.37	10.47±0.35	8.93±0.28	7.44±0.28	<0.0001
	b	11.81±0.37	10.29±0.36	8.7±0.30	7.19±0.29	<0.0001
Healthy choice subscore	*a*	3.67±0.04	4.76±0.03	5.31±0.03	6.09±0.03	<0.0001
	b	3.70±0.04	4.79±0.04	5.34±0.03	6.09±0.03	<0.0001
Whole grain *(% of grains)*	*a*	8.52±0.74	16.43±1.03	20.57±0.94	31.37±1.32	<0.0001
	b	8.01±0.83	15.93±1.05	20.26±0.99	31.27±1.45	<0.0001
Dietary fiber density (*gr/1000kcal)*	*a*	5.73±0.11	7.82±0.14	9.72±0.25	12.13±0.19	<0.0001
	b	5.72±0.11	7.75±0.13	9.67±0.25	12.1±0.19	<0.0001
Total fat (*% Energy)*	*a*	36.49±0.40	32.13±0.41	30.14±0.34	27.83±0.30	<0.0001
	b	36.69±0.40	32.5±0.38	30.48±0.37	28.14±0.34	<0.0001
Saturated fatty acid (*% Energy)*	*a*	13.22±0.22	10.46±0.19	9.31±0.12	8.09±0.10	<0.0001
	b	13.25±0.21	10.54±0.18	9.37±0.13	8.15±0.11	<0.0001
Cholesterol intake *(mg/day)*	*a*	362.54±9.71	285.01±9.09	257.22±7.65	215.69±6.07	<0.0001
	b	362.56±11.06	285.03±10.94	257.42±8.89	216.06±9.96	<0.0001
Low-fat dairy and meat products *(%)*	*a*	31.05±1.03	38.77±0.94	46.21±0.84	55.06±0.99	<0.0001
	b	31.39±1.21	39.08±1.08	46.58±0.91	55.46±1.19	<0.0001

Sodium *(mg/day)*	*a*	3221.9±55.92	3043.71±59.75	3095.58±45.27	2897.94±67.97	0.0145
	b	3207.96±66.03	3030.12±82.18	3083.87±58.08	2888.63±78.68	0.0148
Alcohol *(drinks/day)*[8]	*a*	1.18±0.08	0.85±0.09	0.6±0.05	0.41±0.04	<0.0001
	b	1.13±0.09	0.8±0.12	0.55±0.08	0.36±0.07	<0.0001

[1]Estimates are weighted means and bootstrapped variances (Balanced Repeated Replication technique). Covariate-adjusted associations were determined using the weighted multivariable linear regression.
[2]Values are adjusted for age, sex, and energy intake (Model a) plus misreporting status (Model b) unless otherwise noted. Added sugar (% energy), dietary fiber density (gr/1000 kcal), total fat (% energy), and saturated fatty acid (% energy) are not adjusted for energy intakes since energy is already accounted for in their definition.
[3]One cup is defined as 237 ml (US), 0.946 cup in metric unit; 1 oz=28.35 grams
[4]The p-trend was estimated using the 2015 DGAI in its continuous form and represents the p-value associated with linear regression coefficient.
[5]Possible scores for the 2015 DGAI ranged from 0-19, with higher scores indicating more healthful and varied dietary patterns.
[6]Legumes were assigned to the meat and beans group for individuals who needed to meet the 1-point criterion for meat and beans group and the extra servings were counted towards the vegetables group (legumes).
[7]Using method proposed by Brisbois et al. to derive estimates of added sugars (175).
[8]One drink =118 ml wine;355 ml beer; or 45 ml distilled spirit

Table 7.4. Weighted correlations among the total and component scores of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) as well as energy intakes in Canadian adults (≥18 years) (n=11,748)[1,2]

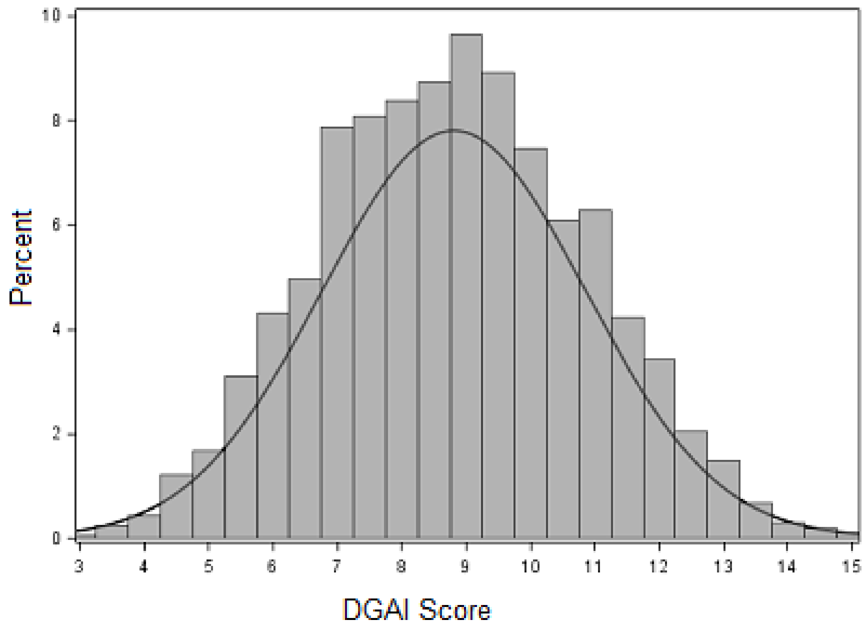
Components	Starchy veg.	Dark green veg.	Red /orange veg.	Other veg.	Legumes	Fruits	Meat and beans	Dairy	Grains	Added sugar	Variety
Starchy veg.	1.00										
Dark green veg.	0.07*	1.00									
Red/orange veg.	0.06*	0.13*	1.00								
Other veg.	-0.02	0.31*	0.22*	1.00							
Legumes	0.01	0.04*	0.06*	0.10*	1.00						
Fruits	-0.03*	0.11*	0.06*	0.11*	0.06*	1.00					
Meat and beans	0.10*	0.08*	0.05*	0.08*	0.1*	0.04*	1.00				
Dairy	0.01	0.03*	0.01	0.02*	0.01	0.10*	0.03*	1.00			
Grains	-0.03*	0.01	-0.05*	0.02*	0.00	0.05*	0.03*	0.08*	1.00		
Added sugar	-0.05*	0.04*	0.07*	0.09*	0.06*	-0.09*	0.02	-0.04*	-0.13*	1.00	
Variety	0.34*	0.63*	0.45*	0.64*	0.36*	0.48*	0.17*	0.06*	0.01	0.04*	1.00
Whole grain	-0.02*	0.01	0.06*	-0.03*	0.06*	0.13*	0.01	0.04*	-0.01	0.03*	0.07*
Fiber density	-0.02*	0.22*	0.18*	0.21*	0.09*	0.34*	-0.05*	-0.07*	0.06*	0.15*	0.36*
Total fat	0.02	0.07*	0.01	0.03*	-0.05*	0.14*	0.02*	0.01	0.12*	-0.13*	0.08*
SFA	0.00	0.06*	0.04*	0.04*	0.05*	0.16*	0.02	-0.23*	0.03*	-0.03*	0.13*
Chole.	-0.06*	-0.01	-0.04*	-0.06*	-0.08*	0.04*	-0.13*	-0.05*	0.03*	-0.05*	-0.06*
Low fat dairy	-0.02*	0.03*	0.04*	0.02*	0.01	0.08*	0.04*	0.21*	0.02*	0.03*	0.06*
Low fat meat	0.01	0.08*	0.12*	0.05*	0.11*	0.09*	0.18*	-0.03*	0.03*	0.02	0.14*
Sodium	-0.06*	-0.02*	-0.03*	-0.20*	-0.14*	0.00	-0.16*	-0.24*	-0.20*	0.04*	-0.15*
Alcohol	-0.01	-0.02*	0.03*	-0.04*	-0.03*	0.05*	-0.05*	0.01	0.04*	-0.11*	-0.01
Food intake subscore	0.28*	0.57*	0.40*	0.59*	0.36*	0.40*	0.35*	0.26*	0.15*	0.33*	0.9*
Healthy choice subscore	-0.04*	0.08*	0.07*	-0.03*	-0.03*	0.22*	-0.07*	-0.12*	0.01	-0.03*	0.09
Total DGAI score	0.17*	0.45*	0.33*	0.39*	0.23*	0.43*	0.20*	0.10*	0.11*	0.21*	0.69*
Energy	0.14*	0.04*	0.04*	0.13*	0.19*	0.08*	0.19*	0.28*	0.18*	-0.13*	0.2*

Cont'd-

Components	Whole grain	Fiber density	Total fat	SFA	Chole.	Low fat dairy	Low fat meat	Sodium	Alcohol	Food intake subscore	Healthy choice subscore	Total DGAI score
Starchy veg.												
Dark green veg.												
Red/orange veg.												
Other veg.												
Legumes												
Fruits												
Meat and beans												
Dairy												
Grains												
Added sugar												
Variety												
Whole grain	1.00											
Fiber density	0.39*	1.00										
Total fat	0.03*	0.20*	1.00									
SFA	0.10*	0.32*	0.46*	1.00								
Cholesterol	0.08*	0.26*	0.17*	0.25*	1.00							
Low fat dairy	0.12*	0.14*	0.09*	0.17*	0.09*	1.00						
Low fat meat	0.03*	0.07*	0.05*	0.13*	-0.18*	0.06*	1.00					
Sodium	0.06*	0.13*	0.08*	0.14*	0.29*	0.01	0.05*	1.00				
Alcohol	0.04*	0.12*	-0.08*	-0.08*	0.11*	0.04*	0.02*	0.09*	1.00			
Food intake subscore	0.08*	0.33*	0.06*	0.06*	-0.10*	0.11*	0.16*	-0.22*	-0.05*	1.00		
Healthy choice subscore	0.45*	0.59*	0.48*	0.6*	0.58*	0.31*	0.18*	0.53*	0.34*	0.03	1.00	
Total DGAI score	0.36*	0.64*	0.37*	0.45*	0.33*	0.29*	0.24*	0.21*	0.2*	0.73*	0.71*	1.00
Energy	-0.09*	-0.21*	-0.09*	-0.10*	-0.40*	-0.06*	-0.01	-0.61*	-0.20*	0.25*	-0.49*	-0.16*

Chole.: Cholesterol; SFA: Saturated Fatty Acid; Veg: Vegetables
*Statistically significant ($p<0.05$)
[1]Estimates are weighted Pearson correlation coefficients
[2]Possible scores for the 2015 DGAI ranged from 0-19, with higher scores indicating more healthful and varied dietary patterns.

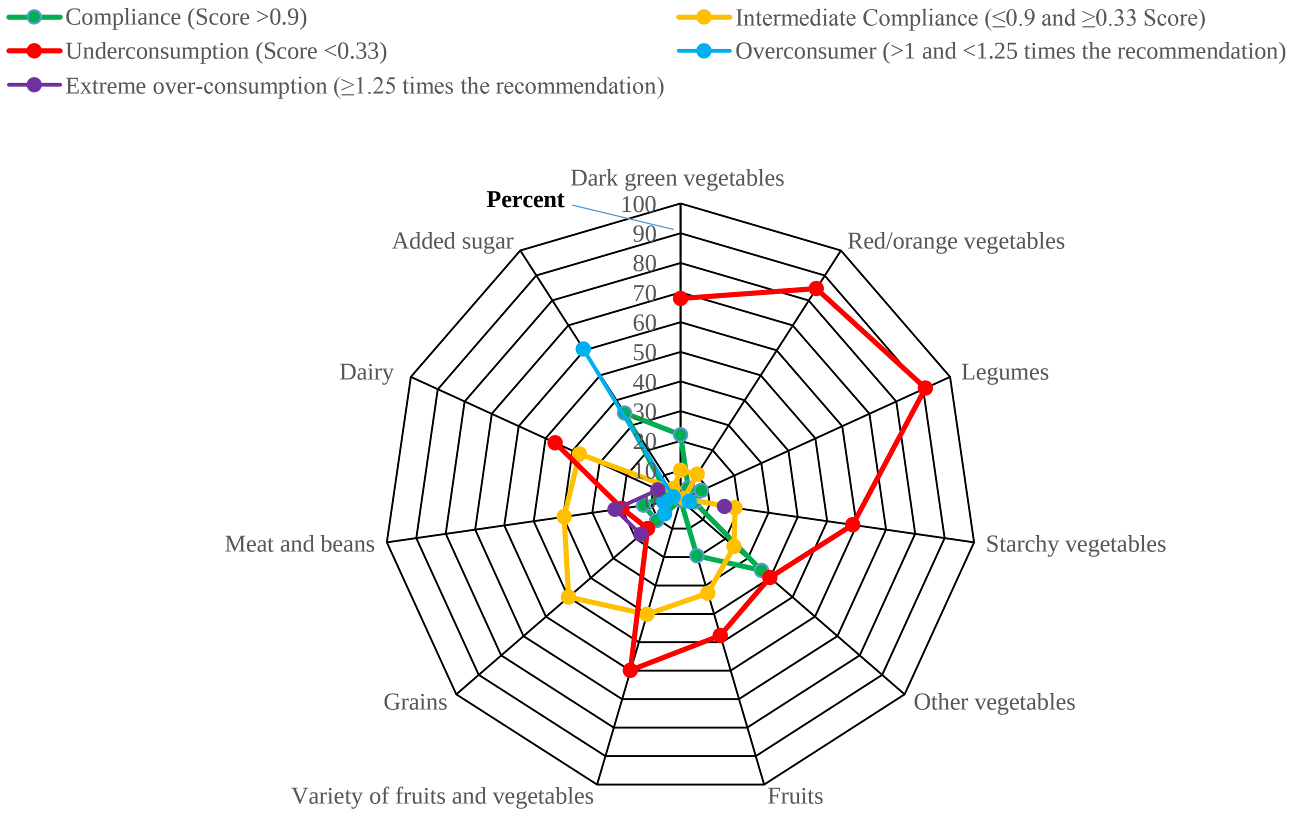
Figure 7.1. Weighted distribution of 2015 Dietary Guidelines for Americans Adherence Index (DGAI) among Canadian adults (≥18 years) (n=11,748).



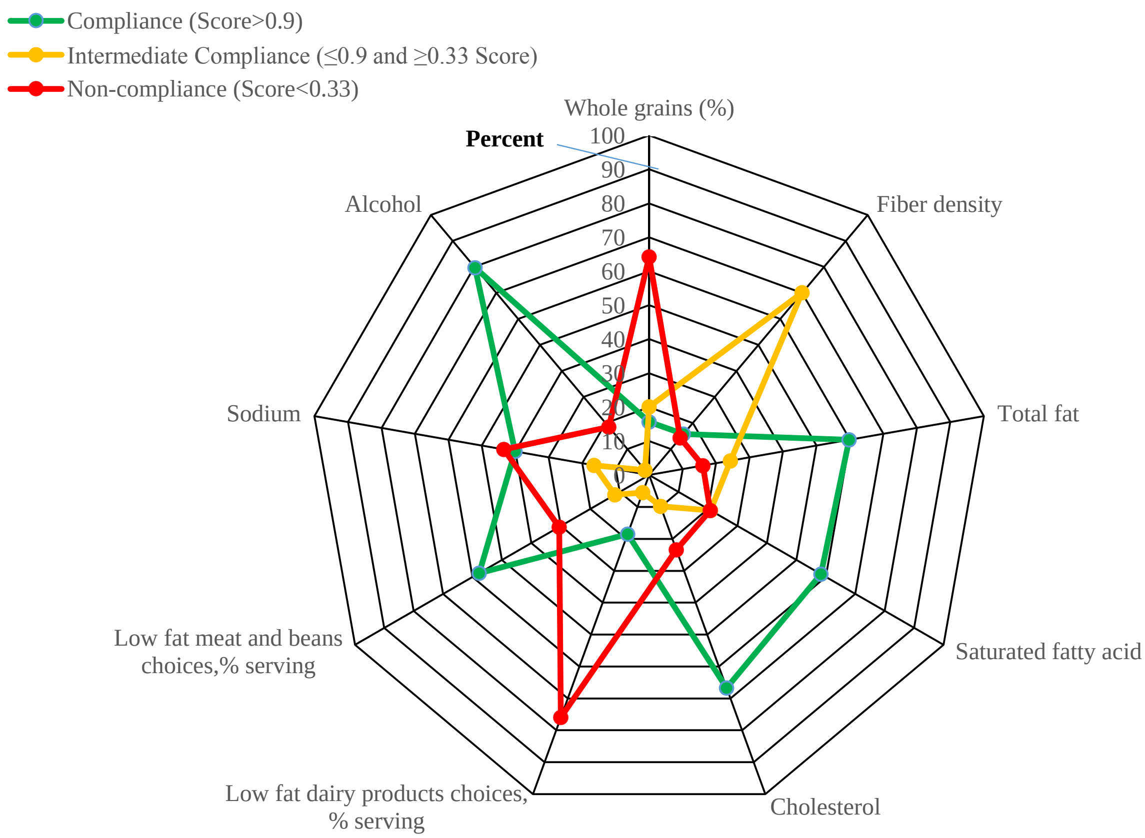
The 1% and 99% of distribution tails are trimmed according to the Statistics Canada's data release requirements. Possible scores for the 2015 DGAI ranged from 0-19, with higher scores indicating more healthful and varied dietary patterns.

Figure 7.2. Weighted percentage of compliance (Score >0.9), intermediate compliance (≤0.9 and ≥0.33 Score), underconsumption (Score<0.33), overconsumption (1< and <1.25 times the recommendation) and extreme overconsumption (≥1.25 times the recommendation) for each of the components of the A) food intake subscore, and B) healthy choice subscore, of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) among Canadian adults (≥18 years) (n=11,748).

a. "Food intake" subscore components



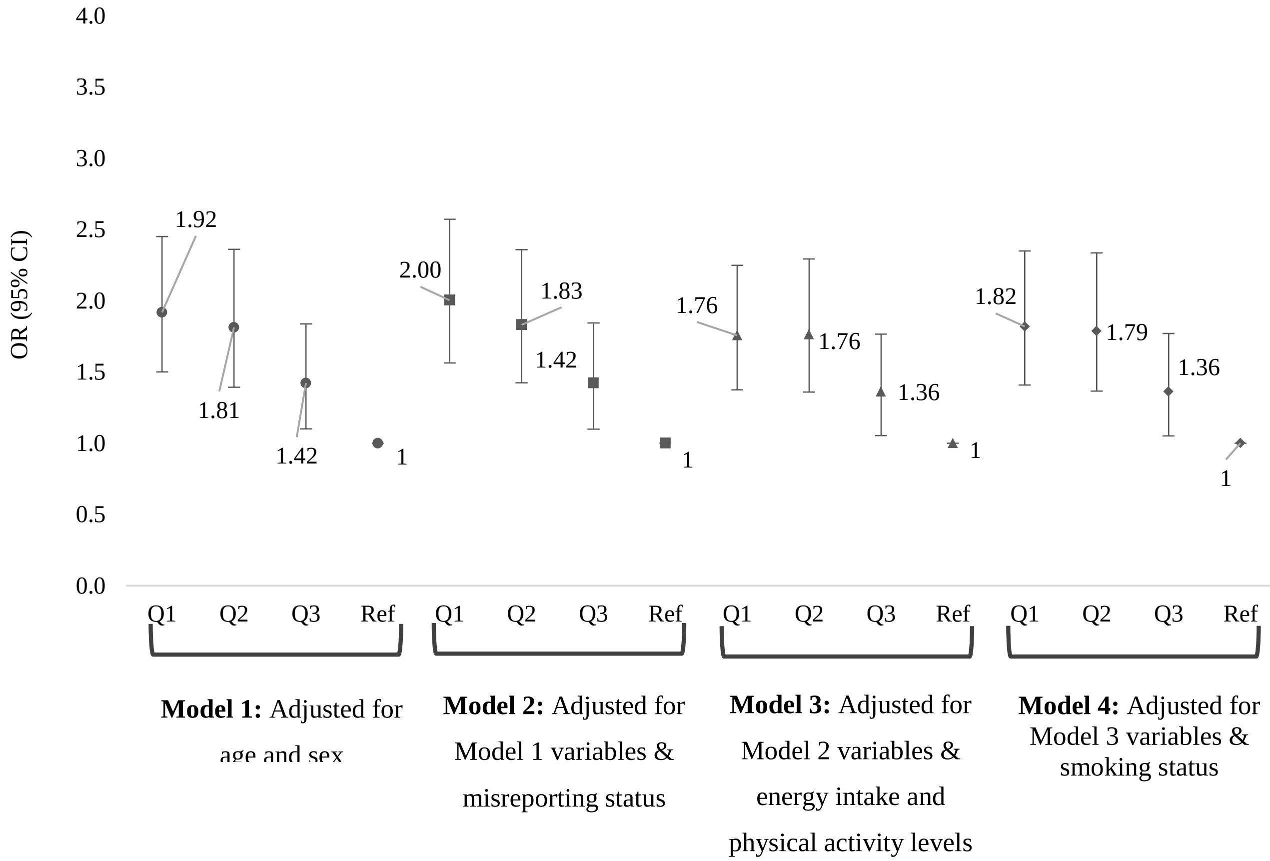
b. "Healthy choice" subscore components



Each spoke of the radar plots shows an individual DGAI component and each line colour represents a different category of compliance. The largest outer circle represents 100% prevalence and the smallest circle represents 0%. Color coding of different compliance groups facilitates identification of food groups with highest percentage of compliers, intermediate compliers, under-consumers, over-consumers and extreme over-consumers for each of the 2015 DGAI components.

Possible scores for the 2015 DGAI ranged from 0-19, with higher scores indicating more healthful and varied dietary patterns. All differences between compliance groups for the 2015 DGAI components were significant ($p<0.0001$). The overconsumption penalty was only calculated for energy-dense food groups including: starchy vegetables, grains, meat, and dairy. There is no "underconsumer" group defined for added sugars.

Figure 7.3. Weighted multivariate adjusted odds ratio (OR) and 95% confidence intervals (CI) represented by vertical bars for obesity risk (BMI≥30 kg/m^2) across the quartile categories of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) among Canadian adults (≥18 years) (n=11,748).

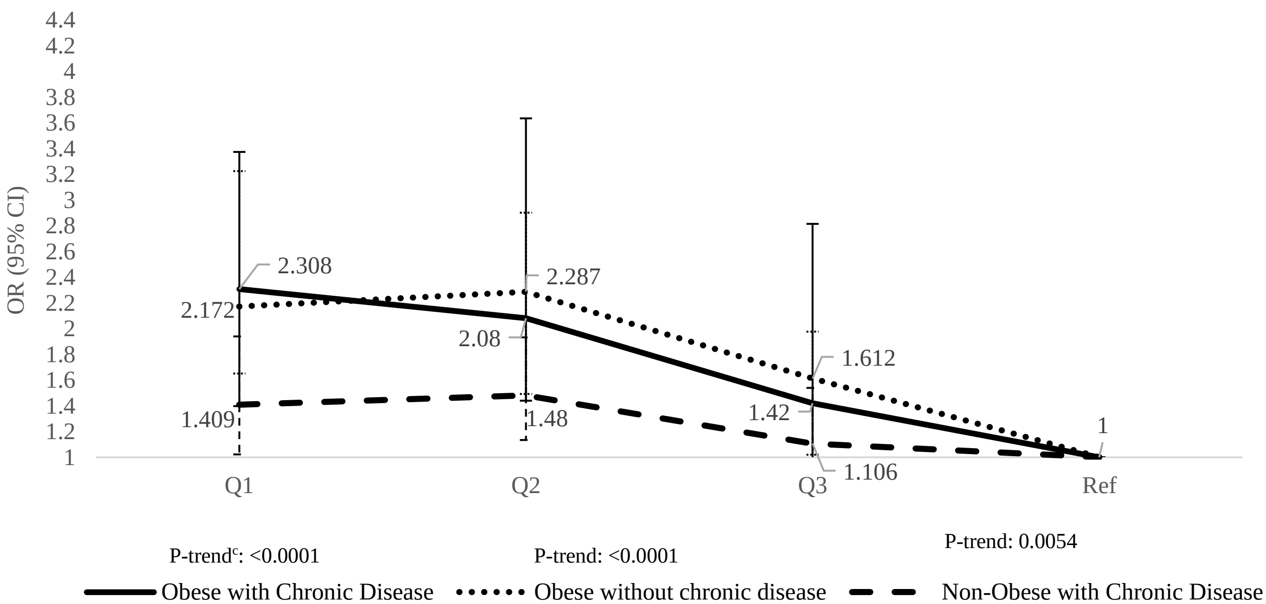


Q:Quartile

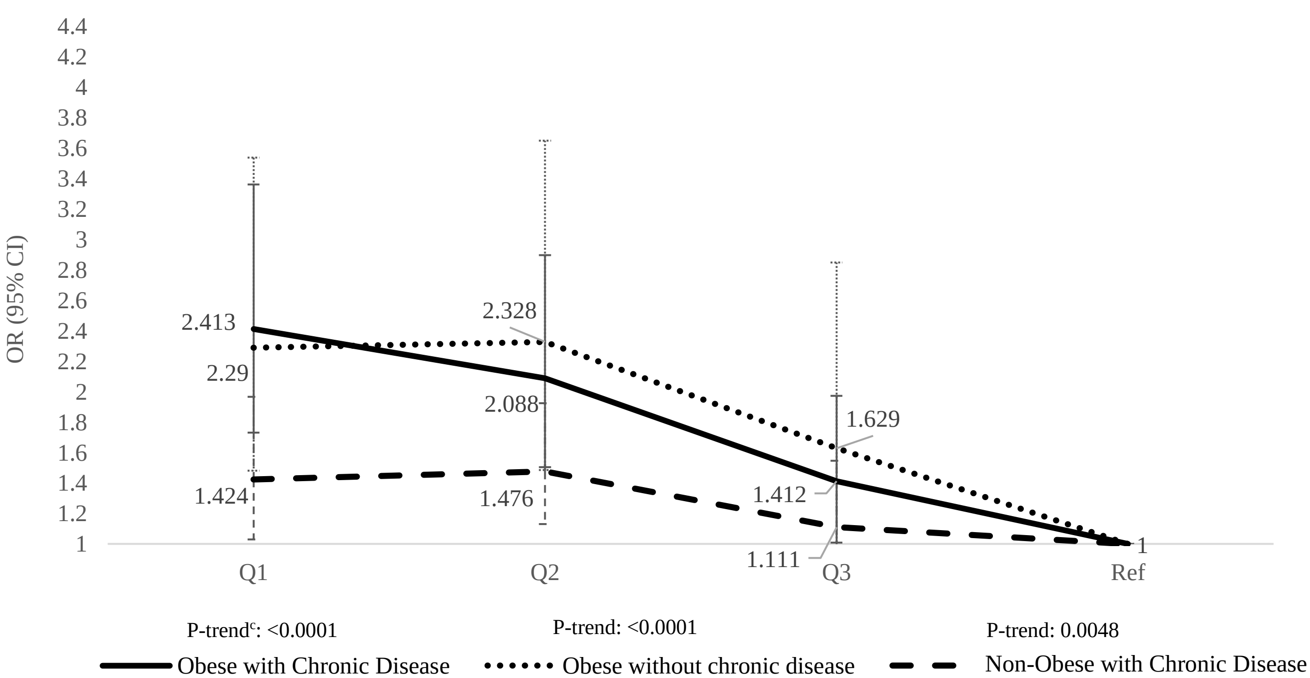
Estimates are based on the multinomial logistic regression- generalized logit model. P-trend is based on the logistic regression coefficient for the 2015 DGAI as a continuous variable.

Figure 7.4. Weighted multivariate adjusted odds ratio (OR) and 95% Confidence Intervals (CI) for the risk of obesity with and without at least one chronic disease across the quartile categories of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) among Canadian adults (≥18 years): A) adjusted for age and sex (Model 1); B) adjusted for Model 1 variables and misreporting (Model 2); C) adjusted for Model 2 variables in addition to energy intake and physical activity levels (Model 3); and D) adjusted for Model 3 variables in addition to smoking status (Model 4) (n=11,748).

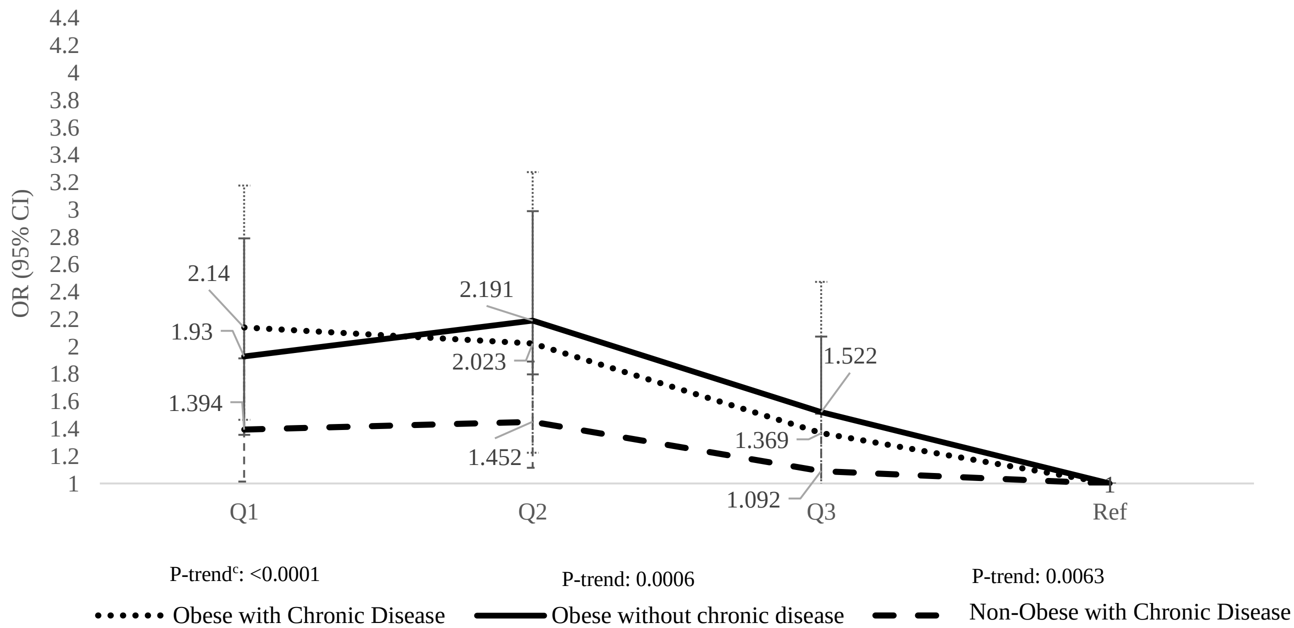
a. Model I: Adjusted for age and sex



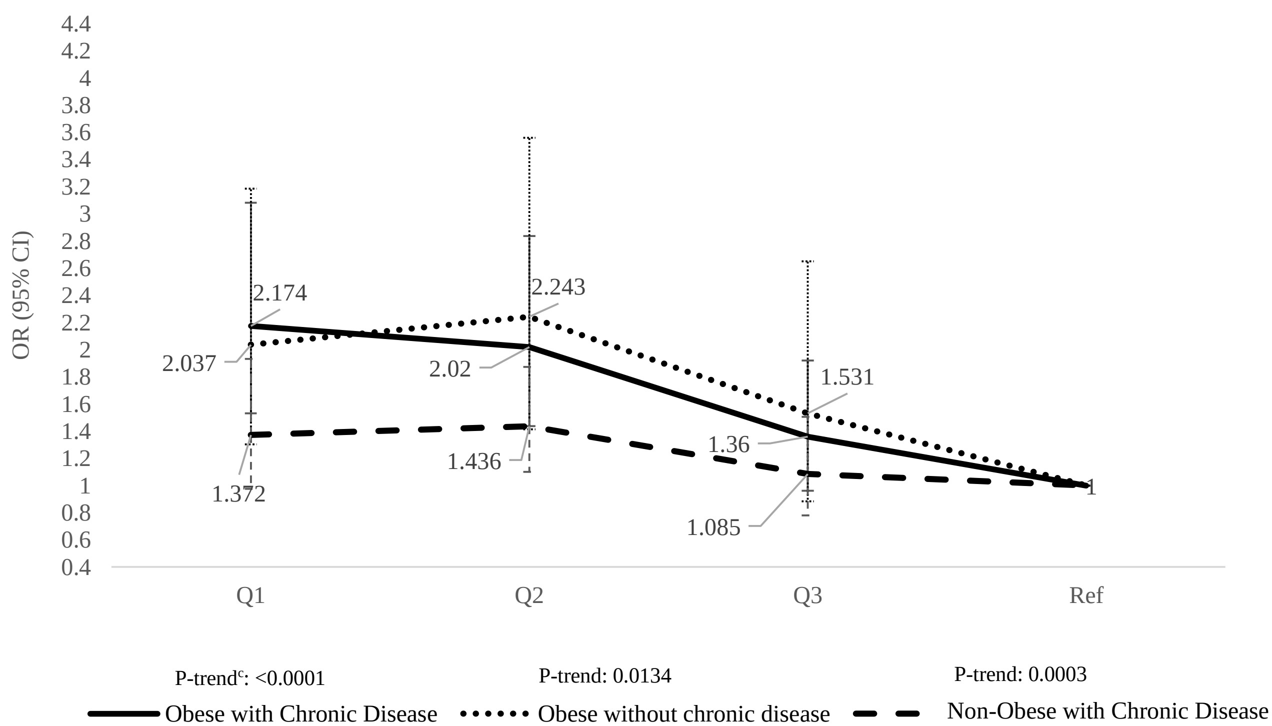
b. Model II: Adjusted for Model I variables and misreporting



c. Model III: Adjusted for Model II variables in addition to energy intake and physical activity



d. Model IV: Adjusted for Model III variables and smoking status



Estimates are based on the multinomial logistic regression- generalized logit model. P-trend is based on the logistic regression coefficient for the 2015 DGAI as a continuous variable. P-trend for the “Obese with Chronic Disease”: <0.0001; “Obese without Chronic Disease”: <0.0003; and “Non-Obese with Chronic Disease”: <0.01, respectively.

Supplementary Table 7.1. Scoring criteria of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) for individuals with 2000 kcal/day estimated energy requirement (EER)[1-4]

DGAI Components[5]					
	Scoring Criteria			Scoring Criteria	
	0 Point	1.0 point		0 Point	1.0 point
Food Intake Sub-score[6]			**Healthy Choice Sub-score**[11]		
Dark green vegetable *(cups/week)*	0	≥ 1.5	Whole grain *(% of grains)*	0	≥ 50%
Red/orange vegetables *(cup/week)*	0	≥ 5.5	Dietary fiber density *(gr/1000kcal)*	0	≥ 14
Legumes *(cup/week)*[7]	0	≥ 1.5	Total fat *(% Energy)*	≤ 10%, ≥ 45%	≥ 20%, ≤ 35%
Starchy vegetables *(cup/week)*[8]	0	5.0	Saturated fatty acid *(% Energy)*	≥ 15%	≤ 10%
Other vegetables *(cup/week)*	0	≥ 4.0	Cholesterol intake *(mg/day)*	≥ 450	≤ 300
Fruits *(cup/day)*	0	≥ 2	Low-fat dairy, and meat products *(%)*[12]	0%	≥ 75%
Variety of fruits and vegetables *(number of components)*[9]	0	6.0	Sodium *(mg/day)*	≥ 3450	≤ 2300
Grains *(oz-equivalent/day)*[8]	0	6.0	Alcohol *(drinks/day)*[13]	≥ 1.5	≤ 1.0
Meat and beans *(oz-equivalent/day)*[8]	0	26			
Dairy *(cup/day)*[8]	0	3			
Added sugar (*% Energy)*[10]	≥ 9%	≤ 6.0%			

Note: This table presents the updated 2015 version of the DGAI, which was previously published by Imamura et. al (2009) (with permission)(170).

[1]The 2015 Dietary Guidelines for Americans Adherence Index (DGAI) was developed based on the 2015 USDA Food Patterns, which has recommendations for 12 levels of energy requirement. The Canadian version of the 2015 DGAI has a total of 19 scores, since one of the Healthy Choice Sub-score components (*trans* fat) was not attainable.

[2]Estimated Energy Requirement was calculated by the IOM factorial equations using each participant's measured height, weight, physical activity level (PAL) (sedentary, low active, moderately active, highly active), age, and sex

[3]One cup is defined as 237 ml (US), 0.946 cup in metric unit; 1 oz=28.35 grams

[4]Intermediate intakes between criteria for 0 and 1.0 points were scored proportionally.

[5]Possible scores for the 2015 DGAI ranged from 0-19, with higher scores indicating more healthful and varied dietary patterns.

[6]Possible maximum score of 11 points

[7]Legumes were assigned to the meat and beans group for individuals who needed to meet the 1-point criterion for meat and beans group and the extra servings were counted towards the vegetables group (legumes).

[8]An overconsumption penalty was imposed by reducing the score proportional to the amount of overconsumption up to 1.25 times higher than the recommended intake. Intakes ≥1.25 times the recommended amount were scored as 0.5 (truncation).

[9]Variety was determined by summing the 6 fruit and vegetables component scores.

[10]Added sugar available in the USDA Food Pattern for 2000-kcal/day energy requirement

[11]Possible maximum score of 8 points

[12]Adherence to recommendations of "low-fat dairy" and "low-fat meat" products was scored separately, each with a minimum score of 0 (for consuming 0% of dairy or meat products as low-fat) and maximum score of 0.5 (for consuming ≥75% of dairy or meat products as low-fat); intermediate percentages received proportional scores between 0 and 0.5. The final scores for adherence to low-fat dairy and meat were then summed for a maximum possible score of 1.0.

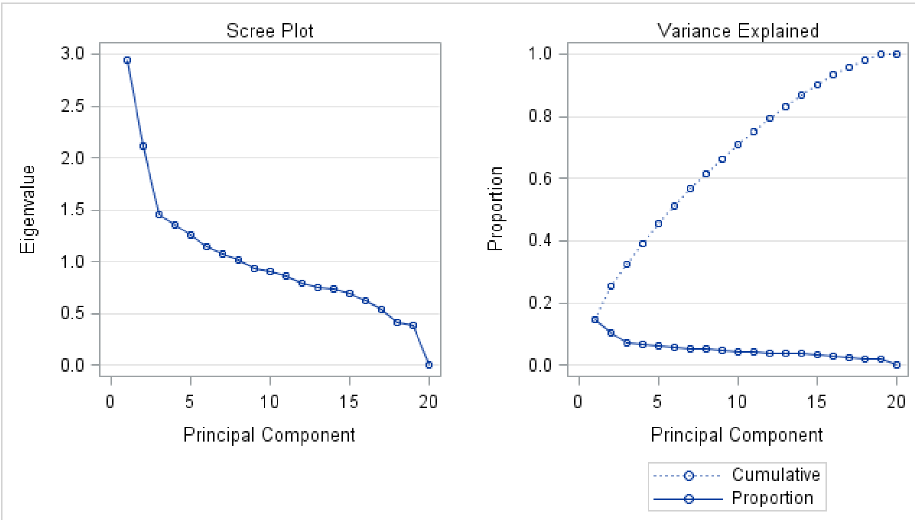
[13]One drink =118 ml wine;355 ml beer; or 45 ml distilled spirit

Supplementary Table 7.2. Weighted mean 2015 Dietary Guidelines for Americans Adherence Index (DGAI) score among Canadian adults (≥18 years) according to the age group, sex and smoking status (n=11,748)[1-3]

	Mean ±SE	**P-value**
Gender		<0.0001
Males	8.56±0.06	
Females	9.28±0.05	
Age group		<0.0001
18 to 30 years	8.33±0.06	
30 to ≤50 years	8.65±0.07	
50 to ≤70 years	9.14±0.06	
>70 years	9.62±0.07	
Smokers		<0.0001
Daily	8.11±0.08	
Occasional	8.5±0.14	
Former	8.96±0.07	
Never	9.28±0.05	

[1]Estimates are weighted means and bootstrapped variances (Balanced Repeated Replication technique) from the weighted analysis of covariance (ANCOVA).
[2]Values are adjusted for age and sex, unless otherwise noted. Age is adjusted for sex only and gender is adjusted for age only.
[3]Possible scores for the 2015 DGAI ranged from 0-19, with higher scores indicating more healthful and varied dietary patterns.

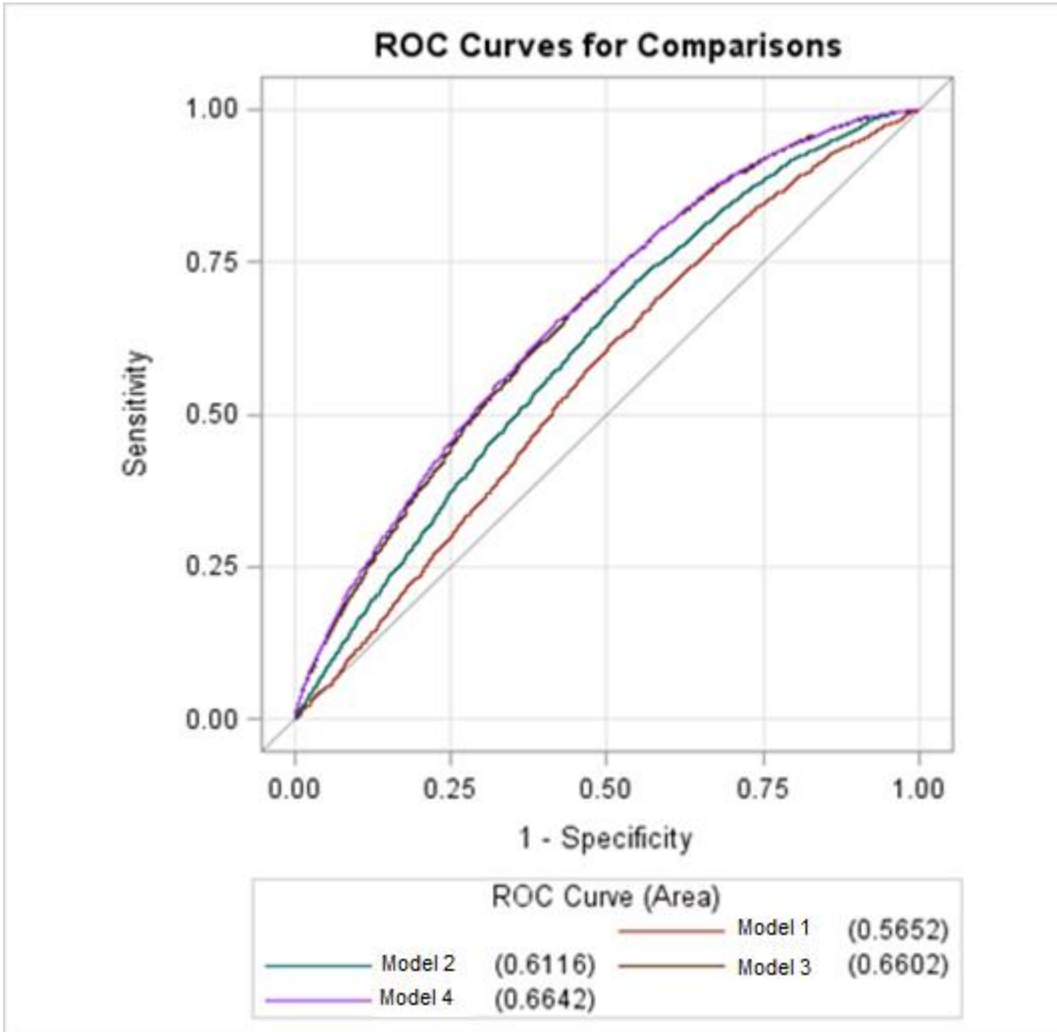
Supplementary Figure 7.1. Eigenvalues of the correlation matrix and scree plot from weighted principle component analysis (PCA) of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) components showing the percentage of explained variance by each of the principal component dimensions among Canadian adults (≥18 years)(n=11,748)



Eigenvalues of the Correlation Matrix

	Eigenvalue	Difference	Proportion	Cumulative
1	2.93654	0.82015	0.1468	0.1468
2	2.1164	0.66972	0.1058	0.2526
3	1.44668	0.09153	0.0723	0.325
4	1.35516	0.09417	0.0678	0.3927
5	1.26098	0.11697	0.063	0.4558
6	1.14401	0.07338	0.0572	0.513
7	1.07063	0.05484	0.0535	0.5665
8	1.01579	0.07748	0.0508	0.6173
9	0.93831	0.02844	0.0469	0.6642
10	0.90987	0.04115	0.0455	0.7097
11	0.86872	0.07849	0.0434	0.7532
12	0.79022	0.03352	0.0395	0.7927
13	0.75671	0.01849	0.0378	0.8305
14	0.73822	0.04706	0.0369	0.8674
15	0.69116	0.06985	0.0346	0.902
16	0.62131	0.08463	0.0311	0.933
17	0.53668	0.12348	0.0268	0.9599
18	0.4132	0.02381	0.0207	0.9805
19	0.38939	0.38939	0.0195	1

Supplementary Figure 7.2. Weighted receiver operating characteristic (ROC) area under the curve (AUC) for the association of the 2015 Dietary Guidelines for Americans (DGAI) and obesity among Canadian adults (≥18 years)(n=11,748)



All ROC contrast estimation p-values for comparison of different models were statistically significant ($p<0.05$). Model 1: Adjusted for age and sex; Model 2: Adjusted for Model 1 variables in addition to misreporting; Model 3: Adjusted for Model 2 variables in addition to energy intake and physical activity levels; Model 4: Adjusted for Model 3 variables in addition to smoking status

In Chapter 7, an *a priori* dietary quality index (i.e., 2015 DGAI) was used for characterizing dietary patterns of Canadians. To complement the findings of Chapter 7, a hybrid method for deriving an energy-dense, high-fat and low-fiber dietary pattern was used in Chapter 8 and its association with obesity with and without an accompanying chronic disease was characterized.

Chapter 8

8 Study #5: Identification of dietary patterns associated with obesity in a nationally-representative survey of Canadian adults: application of *a priori*, hybrid and simplified dietary pattern techniques

This manuscript is under-review at the *"American Journal of Clinical Nutrition"* for publication: Jessri M, Wolfinger RD, Lou WY, L'Abbé MR. Identification of dietary patterns associated with obesity in a nationally-representative survey of Canadian adults: application of *a priori*, hybrid and simplified dietary pattern techniques. American Journal of Clinical Nutrition (Under-review and revisions submitted).

This study addressed the objective #5 of my thesis, to:

- Characterize dietary patterns of Canadians associated with reduced risk of obesity using the weighted partial least square (wPLS) analysis (energy dense, high-fat and low-fiber), and determine its association with risk of unhealthy and healthy obesity among participants of the CCHS 2.2

Student's contribution:

I conceptualized and designed the original study and conducted the statistical analyses at the Research Data Center of Statistics Canada. I independently prepared the data tables, interpreted the results and drafted the manuscript before engaging the co-authors in revising the final version for submission to the "*American Journal of Clinical Nutrition".*

8.1 Abstract

Background: Analyzing the effects of overall dietary patterns is an important alternative approach for examining the complex role of nutrition in etiology of obesity and chronic diseases.

Objective: The objectives were to evaluate the dietary patterns of Canadians using *a priori*, hybrid and simplified dietary pattern techniques, and to compare the efficiency of these methods for explaining the obesity risk with and without an accompanying chronic disease (unhealthy/healthy obesity).

Design: Dietary recalls from 11,748 participants (≥18 y) in the cross-sectional nationally-representative Canadian Community Health Survey 2.2 were used. *A priori* dietary pattern was characterized using previously-validated 2015 Dietary Guidelines for Americans Adherence index (DGAI). Weighted partial least squares (wPLS)(hybrid method) was used to derive an energy-dense (ED), high-fat (HF) and low fiber density (LFD) dietary pattern using 38 food groups. The associations of derived dietary patterns with disease outcomes were then tested using multinomial logistic regression.

Results: An ED,HF,LFD dietary pattern had high loadings for fast foods, carbonated drinks, refined grains and low loadings for whole fruits, and vegetables (≥|0.17|). Food groups with significant loading were summed to form a simplified dietary pattern score. Moving from the first (best) to the fourth (worst) quartiles of the ED,HF,LFD and the simplified dietary pattern scores were associated with increasingly elevated risk of unhealthy obesity, with individuals in quartile 4 having 3.136 (95%CI:2.137-4.601) and 3.285 (2.251-4.792) times higher risk, respectively (p-trend<0.0001). Individuals who adhered the most to the 2015 DGAI recommendations (fourth quartile) had 55.6% lower risk of unhealthy obesity (p-trend<0.0001). The associations between dietary patterns and healthy obesity as well as being unhealthy non-obese were weaker, albeit significant.

Conclusions: Dietary patterns in line with the 2015 DGA and low in energy density and fat and high in dietary fiber are associated with reduced risk of obesity and chronic diseases among Canadians.

Keywords: Dietary Patterns, Partial Least Squares, Simplified Dietary Pattern, Dietary Guidelines for Americans Adherence Index, Obesity, Chronic Diseases, Canadian

8.2 Introduction

During the past few decades, the prevalence of obesity and other chronic diseases has increased dramatically worldwide. In Canada, the rate of adult obesity has increased from 6.1% in 1985 to 18.3% in 2011, respectively (2). It has been suggested that the failure of preventive nutrition in halting the obesity and chronic disease epidemic may be due to the strong focus of nutrition research on the impact of single foods or nutrients ("reductionist approach") (168), rather than on dietary patterns. This is important as foods are consumed in complex combinations which can have synergistic or antagonistic effects (168). In addition, the strong multicollinearity of foods results in impairment of regression results by producing wide confidence intervals (CIs) and unstable estimates (193). Finally, the comprehensive dietary pattern approach is more useful for developing dietary guidelines as it is easier for the public to interpret and adopt an explicit overall healthy dietary pattern (67).

To examine the association between dietary patterns and chronic disease risk, researchers have used various dietary pattern derivation techniques. In hypothesis-oriented *(a priori*) method, dietary quality indexes are used to score individuals based on their adherence to dietary guidelines (11). Recently, we updated the 2005 Dietary Guidelines for Americans Adherence Index (DGAI) (80) to reflect changes in the Health and Human Services (HHS)/United States Department of Agriculture (USDA) 2015 DGA (67) and validated this 19-score index among a nationally-representative sample of Canadians (Chapter 7). Generally, the DGAI is focused on energy overconsumption and energy density, and is the only *a priori* index that measures diet quality in terms of adherence to one of the 12 energy-based USDA Food Patterns (80). The most recently-developed dietary pattern techniques are hybrid methods such as the partial least squares (PLS), which combine *a priori* information with *a posteriori* statistics to create uncorrelated patterns in food groups that relate to specific outcomes of interest (71). Hybrid methods enable confirmation of closely-related pathways through which diet may affect chronic disease risk (11). One potential limitation of dietary patterns derived by hybrid techniques that they are dependent on the population under study and may not be reproducible in other populations (194). This issue may be overcome by construction of a "simplified dietary pattern" score in which unweighted standardized *z*-scores of food groups with high correlations are summed to represent the most informative foods in dietary pattern analysis (195).

Thus far, no previous study has evaluated dietary patterns in relation to risk of obesity and chronic diseases using energy-based *a priori* and hybrid dietary pattern techniques in a large-scale nationally representative survey. In addition, the usefulness of simplified dietary pattern scores generated from the PLS has not been tested. The objectives of this research were therefore to: 1) evaluate dietary patterns of Canadians using the 2015 DGAI; 2) identify an energy-dense (ED), high fat (HF) and low fiber density (LFD) dietary pattern using the weighted PLS (wPLS); 3) construct a simplified dietary pattern score based on the wPLS-derived pattern; and 4) compare the efficiency of these 3 dietary pattern scores in explaining the risk of obesity with and without an accompanying chronic disease (healthy and unhealthy obesity). We hypothesized that individuals with unhealthy obesity phenotype would benefit more from following a healthy dietary pattern, as compared to healthy obese individuals or normal-weight with at least one chronic disease.

8.3 Subjects and Methods

8.3.1 Study population

This study used the data from the Canadian Community Health Survey (CCHS) cycle 2.2 (2004/5), which is the only national Canadian nutrition survey available in >30 years (96). Data were collected under the authority of the Statistics Act of Canada (97). All data analyses were conducted at the Statistics Canada's Research Data Center. Details regarding the sampling framework and survey procedures of CCHS 2.2 have been published previously (96). In brief, CCHS 2.2 is a complex multistage cross-sectional national survey which includes 35,107 Canadians ≥2 years from 10 provinces, representing >98% of the Canadian population (97). For the purpose of this study, we excluded all pregnant and breastfeeding women, those with invalid/missing dietary recalls (as defined by Statistics Canada) , and individuals with missing values for measured anthropometry, energy intakes and physical activity levels. To be able to evaluate the association of dietary patterns with lifestyle and socio-demographic characteristics, we additionally removed individuals with missing values for these variables, leaving a total of 11,748 Canadian adults (≥18 years) for all analyses. The socio-demographic and lifestyle characteristics of individuals included in this research were not significantly different than those who were excluded due to missing variables (data not shown), and the final sample represented the Canadian population homogenously.

8.3.2 Data collection

Trained interviewers conducted all data collection interviews and weight and height were measured in person and at participants' homes (30). Interviewer-administered questionnaires were used to collect lifestyle and socio-demographic data as well as medical diagnosis of chronic disease. Body mass index (BMI) was calculated dividing the weight (kg) by square of height (meters), and BMI values ≥25-29.99 kg/m^2 and ≥30 kg/m^2 were considered as overweight and obese, respectively. Presence of hypertension, cardiovascular diseases, diabetes and cancer was determined using self-report of a medical diagnosis and/or presence of any chronic diseases. The 24-hour dietary recalls were collected using the modified version of the USDA Automated Multiple Pass Method (AMPM) (30). Food items reported by participants were coded by dietitians and recipes and ethnic meals were disaggregated into their main constituents for nutrient analyses (30). All foods and beverages consumed in the previous 24 hours (midnight to midnight) were collected and their nutrient compositions were analyzed using Health Canada's Canadian Nutrient File (CNF) (2001b Supplement) (100). Since the CNF does not include information on added sugar content of Canadian foods, we used the method described by Brisbois et al. to calculate added sugar values (175). Dietary glycemic index (GI) was estimated using average values reported in the International GI table (137) assigned to each of the Bureau of Nutritional Sciences (BNS) food categories (139), as described previously (140, 141). Dietary glycemic load (GL) was then calculated by multiplying the GI value by the grams of food carbohydrates and dividing by 100 (137).

8.3.3 Dietary pattern methods

8.3.3.1 *A priori* Dietary pattern: 2015 Dietary Guidelines for Americans Adherence Index (DGAI)

The original DGAI proposed by Fogli-Cawley et al. was developed based on the 2005 DGA (80). Recently, we updated the 2005 DGAI (80) based on the 2015 USDA Food Patterns (67) and validated this tool for use among the Canadian population (Chapter 7). The USDA Food Patterns translate the DGA recommendations into quantified guidance on the type and amount of foods to consume at 12 different levels of energy requirement (67). Eleven of the twenty DGAI components evaluate energy-specific *"food intake"* recommendations (based on the 12 USDA Food Patterns), including: 5 vegetable subgroups (i.e., dark green vegetables, red/orange vegetables, other vegetables, starchy vegetables and legumes); fruits; variety of vegetables and fruits; meat and beans; dairy; grains; and added sugar (80). Eight of the DGAI components are based on the universal *"healthy choice"* recommendations and include: percentage of whole grains, fiber intake, 4 recommendations related to fat (total fat, saturated fat, cholesterol, low-fat products), sodium intake and alcohol consumption. In the present study, we were unable to calculate one of the healthy choice subscore recommendations (i.e., *trans* fat) due to the lack of *trans* fat data in the CNF; as a result, the total 2015 DGAI had a maximum of 19 total scores in this research.

To score each of the 19 index components, we used a proportional scoring scheme proposed by Imamura et al. to ensure that individuals are given a continuous score ranging from 0 (non-adherence) to 1 (total adherence) proportional to their degree of compliance with the recommendations (170). Participants were penalized for overconsumption of energy-dense food items (i.e., starchy vegetables, dairy, meat and beans, and grains) by reducing the index score proportionally up to 1.25 times the recommended intake amount (170). For overconsumption amounts ≥1.25 times the recommendation, participants were penalized by a maximum of 0.5 scores.

8.3.3.2 Hybrid dietary pattern: Weighted partial least squares (wPLS)

wPLS regression was used to derive a dietary pattern associated with obesity risk (71).The PLS is a flexible multivariate method which enables extraction of pattern scores based on mathematical algorithms aimed to maximize the covariance between disease-specific responses and explanatory variables. Generally, the PLS is a useful model for high-dimensional data and includes knowledge about intermediary variables on the pathway to disease. Compared to the Reduced Rank Regression (RRR), the PLS is typically a more flexible technique, enabling discovery of important disease-specific dietary exposures that have not been previously identified in etiology of chronic diseases (196). The flexibility allowed by PLS to derive dietary patterns partially unconstricted by the choice of response variables is an important advantage of PLS over the RRR.

In the present study, the weighted nonlinear iterative partial least squares (NIPALS) algorithm was used to derive dietary patterns that explain maximum variation in three obesity-related "response" variables, including energy density (ED), percentage of energy as fat (%EF), and fiber density (FD), as well as 38 food groups as "predictor" variables. All dietary data were centered and scaled (standardized) for dietary pattern analyses. We grouped all reported food items into 38 standardized (z-score) food groups according to their nutrient profile and culinary usage, within the constraints of Health Canada Bureau of Nutritional Sciences (BNS) food groups (139) to reduce subjectivity (65) (Supplementary Table 8.1). Some frequently consumed foods (e.g., tea, and coffee) were kept as separate groups since they represented distinct food choices.

The response variables used in this research (ED, %EF, FD) were chosen *a priori* and were hypothesized to be on the pathway between dietary intakes and obesity, as discussed previously (197-201). Currently, the World Health Organization (WHO) and the scientific community recognize ED, %EF and FD as key targets for improving diet quality and for prevention of chronic diseases (104, 106, 198-203). To calculate dietary energy density, total energy from foods (Kcal) was divided by weight of foods (grams), while excluding beverages as they disproportionately influence energy density (204, 205). Fiber density was derived by calculating grams of fiber intake per 1000 Kcal of energy. Percentage of energy from fat was calculated by dividing daily energy from fat (Kcal) by total energy intakes (Kcal) and multiplying by 100.

In the present study, the first extracted dietary pattern independently explained the maximum variation in the response variable (28.2%), while the subsequent two wPLS-derived dietary patterns only explained <10% of the response variation. In addition, these latter two dietary patterns were not interpretable and did not represent major dietary patterns in the Canadian population. Generally, the first extracted dietary pattern is always optimal as there are no other linear functions of predictors and response variables that have a higher amount of variation explained (206, 207). As a result, only the first dietary pattern was retained for more concise results and consistency with previous studies (199, 202, 208, 209).

The importance of each of the 38 food groups (predictors) in the first wPLS-derived dietary pattern was estimated through the variable importance in the projection (VIP) statistic (210), which was calculated by weighting the sum of squares of PLS weights. A VIP statistic greater than 0.8 was used to identify food groups with a significant contribution to the final wPLS-derived dietary pattern. As presented in Table 8.1, higher scores on the first dietary pattern were positively correlated with ED (r=0.673) and %EF (r=0.33) and negatively correlated with FD (r=-0.533); this pattern was therefore labelled as an energy dense, high fat, low fiber density (ED, HF, LFD) dietary pattern. This pattern explained 45.34%, 28.44% and 10.88% of the variation in ED, FD and %EF, respectively. Each subject was assigned a dietary pattern z-score reflecting their compliance with the ED, HF, LFD dietary pattern (199, 200). Dietary pattern scores are in fact the product of food group intake and factor loading for the corresponding food group, summed across all 38 food groups. In order to ensure a sound interpretation, food groups were ranked by decreasing absolute factor loading and only those with loadings >|0.17| were considered significant (193).

To confirm the derived dietary pattern, several secondary analyses were performed. In the first step, we examined the robustness of the dietary pattern by randomly splitting (50%) the data five times (split cross-validation) and repeating the wPLS regression analyses on half of the population (i.e., analyses was repeated 5 times). Dietary patterns derived in 1 subsample were confirmed in the second sample. Factor loadings of the derived dietary patterns were materially the same and the mean of correlation coefficients between the 5 cross-validated dietary pattern scores was r=0.988. In the second step, we ungrouped and entered all food items into the wPLS regression analyses to evaluate the effect of food grouping decisions on the resulting dietary pattern. In addition, we examined the potential variations in dietary patterns among different age and gender groups by stratifying our sample and deriving separate dietary patterns in population subgroups. There were no major differences in the factor loadings and the derived dietary pattern in any of these secondary confirmatory analyses, and participants were finally analyzed together and all models were adjusted for potential confounding variables (including age and gender).

8.3.3.3 Simplified dietary pattern

To address the criticism regarding the lack of reproducibility of data-driven dietary patterns and their dependence on the population under study, we constructed a robust "simplified dietary pattern" score as proposed by Schulze et al. (68). Previous studies have shown that simplified dietary pattern scores closely approximate the dietary pattern scores derived from factor analyses or the RRR with the extra advantage of being reproducible in future studies (68); however, application of this technique to the PLS-derived pattern is unknown.

In the present study, a simplified dietary pattern score was constructed from the food groups with the highest loadings and correlations with the wPLS-derived dietary pattern score. For this purpose, the following food groups (gram/day) were first standardized (Mean=0, SD=1) while retaining the direction of their factor loading, and then summed up to build the simplified dietary pattern score (68, 211): fast foods, carbonated drinks, refined grains, solid fat, processed meat, cheese, baked goods, gravies, sauces and dressings, and sugars and syrups (each weighted +1), and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables, and yogurt (each weighted -1). A higher simplified dietary pattern score in this research indicated a lower diet quality. Overall 49.18% of all response variation was explained by these key 14 food groups, with whole fruits (9.18%), solid fat (5.17%), fast food (4.73%), carbonated drinks (3.94%) and orange vegetables (3.83%) explaining the most response variation (data not shown).

8.3.4 Handling dietary misreporting

Previously, our group demonstrated a widespread prevalence of selective and differential misreporting (under- and over-reporting) among Canadian adolescents and adults (14). In addition, we confirmed that misreporting bias may reverse or hide diet-disease relationships and therefore needs to be adjusted for in nutritional surveys (14). In the present study, each participant was classified as under-reporter, plausible-reporter or over-reporter by comparison of their reported energy intakes with estimated energy requirements (EER). EERs were calculated using the Institute of Medicine (IOM) factorial equations, which require participants' sex, age, physical activity level (PAL) (sedentary, low active, moderately active, and high active), and measured weight and height (112). McCrory et al.'s method (23, 36, 63)(for 4 levels of physical activity) was then used to directly compare individuals' energy intakes with EER using cut-points for their agreement based on error propagation calculations. We constructed all CIs in Log scale and exponentiated the cut-points to account for the skewed distribution of energy intakes in the CCHS 2.2 (14). Based on the CCHS 2.2 data, individuals were categorized as under-reporter if their energy intakes were <70% of their EER. Participants whose energy intakes were 70-142% of their EER and >142% of their EER were classified as plausible- and over-reporters, respectively (±1 SD). All dietary analyses in this research were additionally adjusted for the potential misreporting bias as recommended previously (14).

8.3.5 Statistical analyses

All data analyses were conducted using JMP Genomics 11.2 and SAS 9.4 (SAS Institute Inc., Cary, NC). A two-tailed p-value <0.05 was used to define statistical significance. Variance estimation was performed using bootstrap balanced repeated replication (BRR) technique to account for the complex sampling framework of the CCHS 2.2 (113, 114). Briefly, BRR generates a replicate weight by randomly selecting a sample with replacement from the original sample and applying all the adjustments to the selected sample. This procedure is repeated 500 times to generate 500 sample survey weights, which are used to estimate variances. All analyses were weighted to ensure a nationally-representative sample, using the sampling survey weights calculated by Statistics Canada based on respondent classes with similar socioeconomic profiles (30).

For all descriptive analyses, participants were divided into quartiles based on the population distribution of dietary pattern scores, with participants in the highest quartile being the most adherent to the dietary pattern. To reduce extraneous variability and confounding effects (212), all nutritional analyses were performed in terms of energy intake using the density approach as described previously (110). Weighted multivariable linear regression and the least-square means were used to examine the associations between the dietary pattern scores and the continuous and categorical variables, respectively. The p-trend for continuous variables across the quartile categories of the dietary pattern scores were p-values from the weighted linear regression coefficient (PROC SURVEYREG). To test the linear trend for categorical variables, we set the median intake of each quartile to each participant in the same quartile and treated the resulting median as a continuous variable in weighted regression analyses (PROC SURVEYLOGISTIC) (213).

To test the correlations between dietary pattern scores and their constituent food groups, weighted Pearson correlation analysis was conducted. The relationship between dietary pattern scores and obesity risk was examined using weighted multinomial logistic regression-generalized logit model (GLM) (PROC SURVEYLOGISTIC), with quartiles of the pattern scores specified as exposure measures. We also evaluated the obesity risk in terms of 1 SD increase in the dietary pattern z-scores (continuous) and estimated the associated odds ratios (OR) and 95% CIs. Quartile 1 was the referent category in all regression analyses for consistency. Potential confounding variables were selected *a priori* from the literature and then tested for relevance in a weighted back-ward regression model where variables with the least influence on the information criteria were excluded. All analyses included potential confounders in successive models and only the most informative are presented for brevity (available from the author upon request). Model I was adjusted for age, sex and misreporting status (under-reporting, plausible reporting and over-reporting); Model II: adjusted for Model I variables plus physical activity (inactive, moderately active and active); and Model III: adjusted for Model II variables plus smoking (daily smoker, occasional smoker, former smoker, and never smoked). Due to the importance of differentiating obesity phenotypes (metabolically healthy and unhealthy obese)(184), regression analyses were also stratified to investigate the association of dietary pattern scores and obesity with and without at least one chronic disease (e.g., diabetes, cardiovascular diseases, cancer), as well as being non-obese with at least one chronic disease. Consistent with previous studies (185), we pooled the presence of all chronic diseases (diabetes, cardiovascular diseases, and cancer) since the latest dietary guidelines also aim to reduce the cumulative risk of diet-related chronic diseases at the population level, which is critical from a public health perspective (67). Finally, we also performed subgroup analyses within the strata of age, sex, physical activity, misreporting and smoking status.

8.4 Results

8.4.1 Part A: Identification of dietary pattern

Supplementary Table 8.2 presents the mean values for each of the three obesity-related response variables used in the wPLS regression. As expected, the adjusted mean values of ED, %EF and FD were significantly different by BMI categories, with obese participants consuming a diet higher in ED and %EF and lower in FD compared to normal-weight individuals ($p<0.001$). Factor loadings for the ED, HF and LFD dietary pattern derived from the wPLS are presented in Figure 8.1 to represent the magnitude and direction of contribution of each food group to the non-simplified dietary pattern score. Generally, the ED, HF and LFD dietary pattern was characterized by high loadings of fast foods, carbonated drinks, refined grains, solid fats, processed meats, cheese, baked goods, gravies, sauces and dressings, and sugars and syrups and low intakes of whole fruits, dark green vegetables, other vegetables and juices, orange vegetables, and yogurt (factor loadings≥|0.17| (193)) (Figure 8.1). Among all food groups, factor loadings of fast foods (+0.35), carbonated drinks (+0.31), and refined grains (+0.29) on one side, and whole fruits (-0.31), dark green vegetables (-0.21), and other vegetables and juices (-0.18) on the other, were the strongest and the magnitude was about double that of the sugars and syrups group (+0.17) and yogurt (-0.17).

The correlations of key food groups (predictors) with obesity-related response variables and total dietary pattern z-scores are presented in Table 8.1. The correlations of informative food groups (predictors) with ED, HF, LFD dietary pattern score were the highest for fast foods ($r=0.514$) followed by whole fruits ($r=-0.447$) ($p<0.0001$). The corresponding correlation coefficients with the simplified dietary pattern score were 0.452 and -0.352 for fast foods and whole fruits, respectively. Even though these predictors were not used for constructing the 2015 DGAI, the majority of them had a moderate correlation with the total 2015 DGAI score ($p<0.0001$). Importantly, the ED, HF and LFD dietary pattern score was highly correlated with the simplified dietary pattern score ($r=0.951$), while the associations of the ED, HF, LFD and the simplified dietary pattern scores with the 2015 DGAI score were moderate at r=-0.565 and r=-0.539, respectively (Table 8.1). When components of the 2015 DGAI were examined individually, higher scores on the ED, HF and LFD dietary pattern were negatively correlated with all 2015 DGAI component scores, except for the weak positive associations for starchy vegetables (r=0.147), grains (r=0.104), meat and beans (r=0.081) and dairy (r=0.095), respectively (Table 8.2). Similar results were observed for the association with the simplified dietary pattern score. Overall, the correlation of the ED, HF and LFD dietary pattern score with the DGAI food intake subscore and healthy choice subscore were r=-0.3 and r=-0.513, respectively.

8.4.2 Part B: Association between dietary pattern scores and nutritional and lifestyle profiles

Participants were classified into quartiles based on the ED, HF and LFD dietary pattern score as well as the simplified dietary pattern score, with higher quartiles corresponding to a less healthy dietary pattern. In order to better elucidate the association between the derived dietary pattern scores and food group intakes, linear trends in consumption of important food groups (loadings ≥|0.17|) across the quartiles of dietary pattern scores are presented in Table 8.3. As expected from the correlation matrix and factor loadings, mean intakes of fast foods, carbonated drinks, refined grains, solid fats, processed meats, cheese, baked goods, gravies sauces and dressings, and sugars and syrups increased monotonically by moving from the first quartile (healthiest) of the dietary pattern score to the fourth (least healthy) (p-trend<0.0001). In contrast, there was a negative linear trend between dietary pattern scores and adjusted mean intakes of whole fruits, dark green vegetables, other vegetables and juices, orange vegetables and yogurt (p-trend<0.0001). Generally, there was an approximately 2-4 fold difference in food group intakes of participants in the first compared to the fourth quartiles of the dietary pattern scores (p-trend<0.0001).

The socio-demographic and lifestyle characteristics of participants across the quartiles of the ED, HF and LFD dietary pattern and simplified dietary pattern scores are presented in Table 8.4. Moving from the first to the fourth quartile of the ED, HF and LFD dietary pattern score, the mean 2015 DGAI score and its food intake and healthy choice subscores decreased by 2.9, 1.12 and 1.77 scores, respectively (p-trend<0.0001). Compared to the first quartile, participants in the highest quartile of ED, HF and LFD dietary pattern score were less likely to be female (33.78±2.27 vs. 59.15±3.2%), older (40.13±0.45 vs. 49.5±0.53 years), multivitamin user (35.76±1.88 vs. 42.8±2.36%), and immigrant (10.67±1.27 vs. 35.18±3.47%), and were less likely to have excellent self-perceived health (16.82±1.04 vs. 22.71±1.36%), and be an urban resident (76.94±1.65 vs. 85.89±1.23%) (p-trend<0.0001). In addition, there was a linear trend towards higher BMI values (1.7 point difference) and higher prevalence of obesity (21.82±1.37% in quartile 4 vs. 14.12±1.08% in quartile 1) by increasing quartiles of the ED, HF and LFD dietary pattern score (p-trend<0.0001). Even though only 8.41% of participants in quartile 1 were obese with ≥ 1 chronic diseases, this number increased to 13.41% in quartile 4 category (p-trend<0.0001). The proportion of physically inactive, daily smoker, alcohol drinker, less-educated, single and Caucasian individuals also increased monotonically moving from the first to the fourth quartile of the ED, HF and LFD dietary pattern score (p-trend<0.0001). Similar findings were observed across the quartiles of the simplified dietary pattern score.

Table 8.5 presents the macro- and micronutrient intakes across the quartile categories of the ED, HF and LFD dietary pattern and simplified dietary pattern scores. After adjusting for age, sex and misreporting status, all associations between the dietary pattern scores and nutrient intakes (as a function of energy intake) were significant. Notably, total calorie intake increased across the quartiles, with quartile 4 participants having absolute calorie intake values that were on average 300 kcal/day higher than those in quartile 1 (p-trend<0.0001). By design of the wPLS algorithm in this study, participants in quartile 4 had higher percentage of energy as total fat (35.47±0.33 vs. 27.05±0.39%) and energy density (1.18±0.02 vs. 0.7±0.02 kcal/gr), while their fiber density intakes (5.98±0.1 vs. 12.23±0.23 g/1000kcal) were significantly lower (p-trend<0.0001). Additionally, there was a significant negative trend across the quartiles of dietary pattern scores for the % of energy from protein and carbohydrates, and densities (gr/1000kcal) of calcium, vitamin A, vitamin D, vitamin C, thiamin, riboflavin, niacin, vitamin B_6, vitamin B_{12}, folate, folacin, phosphorus, magnesium, iron, zinc, potassium and moisture (p-trend<0.0001). On the contrary, the percentage of participants who skipped breakfast (11.78±1.21 vs. 7.71±1%) and percentage of energy from Solid Fats and Added Sugars (SoFAs) (41.3±0.65 vs. 21.7±0.58%) was significantly higher in the fourth quartile category, compared to the first (p-trend<0.01).

8.4.3 Part C: Association between dietary pattern scores and obesity

Figure 8.2 presents the multivariate-adjusted ORs for the risk of obesity across the quartile categories of ED, HF and LFD dietary pattern score (2a), simplified dietary pattern score (2b), and the 2015 DGAI score (2c). Moving from the lowest quartile (healthiest) of the ED, HF and LFD dietary pattern score to the highest (unhealthiest), the odds of obesity mutually adjusted for all potential confounders (age, sex, misreporting, physical activity and smoking) increased from 1.639 (95% CI: 1.212-2.217) in quartile 2, to 1.739 (1.296-2.334) in quartile 3, and 3.551 (2.605-4.841) in quartile 4, respectively (p-trend<0.0001). Similar-sized adjusted ORs were observed for obesity risk across the quartiles of simplified dietary pattern score, increasing from 1.455 (95% CI: 1.072-1.976) in quartile 2 to 1.621 (1.203-2.182) in quartile 3, and 3.094 (2.221-4.311) in quartile 4, respectively (p-trend<0.0001). In addition, moving from quartile 1 to quartile 4 of the 2015 DGAI decreased the risk of obesity in the fully-adjusted model by 49.4% (95% CI: 37.7-67.8; P-trend<0.0001). Adjusting for different confounders did not change the magnitude or direction of observed associations significantly, suggesting that confounders were not responsible for the observed effects.

When participants were jointly classified for the risk of obesity as well as having at least one chronic disease, differences were observed between individuals with healthy and unhealthy obesity phenotypes in the magnitude of their association with dietary pattern scores (Figure 8.3).

Following an ED, HF and LFD dietary pattern was associated with a gradient increased risk of unhealthy obesity phenotype in a multivariate-adjusted model, from OR of 1.305 (0.909-1.873) in quartile 1 to 1.803 (1.276-2.548) in quartile 2 and 3.136 (2.137-4.601) in quartile 4, respectively (p-trend<0.0001). Even though the probability of healthy obesity and being non-obese with at least one chronic disease also increased consistently across the increasing quartiles of ED, HF and LFD dietary pattern score, the magnitude of this increase was weaker compared to the unhealthy obese phenotype. Classifying individuals according to the simplified dietary pattern score resulted in slightly stronger ORs for the risk of unhealthy obesity, with participants in quartile 4 having 3.285 (2.251-4.792) times higher risk, compared to the first quartile (p-trend<0.0001) (Figure 8.3b). Similarly, the highest quartile of the 2015 DGAI score (healthiest dietary pattern) was associated with a significant linear reduction in the risk of unhealthy obesity (OR: 0.444 (0.312-0.633) and healthy obesity (OR: 0.451 (0.285-0.711)), compared to the first quartile (least healthy diet) (p-trend<0.0001).

Finally, we used continuous dietary pattern z-scores as predictors of obesity in strata of sex, age, reporting accuracy, physical activity, and smoking status after controlling for confounding variables (Supplementary Figure 8.1). The risk of obesity increased per 1 SD increment in the ED, HF and LFD dietary pattern z-score among all the examined subgroups (p<0.05), except for occasional smokers. Each 1 SD increase in the ED, HF and LFD dietary pattern z-score corresponded with 1.543 (95%CI: 1.239-1.922) times higher risk of obesity among physically-active individuals, followed by 1.502 (95%CI: 1.258-1.793) times higher risk among those with moderate physical activity and 1.491 (95%CI: 1.326-1.677) times higher risk among plausible reporters (P-value<0.0001). Slightly weaker associations were observed between the simplified dietary pattern z-scores and obesity risk, even though all subgroup analyses were positive and significant, except among participants aged ≥70 years and occasional smokers (Supplementary Figure 8.1b). As shown in Supplementary Figure 8.1c, consistent negative associations were observed between 1-SD increase in the 2015 DGAI z-score and obesity risk among all population subgroups in multivariable-adjusted models, even though the association did not reach statistical significance for males, under-reporters, daily smokers and occasional smokers (p-value>0.05).

Overall, for 1 SD increase in the ED, HF, LFD dietary pattern and simplified dietary pattern scores, the risk of obesity increased 1.406 times (05% CI: 1.283-1.54) and 1.079 times (1.056-1.102), respectively, while the risk of obesity reduced by 11.9% per 1 SD increase in the 2015 DGAI z-score (p-value <0.0001).

8.5 Discussion

In this nationally-representative survey of Canadian adults, we observed a strong and consistent relationship between an energy-dense, high-fat and low-fiber dietary pattern and risk of obesity. This effect was significant among sub-populations with and without an accompanying chronic disease as well as among different population subgroups (based on age, sex, reporting accuracy, physical activity and smoking status). The simplified dietary pattern score was similarly associated with obesity phenotypes among population subgroups. Comparing these two dietary pattern scores with the 2015 DGAI score, we demonstrated that the hybrid and *a priori* methods could be used as complementary techniques to define dietary patterns, since they each have different strengths and target different aspects of dietary intakes. Overall, the benefits of adherence to an overall healthy dietary pattern (*a priori*) were compatible to avoidance of unhealthy dietary patterns (hybrid).

In line with previous studies (211), dietary patterns were strongly associated with several socio-demographic, nutritional and lifestyle characteristics. Specifically, young males, those who were physically inactive, single and less-educated, daily smokers, alcohol drinkers, rural residents, and Caucasians were more likely to follow an unhealthy ED, HF, LFD dietary pattern. There was also a 2-4 times difference between the first and the fourth quartile of the ED, HF, LFD and simplified dietary pattern scores in intakes of key food groups and nutrients, resulting in participants in quartile 4 having significantly lower-quality diets, and thus not meeting current dietary recommendations. The significantly lower quality of diets and lifestyle behaviours in quartile 4 of an ED, HF and LFD dietary pattern score resulted in 3 times higher risk of unhealthy and healthy obesity, compared to the first quartile. Due to the strong correlation of the ED, HF and LFD dietary pattern score with the simplified dietary pattern score (r=0.95), the latter was also strongly associated with 2-3 times higher risk of healthy and unhealthy obesity phenotypes. However, the confidence intervals were significantly smaller for the estimates using the simplified dietary pattern score compared to the wPLS-derived pattern score, confirming the reduction of noise and increased reliability of findings using the simplified pattern method. The dietary pattern we identified through the wPLS procedure was very similar to the patterns derived using the RRR or cluster analysis in other studies to explain obesity risk, including the European Prospective Investigation into Cancer and Nutrition–Potsdam cohort which found high-fat foods (sauces, fats and meat) as the main predictors of subsequent weight gain (199). Using principal component analysis and cluster analysis in the Baltimore Study, dietary patterns high in reduced-fat dairy, high-fiber grains and cereals, vegetables and fruits, and low in meats, soda, refined grains and high-fat dairy products were significantly associated with lower weight gain prospectively (214, 215). Similarly, among Swedish severely-obese adults, an energy-dense, high-saturated fat and low-fiber dietary pattern that had high loadings of fast food and snacks and low loading of fruits and vegetables was shown to increase body weight, waist circumference, blood pressure, serum insulin, and lipid profile during a 10-year follow-up (202). These results have also been confirmed among children and adolescents (198-200). The potential mechanism underlying these effects may be related to the impact of energy-dense diets on desensitizing appetite control mechanisms, which can lead to higher energy intakes (216). Energy-dense diets are also usually low in fiber and high in fat, which is metabolized at lower energetic cost, provides higher calories and is less satiating compared to other macronutrients (217). Considering the effect seen in Southgate et al.'s study (218), the difference we observed in fiber intakes between the first and the fourth quartile of the ED, HF, LFD dietary pattern score (6.25 grams) would be associated with 27.5 kcal reduction in energy absorbed in a day and equivalent to 10,037 kcal reduction in one year, which makes about 1.28 kg difference in fat mass (198).

In the present study, adherence to the validated 2015 DGAI was associated with a 55% reduction in the risk of both obesity phenotypes, with consistent results among most population subgroups. This finding is in agreement with those of others that showed an inverse relationship between adherence to the USDA DGA and risk of obesity, metabolic syndrome, insulin resistance and coronary heart disease (80, 169, 171-173). Potential mechanisms underlying these effects may include lower energy density, added sugars, saturated fat and processed meat content of the USDA Food Patterns as well as their higher recommendations for intake of fiber, fruits, vegetables and whole grains, all of which have been shown to mediate reduced risk of chronic diseases.

The wPLS regression identified fast foods and whole fruits as the most important predictors of obesity (loading criterion) among Canadian adults. In fact, predictor loadings for these 2 food groups were almost double those of the yogurt, and sugars and syrups, which were also significant (≥|0.17|). This indicates that when all other food groups are held constant, a 1 SD change in fast food or whole fruit intakes has double the effects on total dietary pattern scores compared to a similar change in intake of yogurt, and sugars and syrups. Particularly, the protective effects of fruits and vegetables would have been even more pronounced if we classified whole fruits, dark green vegetables, other vegetable and juices, and orange vegetables into one food group, as these 4 are the top positive drivers of the total wPLS-derived dietary pattern score (Figure 8.1). This point reinforces the importance of efforts to encourage fruit and vegetable consumption as part of a healthy dietary pattern, rather than focusing exclusively on exclusion of high-fat or high energy-dense foods such as sugars and syrups.

This study has several strengths. This is the first and the largest nationally-representative study to examine dietary patterns of Canadians in relation to a wide range of lifestyle behaviours, nutrient profiles and chronic diseases. In fact, the main methodological challenge we addressed in this study was modifying the PLS algorithms to incorporate sampling survey and bootstrapping weights (using JMP-Genomics software) to characterize dietary patterns at the national population level. A simplified dietary pattern was also generated from the wPLS output for comparison and to ensure future generalization of results in other populations. In addition, we used the 2015 HHS/USDA DGA, validated in a previous study (Chapter 7), to enable future replication of results in other populations and for comparison purposes. Using measured anthropometry, confounder adjustments, and sensitivity analyses were other strengths of this research. Additionally, all analyses controlled for the systematic selective and differential misreporting bias as described previously (14).

Findings of this research should be considered in light of few limitations. Random non-differential measurement error associated with the use of dietary recalls was inevitable, and therefore the association of dietary patterns with obesity and chronic diseases are likely to have been conservative and attenuated (92) . In addition, causal and temporal inference is limited due to the cross-sectional design of this survey (91). The third limitation relates to the 2015 DGAI scoring, where we were unable to calculate the DGAI *trans fat* component due to lack of data in the CNF.

8.5.1 Conclusions and implications

In this study, higher scores for the poor quality ED, HF, LFD dietary pattern and simplified dietary pattern were associated with 2-3 times higher risk of obesity with and without a chronic disease among population subgroups. Additionally, more compliance to the 2015 HHS/USDA DGA, evaluated in terms of the DGAI, reduced the risk of obesity phenotypes by over 50%. These results support the growing evidence that there is more than 1 approach for healthy eating and that foods can be combined differently for achieving an optimal dietary pattern.

An important observation in this study was that higher scores on the ED, HF, LFD dietary pattern and lower score on the 2015 DGAI increased the risk of both obesity phenotypes as well as risk of being non-obese with at least one chronic disease, which indicates that all body weight subgroups would benefit from adherence to an overall healthy dietary pattern, even though the highest benefit was provided to the unhealthy obese group. In light of the current obesity epidemic, our findings encourage development of public health messages and relevant clinical practice guidelines to target different obesity phenotypes with an emphasis on the consumption of an overall healthy dietary pattern.

Future longitudinal studies are needed to further document the benefits of adherence to a dietary pattern in line with the 2015 HHS/USDA DGA and compare results to those from diets low in ED and %EF and high in FD at the population level. Since even those in the highest quartile of the 2015 DGAI still had room for improvement (maximum score: 10.30-15.60/19), a promising future direction is further enhancing the risk reduction strategies through achieving more optimal diet quality scores. Collectively, findings of this nationally-representative survey may be used for informing public health policies for prevention of obesity and other chronic diseases (27) among the Canadian population and others consuming "Western" type diets (126).

Table 8.1. Weighted Pearson correlation coefficients (*r*-values) between important predictors (food groups), response variables, and energy-dense, high-fat and low-fiber density pattern score derived from the weighted partial least squares (wPLS) (centered and scaled), simplified dietary pattern score and the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) score among adult participants of the Canadian Community Health Survey, cycle 2.2 (n=11,748)[*]

	Response Variables			**Total Dietary Pattern Scores**		
	Energy Density	**Fiber Density**	**% E from Fat**	**Energy-Dense, High-Fat & Low-Fiber Density Pattern (wPLS)**	**Simplified Dietary Pattern**[†]	**2015 DGAI**[‡]
Predictor Variables[§]						
Positive association						
Fast Foods	0.299	-0.17	0.152	0.514	0.452	-0.222
Carbonated Drinks	0.238	-0.247	-0.019[ǀ]	0.456	0.419	-0.242
Refined Grains	0.221	-0.195	0.036	0.42	0.409	-0.174
Solid Fats	0.2	-0.154	0.302	0.375	0.364	-0.197
Processed Meats	0.107	-0.127	0.163	0.3	0.341	-0.175
Cheese	0.162	-0.155	0.241	0.298	0.3	-0.245
Baked Goods	0.265	-0.095	0.097	0.289	0.325	-0.039
Gravies, Sauces and Dressings	0.068	-0.094	0.156	0.254	0.157	-0.135
Sugars and Syrups	0.196	-0.098	-0.011 [NS]	0.245	0.287	-0.063
Inverse association						
Whole Fruits	-0.394	0.315	-0.145	-0.447	-0.352	0.332
Dark Green Vegetables	-0.272	0.184	0.012[NS]	-0.311	-0.347	0.171
Other Vegetables and Juices	-0.258	0.163	-0.005 [NS]	-0.259	-0.28	0.232
Orange Vegetables	-0.266	0.208	-0.029[¶]	-0.249	-0.247	0.143
Yogurt	-0.173	0.085	-0.083	-0.242	-0.277	0.151
Response Variables						
Energy Density	1	-0.441	0.411	0.673	0.655	-0.498
Fiber Density		1	-0.293	-0.533	-0.509	0.547
% Energy from Fat			1	0.33	0.282	-0.325
Total Dietary Pattern Scores						
Energy-Dense, High-Fat & Low-Fiber Density Pattern (wPLS)				1	0.951	-0.565
Simplified Dietary Pattern					1	-0.539

NS: Not Significant

[*]All p-values are <0.0001 unless otherwise noted.

[†]Sum of standardized intakes of fast foods, carbonated drinks, refined grains, solid fats, processed meats, cheese, baked goods, gravies, sauces and dressings, sugars and syrups (all with +1 weights), and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables and yogurt (all with -1 weights)

[‡]DGAI scores ranged from 0-19 possible points with higher scores indicating more healthful and varied dietary patterns.

[§]Food groups that contributed the most to the w-PLS derived dietary pattern score (factor loading ≥|0.17|)

[ǀ]P-value: 0.042

[¶]P-value: 0.002

Table 8.2. Weighted Pearson correlation coefficients (*r*-values) between components of the 2015 Dietary Guidelines for Americans Adherence Index (DGAI) (Food Intake Subscore and Healthy Choice Subscore) and energy-dense, high-fat and low-fiber density pattern score derived from the weighted partial least squares (wPLS) (centered and scaled) as well as simplified dietary pattern score among adult participants of the Canadian Community Health Survey, cycle 2.2 (n=11,748)*

	A priori Dietary Pattern Score			Hybrid Dietary Pattern Scores	
	Total DGAI Score†	**Food Intake Subscore**‡	**Healthy Choice Subscore**§	**Energy-Dense, High-Fat & Low-Fiber Density Pattern (wPLS)**	**Simplified Dietary Pattern**ǀ
DGAI Food Intake Subscore					
Dark green vegetables	0.45	0.568	0.075	-0.219	-0.222
Red/orange vegetables	0.331	0.403	0.071	-0.17	-0.18
Legumes	0.229	0.357	-0.031	-0.061	-0.104
Starchy vegetables	0.167	0.28	-0.044	0.147	0.154
Other vegetables	0.392	0.59	-0.032	-0.239	-0.252
Fruits	0.433	0.403	0.218	-0.34	-0.277
Variety of fruits and vegetables	0.692	0.895	0.093	-0.322	-0.318
Grains	0.113	0.153	0.008NS	0.104	0.112
Meat and beans	0.198	0.346	-0.066	0.081	0.06
Dairy	0.095	0.255	-0.123	0.095	0.066
Added sugar	0.214	0.332	-0.028	-0.251	-0.259
Food Intake Subscore	0.725	1	0.033		
DGAI Healthy Choice Subscore					
Whole grain	0.363	0.077	0.448	-0.218	-0.221
Dietary Fiber density	0.642	0.333	0.593	-0.572	-0.541
Total fat	0.368	0.055	0.478	-0.175	-0.15
Saturated fatty acid	0.451	0.057	0.597	-0.308	-0.286
Cholesterol	0.329	-0.097	0.576	-0.268	-0.275
Low fat dairy	0.293	0.113	0.311	-0.153	-0.164
Low fat meat	0.237	0.158	0.183	-0.069	-0.041
Sodium	0.212	-0.221	0.533	-0.292	-0.249
Alcohol	0.2	-0.045	0.336	-0.103	-0.051
Healthy Choice Subscore	0.713				
Hybrid Dietary Pattern Scores					
Energy-Dense, High-Fat & Low-Fiber Density Pattern (wPLS)		-0.3	-0.513		
Simplified Dietary Pattern		-0.308	-0.469		

NS: Not Significant
*All p-values are <0.0001 unless otherwise noted
†DGAI scores ranged from 0-19 possible points with higher scores indicating more healthful and varied dietary patterns.
‡Food intake subscores ranged from 0-11 possible points and are evaluated based on energy level
§Healthy choice subscores ranged from 0-8 possible points and are evaluated on the same calorie level for all individuals

[l]Simplified dietary pattern score is the sum of standardized intakes of fast foods, carbonated drinks, refined grains, solid fats, processed meats, cheese, baked goods, gravies, sauces and dressings, sugars and syrups (all with +1 weights), and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables and yogurt (all with -1 weights)

Table 8.3. Weighted mean daily intakes of informative foods (factors loading ≥|0.17|) across the quartile categories of energy-dense, high-fat and low fiber density (ED, HF, LFD) dietary pattern score derived from the weighted partial least squares (wPLS) (centered and scaled), and simplified dietary pattern score among adult participants of the Canadian Community Health Survey, cycle 2.2 (n=11,748)[*,†,‡]

Predictors *(gr/d)*[§]	**ED, HF, LFD Dietary Pattern Score Quartiles**				**Simplified Dietary Pattern Score Quartiles[ǁ]**			
	1 (Healthiest)	**2**	**3**	**4 (Least Healthy)**	**1 (Healthiest)**	**2**	**3**	**4 (Least Healthy)**
Positive association								
Fast Foods	55.94±5.74	85.77±6.44	120.81±6.54	233.2±9.84	60.32±6.29	88.35±6.24	126.40±6.83	219.08±9.86
Carbonated Drinks	101.21±15.24	166.97±15.8	251.1±18.59	500.08±24.32	110.11±16.18	175.99±16.13	253.42±17.60	477.29±26.14
Refined Grains	30.26±2.71	42.86±2.69	55.52±3.14	89.19±3.49	29.49±2.68	41.02±2.74	60.07±3.00	86.71±3.52
Solid Fats	13.48±1.43	20.64±1.55	25.14±1.84	43.13±2.76	13.14±1.46	20.03±1.49	26.05±1.68	43.08±2.76
Processed Meats	7.68±2.09	13.18±2.08	17.84±2.37	37.54±3.81	6.83±2.02	11.64±2.09	16.87±2.27	41.38±3.82
Cheese	16.23±2.38	23.41±2.29	27.93±2.6	41.09±3.41	16.21±2.36	21.42±2.20	27.94±2.65	43.08±3.23
Baked Goods	32.47±3.34	45.42±3.47	62.73±3.72	81.22±5.01	28.65±3.33	44.92±3.45	59.46±3.92	89.03±5.01
Gravies, Sauces and Dressings	14.39±1.7	16.31±1.82	19.83±2.43	32.95±2.55	16.97±1.79	19.50±2.54	19.61±2.14	26.82±2.53
Sugars and Syrups	14.73±2.13	19.02±1.57	25.15±1.66	31.60±2.47	13.05±1.57	19.31±2.23	23.71±1.67	34.57±2.39
Inverse association								
Whole Fruits	281.13±13.17	138.57±6.97	89.28±7.27	21.73±9.74	261.29±12.22	136.12±9.63	98.01±7.54	46.10±9.21
Dark Green Vegetables	70.65±7.49	28.27±2.56	21.38±3.13	11.67±4.18	73.10±7.47	26.79±2.46	23.54±3.19	10.63±4.15
Other Vegetables and Juices	146.59±7.95	88.18±5.64	53.83±3.94	35.82±5.19	144.68±7.91	90.63±6.17	57.72±3.89	35.18±5.02
Orange Vegetables	105.48±5.66	67.36±4.2	46.08±3.96	22.85±3.28	101.99±5.90	65.51±4.21	51.48±3.94	25.25±3.33
Yogurt	48.00±4.03	18.42±2.50	11.08±2.05	2.36±2.40	52.57±3.83	16.99±2.48	8.83±1.84	3.04±2.29

[*]Estimates are weighted least square means and bootstrapped variances (Balanced Repeated Replication technique)

[†]Means are adjusted for age, sex, energy intake and misreporting status (under-reporting, plausible reporting and over-reporting) (cut-off for plausible reporting: 0.7≤Energy Intake/Estimated Energy Requirement≤1.42)

[‡]The p-trend was estimated using the dietary pattern score in its continuous form and represents the p-value associated with linear regression coefficient. All p-value for trends are <0.0001

[§]Food groups that contributed the most to the dietary pattern score (factor loading ≥|0.17|)

[ǁ]Sum of standardized intakes of fast foods, carbonated drinks, refined grains, solid fats, processed meats, cheese, baked goods, gravies, sauces and dressings, sugars and syrups (all with +1 weights) and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables and yogurt (all with -1 weights),

Table 8.4. Weighted analysis of the socio-demographic and lifestyle characteristics across the quartile categories of energy-dense, high-fat and low fiber density (ED, HF, LFD) dietary pattern score derived from the weighted partial least squares (wPLS) (centered and scaled), and simplified dietary pattern score among adult participants of the Canadian Community Health Survey, cycle 2.2 (n=11,748)[*,†,‡]

	ED, HF, LFD Dietary Pattern Score Quartiles				**Simplified Dietary Pattern Score Quartiles**[§]			
	1 (Healthiest)	**2**	**3**	**4 (Least Healthy)**	**1 (Healthiest)**	**2**	**3**	**4 (Least Healthy)**
DGAI Score[ǁ]	10.35±0.06	9.08±0.08	8.3±0.06	7.45±0.06	10.35±0.06	9.05±0.08	8.31±0.06	7.51±0.06
Food intake subscore[¶]	4.62±0.06	3.85±0.06	3.52±0.05	3.5±0.05	4.66±0.05	3.83±0.06	3.52±0.05	3.5±0.05
Healthy choice subscore[**]	5.73±0.05	5.24±0.06	4.78±0.05	3.96±0.05	5.69±0.05	5.22±0.05	4.8±0.05	4.01±0.06
Female, *%*	59.15±3.2	60.88±2.75	46.14±3.9	33.78±2.27	58.13±3.08	58.95±3.41	47.82±2.96	34.99±2.58
Age, *yr*	49.5±0.53	48.38±0.73	46.27±0.52	40.13±0.45	49.28±0.47	48.33±0.73	45.78±0.54	40.74±0.45
BMI, kg/m^2	25.56±0.21	26.62±0.28	26.57±0.19	27.26±0.23	25.52±0.21	26.71±0.29	26.53±0.18	27.22±0.24
Obesity, *%*	14.12±1.08	19.17±1.54	19.22±1.3	21.82±1.37	14.64±1.16	18.64±1.4	19.14±1.31	21.8±1.34
Obese with ≥1 chronic disease, *%*	8.41±0.66	10.04±0.85	11.77±0.97	13.41±1	8.27±0.64	10.17±0.78	11.97±1.06	13.22±0.99
Low-active participants, *%*	45.96±2.16	53.46±2.13	56.02±2.54	58.53±1.8	46.25±2	54.52±2.41	54.7±2.37	58.39±1.88
Current daily smokers, *%*	10.59±0.75	16.29±1.25	19.68±1.23	26.25±1.63	11.18±0.81	17.47±1.24	20.06±1.31	23.98±1.59
Multivitamin users, *%*	42.8±2.36	42.13±2.2	37.61±2.11	35.76±1.88	43.46±2.49	40.37±2.28	38.67±2.24	35.79±1.81
Drank alcohol in the past 12 months, *%*	74.16±2.1	79.9±2.01	83.4±1.37	84.85±1.29	76.66±2.05	78.35±1.79	82.47±1.52	84.73±1.25
Highest household education, *%*								
<Secondary school	7.82±0.77	11.79±0.87	12.02±0.93	13.93±1.05	8.07±0.82	12.01±0.89	12.38±0.87	13.1±1.11
Post-secondary education	76.07±1.55	66.85±1.83	66.37±1.77	62.48±1.83	75.48±1.68	66.42±1.82	65.65±1.84	64.17±1.85
Highest respondent education, *%*								
<Secondary school	18.26±1.4 [NS]	26.27±1.58	25.55±1.4	31.03±1.49	19.11±1.57	25.25±1.58	25.83±1.36	30.66±1.48
Post-secondary education	51.49±2.04 [NS]	39.96±2	40.86±1.71	34.52±1.53	50.17±2.17	41.33±2.12	40.58±1.76	34.98±1.48
Marital Status, *%*								
Married	26.79±11.08[††]	20.99±9.43	21.27±9.68	22.49±10.15	27.03±11.34[††]	22.49±9.83	19.15±8.92	23.07±10.28
Single/Never married	39.32±13.12[††]	47.16±13.8	46.74±14.01	44.96±14.03	38.97±13.31[††]	44.9±13.57	49.96±14.03	44.09±13.9
Immigrant, *%*	35.18±3.47	24.34±3.19	14.1±2.02	10.67±1.27	33.48±3.48	23.16±2.89	16.66±2.06	10.99±1.5
Aboriginal, *%*	0.74±0.25	0.99±0.34	1.17±0.37	1.59±0.5	0.81±0.28[††]	0.88±0.3	1.26±0.4	1.52±0.48
Caucasian, *%*	73.6±2.36	84.66±2.31	91.51±1.31	93.65±0.82	75.15±2.55	84.76±2.11	90.77±1.24	92.79±0.98
<5 vegetables and fruits consumed per day, *%*	53.03±2.94	68.38±1.99	75.24±2.07	80.47±1.54	53.78±2.75	67.96±2.15	74.99±2.01	80.19±1.68
Excellent self-perceived health, *%*	22.71±1.36	20.89±1.37	19.39±1.25	16.82±1.04	23.69±1.38	19.95±1.28	18.91±1.22	17.21±1.09

Low stress level, *%*	40.92±2.06[††]	42.1±2.4	37.22±2.22	37.26±1.68	41.9±2.1[††]	40.56±2.21	37.22±2.17	37.71±1.76
Highest income group, *%*	38.42±1.99 [NS]	40.48±2.59	42.75±3.2	40.79±3.12	39.24±1.93 [NS]	41.82±2.81	40.56±2.95	40.78±3.13
Employed and at work during the last week, %	44.27±2.23 [NS]	47.13±2.32	44.11±2.49	48.81±2.04	45.42±2.13 [NS]	46.4±2.33	45.23±2.31	47.34±2.19
Urban residents, *%*	85.89±1.23	83.02±1.7	79.82±1.87	76.94±1.65	84.93±1.43	83.36±1.78	78.9±1.7	78.44±1.69

DGAI: Dietary Guidelines for Americans Adherence Index; BMI: Body mass index; NS: Not Significant

[*]Estimates are weighted least square means or percentages with bootstrapped variances (Balanced Repeated Replication technique)

[†]Values are adjusted for age and sex, unless otherwise noted. Age is adjusted for sex only and gender is adjusted for age only.

[‡]The p-trend was estimated using the dietary pattern score in its continuous form and represents the p-value associated with linear regression coefficient for continuous variables and the logistic regression coefficient for the categorical variables. All p-value for trends are <0.0001 unless otherwise specified.

[§]Sum of standardized intakes of fast foods, carbonated drinks, refined grains, solid fats, processed meats, cheese, baked goods, gravies, sauces and dressings, sugars and syrups (all with +1 weights), and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables and yogurt (all with -1 weights)

[ǀ]Scores ranged from 0-19 possible points with higher scores indicating more healthful and varied dietary patterns.

[¶]Scores ranged from 0-11 possible points and are evaluated based on energy level

[**]Scores ranged from 0-8 possible points and are evaluated on the same calorie level for all individuals.

[††]P-trend <0.05

Table 8.5. Weighted mean daily intakes of macro- and micronutrients, reported as percentage of energy or per 1000 kcal (density approach), across quartile categories of energy-dense, high-fat and low fiber density (ED, HF, LFD) dietary pattern score derived from the weighted partial least squares (wPLS) (centered and scaled), and simplified dietary pattern score among adult participants of the Canadian Community Health Survey, cycle 2.2 (n=11,748)*,†,‡

	ED, HF, LFD Dietary Pattern Score Quartiles				**Simplified Dietary Pattern Score Quartiles**§			
	1 (Healthiest)	**2**	**3**	**4 (Least Healthy)**	**1 (Healthiest)**	**2**	**3**	**4 (Least Healthy)**
Energy intake, *Kcal*	2377±26	2366±30	2402±30	2677±31	2400±27	2364±29	2402±33	2669±31
Total Fat, *% Energy*	27.05±0.39	30.69±0.41	32.27±0.41	35.47±0.33	27.75±0.39	30.41±0.4	32.28±0.47	35.09±0.32
Fiber density, *g/1000 kcal*	12.23±0.23	8.52±0.17	7±0.13	5.98±0.1	12.05±0.23	8.45±0.18	7.01±0.12	6.25±0.11
Energy density, *kcal/gr*	0.7±0.02	1.16±0.09	1.2±0.02	1.18±0.02	0.69±0.02	1.16±0.09	1.2±0.03	1.18±0.02
Saturated fat, *% Energy*	7.92±0.17	9.86±0.21	10.76±0.18	12.23±0.18	8.11±0.16	9.73±0.18	10.76±0.18	12.16±0.19
Monounsaturated fatty acid, *% Energy*	10.68±0.21	12.19±0.19	12.93±0.2	14.26±0.17	10.99±0.22	12.16±0.21	12.88±0.24	14.07±0.16
Polyunsaturated fatty acid, *% Energy*	5.43±0.12 NS	5.55±0.12	5.58±0.11	5.79±0.1	5.56±0.13NS	5.49±0.13	5.58±0.14	5.74±0.1
Linoleic acid, *% Energy*	4.22±0.1††	4.38±0.1	4.47±0.09	4.72±0.09	4.32±0.11††	4.32±0.11	4.45±0.11	4.7±0.09
Linolenic acid, *% Energy*	0.81±0.03NS	0.75±0.02	0.76±0.03	0.82±0.02	0.84±0.03††	0.74±0.02	0.78±0.03	0.79±0.02
Protein, *% Energy*	16.98±0.25	16.91±0.29	16.09±0.25	14.69±0.24	17.3±0.24	16.68±0.28	16.15±0.26	14.53±0.21
Alcohol, *% Energy*	2.11±0.19 NS	3.1±0.34	4.36±0.42	2.79±0.26	2.1±0.24 NS	3.47±0.31	3.73±0.39	2.11±0.3
Carbohydrate, *% Energy*	54.1±0.46	49.54±0.54	47.55±0.46	47.3±0.44	52.84±0.47	49.45±0.49	47.84±0.51	48.27±0.44
Added sugar, *% Energy*	6.91±0.29	9.73±0.39	11.11±0.34	13.56±0.34	6.99±0.28	9.88±0.39	10.99±0.34	13.46±0.33
Cholesterol density, *mg/1000 kcal*	102.44±3.88	131.11±5.07	144.47±4.62	146.78±3.66	100.82±3.88	120.31±4.71	146.79±4.66	153.29±3.74
Calcium density, *mg/1000 kcal*	454.88±9.96	418.23±8.93	409.64±7.77	404.13±7.52	463.52±9.47	411.85±9.23	405.51±8.2	405.92±7.31
Vitamin A density in retinol activity equi., *µg/1000 kcal*	465.39±31.53	350.35±12.74	287.46±12	271.3±11.53	470.65±31.51	338.74±13.89	293.67±11.38	273.81±11.14
Vitamin D density, *µg/1000 kcal*	3.23±0.22	3.06±0.14	2.77±0.13	2.49±0.11	3.03±0.16††	3.11±0.24	2.83±0.13	2.55±0.11
Vitamin C density, *mg/1000 kcal*	95.27±2.48	67.78±2.47	52.3±2.17	42.06±1.66	92.78±2.45	67.06±2.36	52.97±2.21	44.62±1.7
Sodium density, *gr/1000 kcal*	1545.3±28.41	1508.32±39.68	1463.07±22.11	1582.99±26.25	1589.72±28.06	1471.02±40.41	1450.78±23.49	1589.29±24.76
Thiamin density, *mg/1000 kcal*	0.95±0.01	0.86±0.02	0.81±0.01	0.75±0.01	0.95±0.01	0.84±0.02	0.8±0.01	0.77±0.01
Riboflavin density, *mg/1000 kcal*	0.99±0.02	0.96±0.02	0.94±0.01	0.89±0.01	0.99±0.02	0.95±0.02	0.94±0.01	0.89±0.01

Niacin density in niacin equivalent, *mg/1000 kcal*	20.64±0.33	20.41±0.41	18.65±0.3	17.05±0.3	20.81±0.31	20.07±0.4	18.95±0.32	16.9±0.28
Vitamin B_6 density, *mg/1000 kcal*	1.17±0.02	0.99±0.02	0.82±0.01	0.68±0.01	1.15±0.02	0.98±0.02	0.84±0.01	0.68±0.01
Vitamin B_{12} density, *µg/1000 kcal*	2.47±0.20	2.05±0.10	2.08±0.09	1.99±0.07	2.58±0.21[††]	2.1±0.1	2.05±0.08	1.9±0.07
Naturally occurring folate density, *µg/1000 kcal*[‖]	161.41±4.23	115.12±2.45	97.01±2.07	82.67±1.81	161.96±4.15	111±2.07	97.83±2.14	85.51±1.8
Folacin density from food sources, *µg/1000 kcal*[¶]	232.31±4.55	179.3±2.53	157.46±2.67	135.04±2.17	227.71±4.37	174.56±2.62	159.78±3.1	141.25±2.28
Phosphorus density, *mg/1000 kcal*	718.03±9.29	662.19±8.48	631.54±7.38	593.59±7.47	725.67±8.39	656.12±10.69	627.49±7.7	595.72±6.83
Magnesium density, *mg/1000 kcal*	199.95±2.94	167.45±3.81	144.29±1.58	124.89±1.9	200.38±2.85	165.84±3.43	144.21±1.85	126.32±1.85
Iron density, *mg/1000 kcal*	7.86±0.11	7±0.1	6.57±0.08	6.16±0.1	7.96±0.11	6.91±0.1	6.53±0.08	6.2±0.11
Zinc density, *mg/1000 kcal*	5.82±0.08	5.46±0.11	5.21±0.08	5.06±0.1	6.04±0.08	5.56±0.11	5.17±0.08	4.85±0.09
Potassium density, *mg/1000 kcal*	1921.69±22.41	1566.3±20.41	1365.66±14.56	1215.38±15.9	1915.83±22.53	1578.3±19.45	1366.49±16.06	1217.63±14.56
Caffeine density, *mg/1000 kcal*	71.6±4.5	101.96±10.5	112.23±5.81	127.02±5.9	80.96±4.42	115.87±11.22	107.61±5.18	112.62±5.47
Moisture density, *gr/1000 kcal*[**]	1750.89±41.89	1432.25±43.34	1257.58±24.7	1221.25±25.75	1649.72±34.24	1443.72±43.65	1335±40.99	1242.08±25.45
Glycemic index	27.83±0.52	33.15±1.53	30.25±0.45	29.43±0.48	27.03±0.5	33.06±1.5	30.83±0.52	29.58±0.49
Breakfast skippers, *%*	7.71±1[††]	9.61±1.25	10.01±1.17	11.78±1.21	7.69±1.01[††]	10.42±1.42	9.31±1.05	11.68±1.25
Energy from Solid Fats and Added Sugars (SoFAs), *%*	21.7±0.58	28.69±0.56	34.52±0.61	41.3±0.65	21.86±0.52	29.57±0.61	33.52±0.65	41.1±0.63

NS: Not Significant

[*]Estimates are weighted least square means and bootstrapped variances (Balanced Repeated Replication technique)

[†]Values are means adjusted for age, sex, and misreporting status (under-reporting, plausible-reporting and over-reporting) (cut-off for plausible reporting: 0.7≤Energy Intake/Estimated Energy Requirement≤1.42)

[‡]The p-trend was estimated using the dietary pattern score in its continuous form and represents the p-value associated with linear regression coefficient. All p-value for trends are <0.0001 unless otherwise specified.
[§]Sum of standardized intakes of fast foods, carbonated drinks, refined grains, solid fatS, processed meatS, cheese, baked goods, gravies, sauces and dressings, sugars and syrups (all with +1 weights), and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables and yogurt (all with -1 weights)
[ǀ]Naturally-occurring folate includes various forms of folate found naturally in food
[¶]Sum of quantities of “naturally-occurring folate” in addition to “folic acid” without considering their differing bioavailability
[**]The water content in foods which is abundant in fruits and vegetables like tomatoes, romaine lettuce, and grapefruit
[††]P-trend <0.01

Figure 8.1. Predictor loadings for the energy-dense, high-fat and low-fiber density dietary pattern derived from the weighted partial least squares (wPLS) analyses (centered and scaled) among adult participants of the Canadian Community Health Survey, cycle 2.2 (n=11,748)

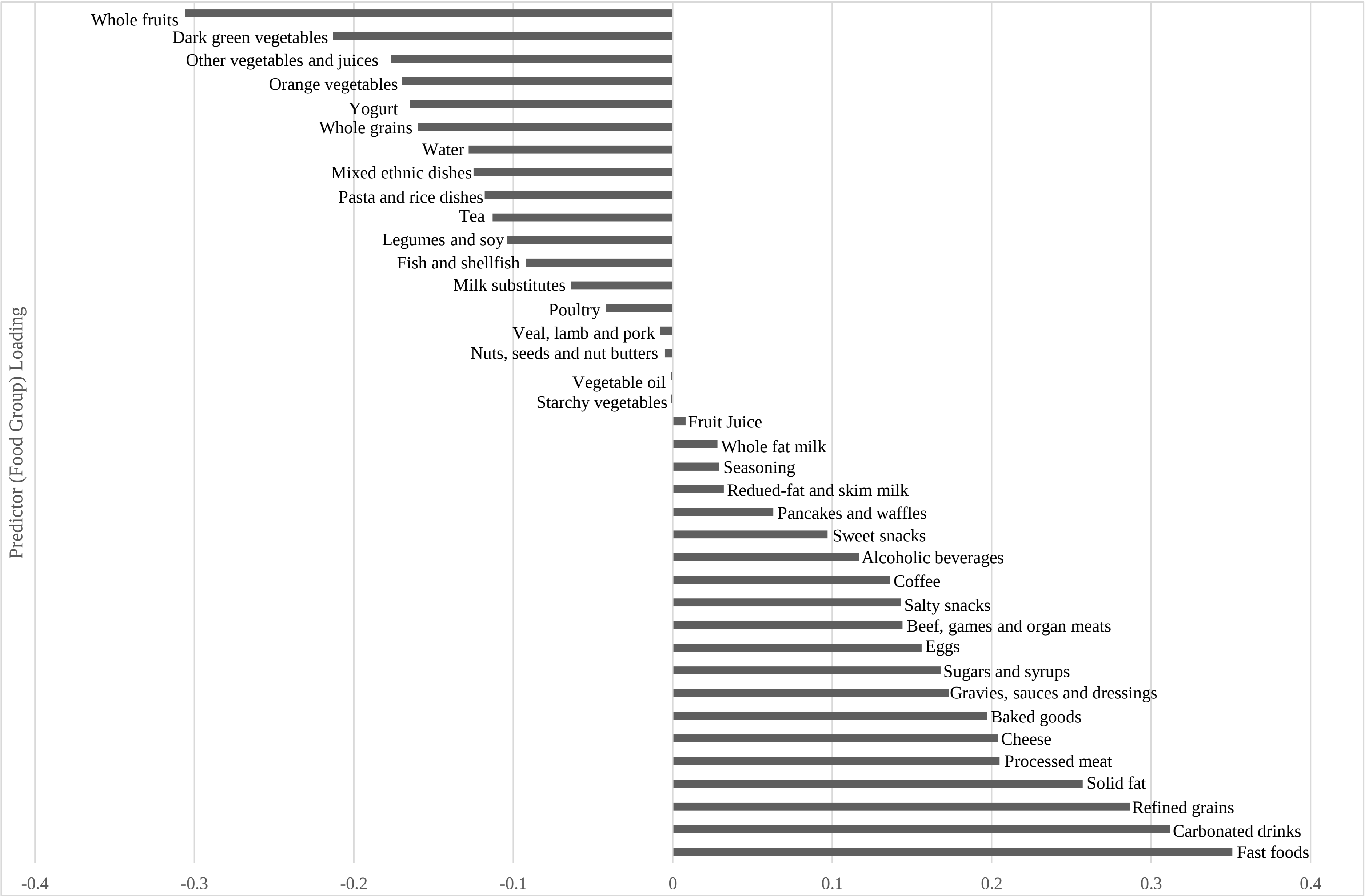
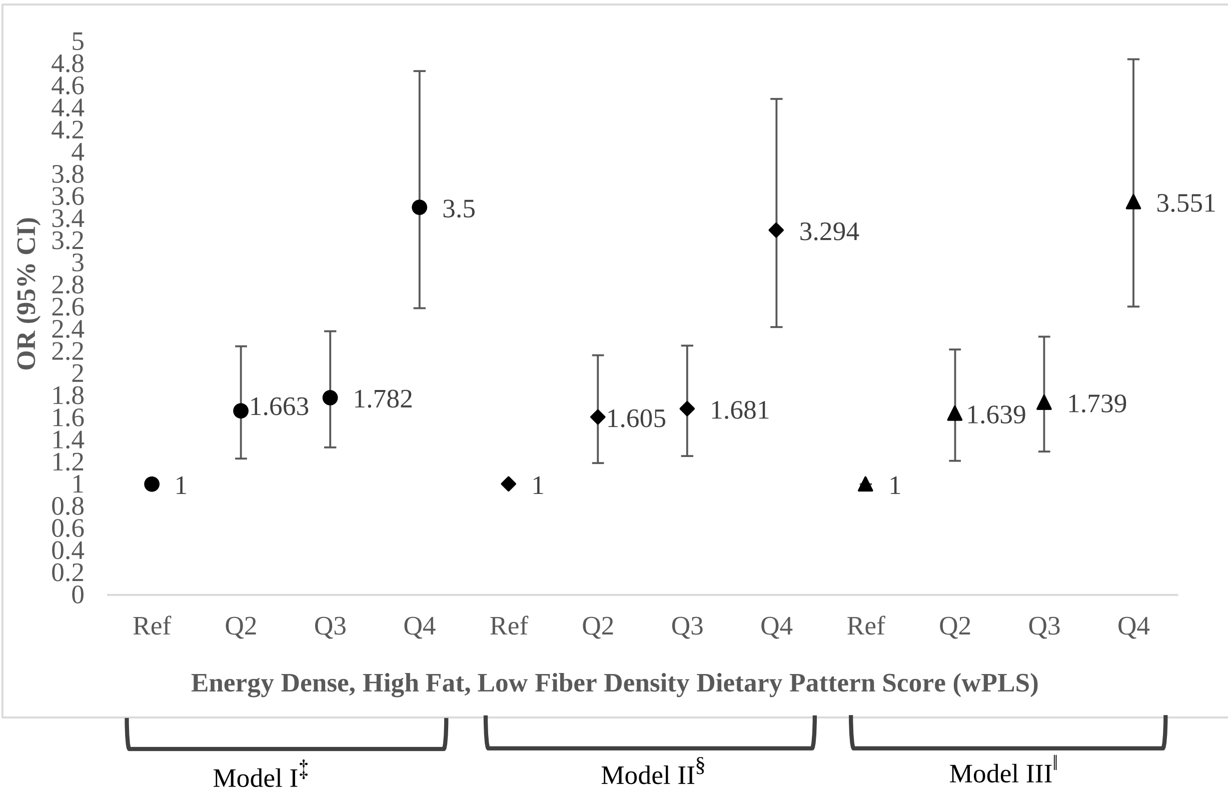
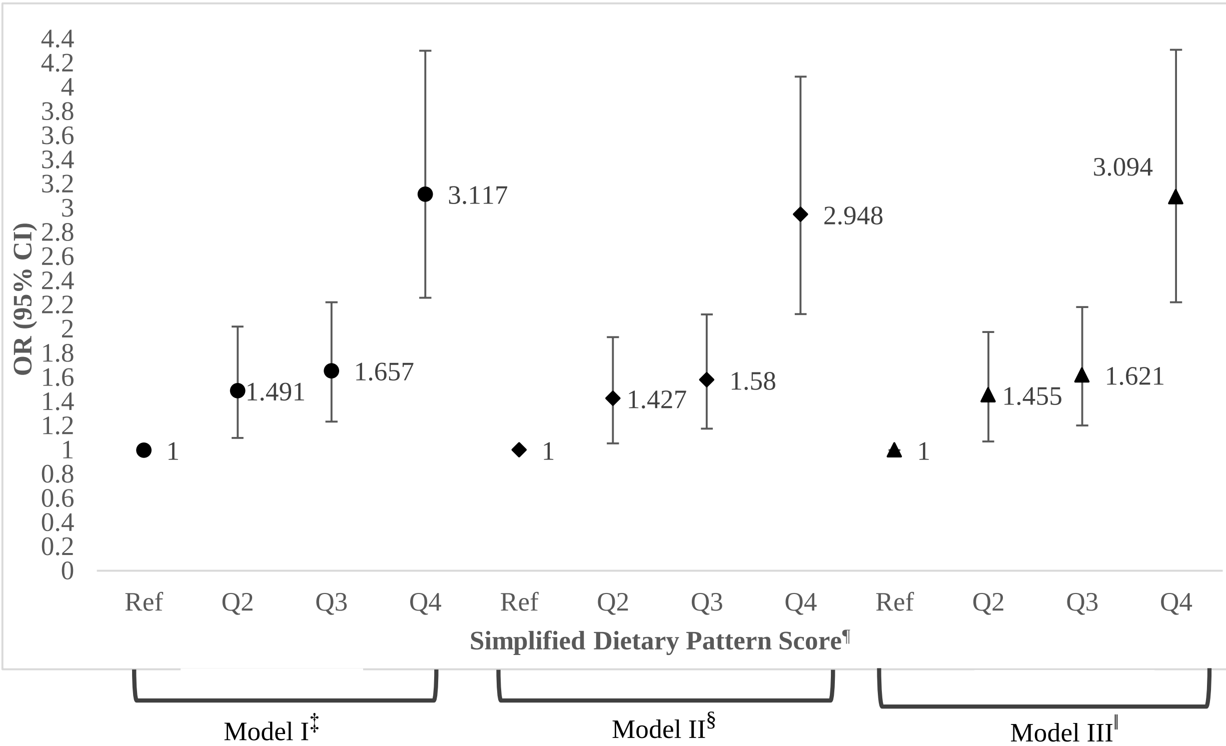


Figure 8.2. Weighted multivariate-adjusted odds ratios (OR) and 95% confidence intervals (CI) for the risk of obesity (BMI≥30 kg/m^2) across the quartile categories of the: a) energy-dense, high-fat, and low-fiber density dietary pattern score derived from the weighted partial least squares (wPLS) (centered and scaled); b) simplified dietary pattern score; and c) 2015 Dietary Guidelines for Americans Adherence Index (DGAI) score among adult participants of the Canadian Community Health Survey, cycle 2.2 (n=11,748)[*,†]

a.

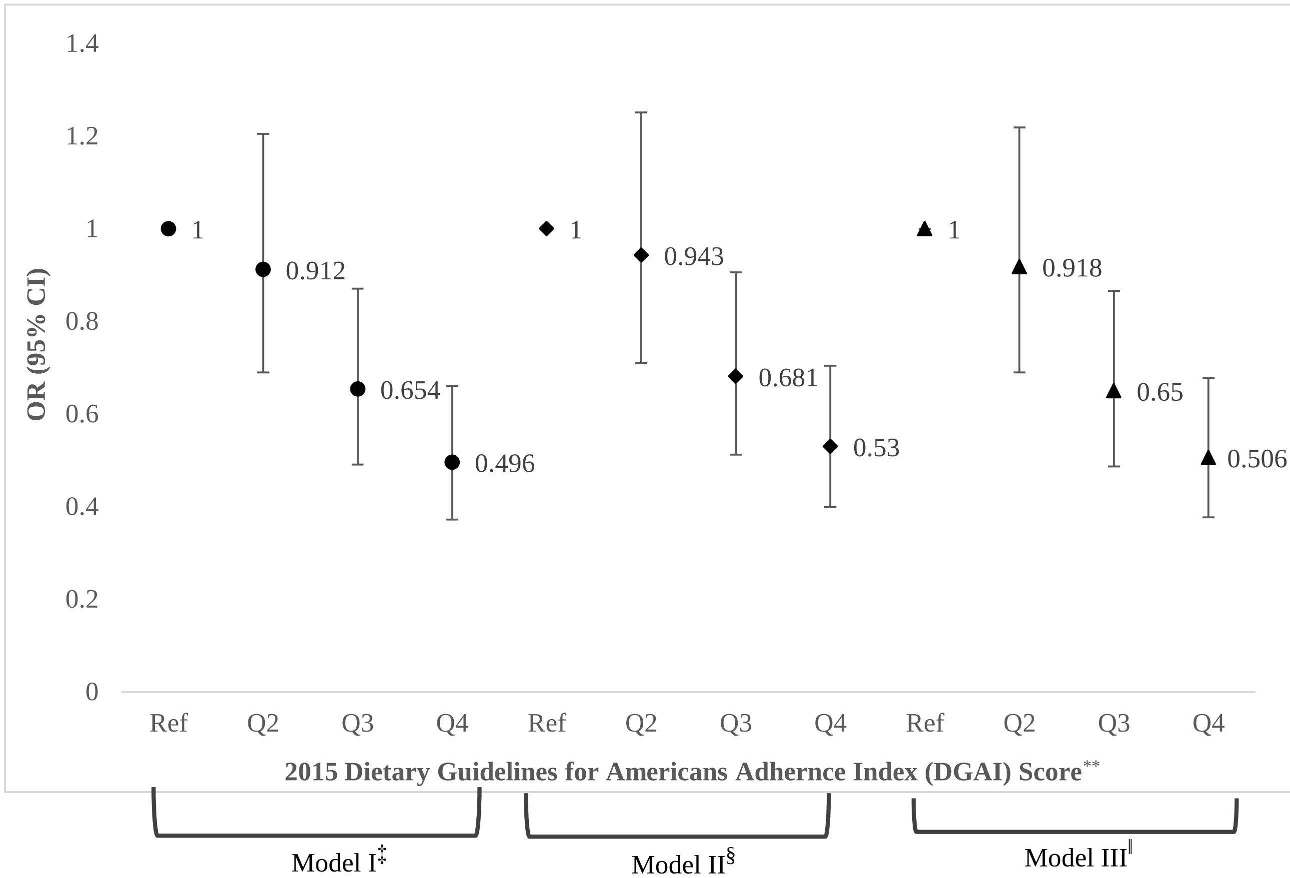


b.



4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
OR (95% CI)
1
1.491
1.657
3.117
1
1.427
1.58
2.948
1
1.455
1.621
3.094
Ref
Q2
Q3
Q4
Ref
Q2
Q3
Q4
Ref
Q2
Q3
Q4
Simplified Dietary Pattern Score¶
Model I‡
Model II§
Model III‖

c.



OR: Odds ratio; 95%CI: 95% Confidence Intervals

*Estimates are weighted odds ratios and bootstrapped confidence intervals (Balanced Repeated Replication technique)

†The p-trend represents the p-value associated with logistic regression coefficient for the dietary pattern score as a continuous variable. All p-value for trends are <0.0001

‡Model I: Adjusted for age, sex, and misreporting status (under-reporter, plausible reporter and over-reporter) (cut-off for plausible reporting: 0.7≤Energy Intake /Estimated Energy Requirement≤1.42)

§Model II: Adjusted for Model I variables in addition to physical activity levels

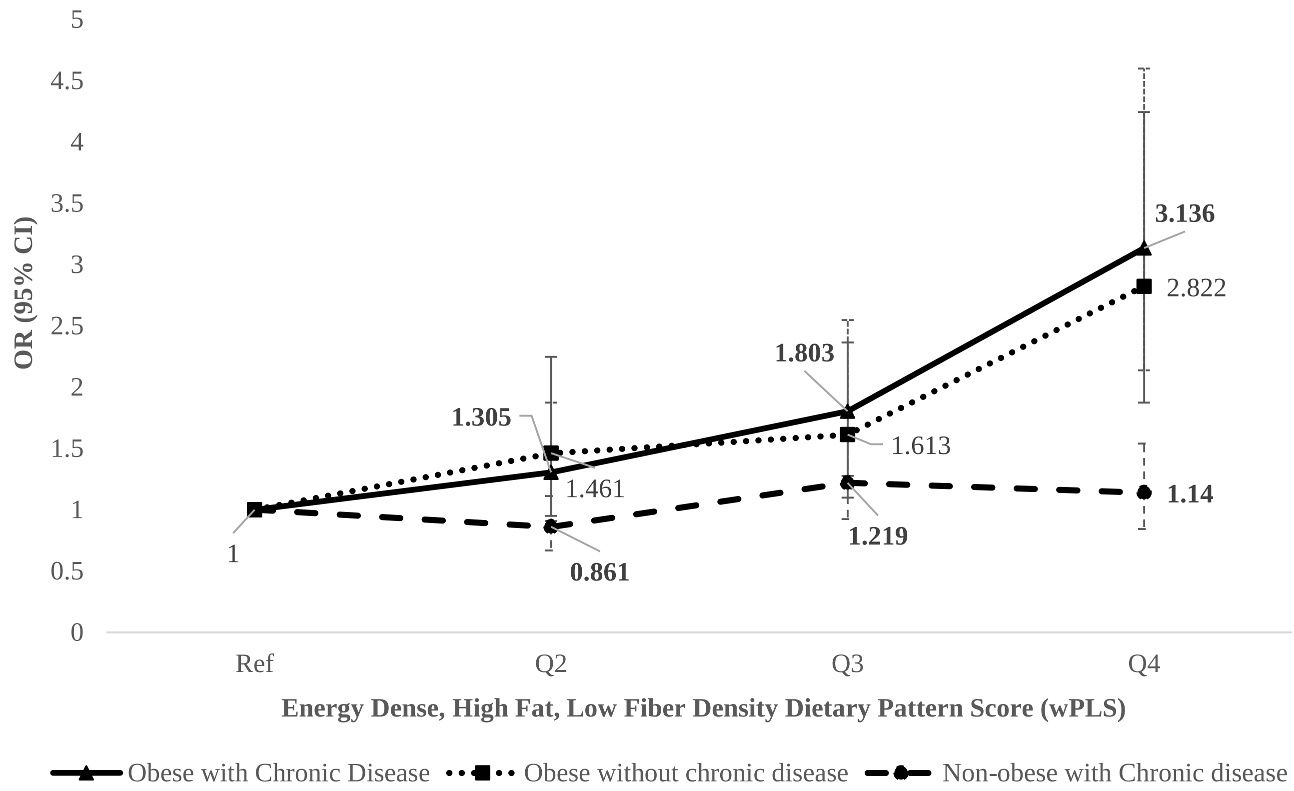
‖ Model III: Adjusted for Model II variables in addition to smoking status

¶Sum of standardized intakes of fast foods, carbonated drinks, refined grains, solid fats, processed meats, cheese, baked goods, gravies, sauces and dressings, sugars and syrups (all with +1 weights), and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables and yogurt (all with -1 weights)

**Scores ranged from 0-19 possible points with higher scores indicating more healthful and varied dietary patterns.

Figure 8.3. Weighted multivariate-adjusted joint classification of obesity risk with at least one chronic disease across the quartile categories of the: a) energy-dense, high-fat, and low-fiber density dietary pattern score derived from the weighted partial least squares (wPLS) (centered and scaled); b) simplified dietary pattern score; and c) 2015 Dietary Guidelines for Americans Adherence Index (DGAI) scores among adult participants of the Canadian Community Health Survey, cycle 2.2 (n=11,748)[*,†,‡,§]

a.

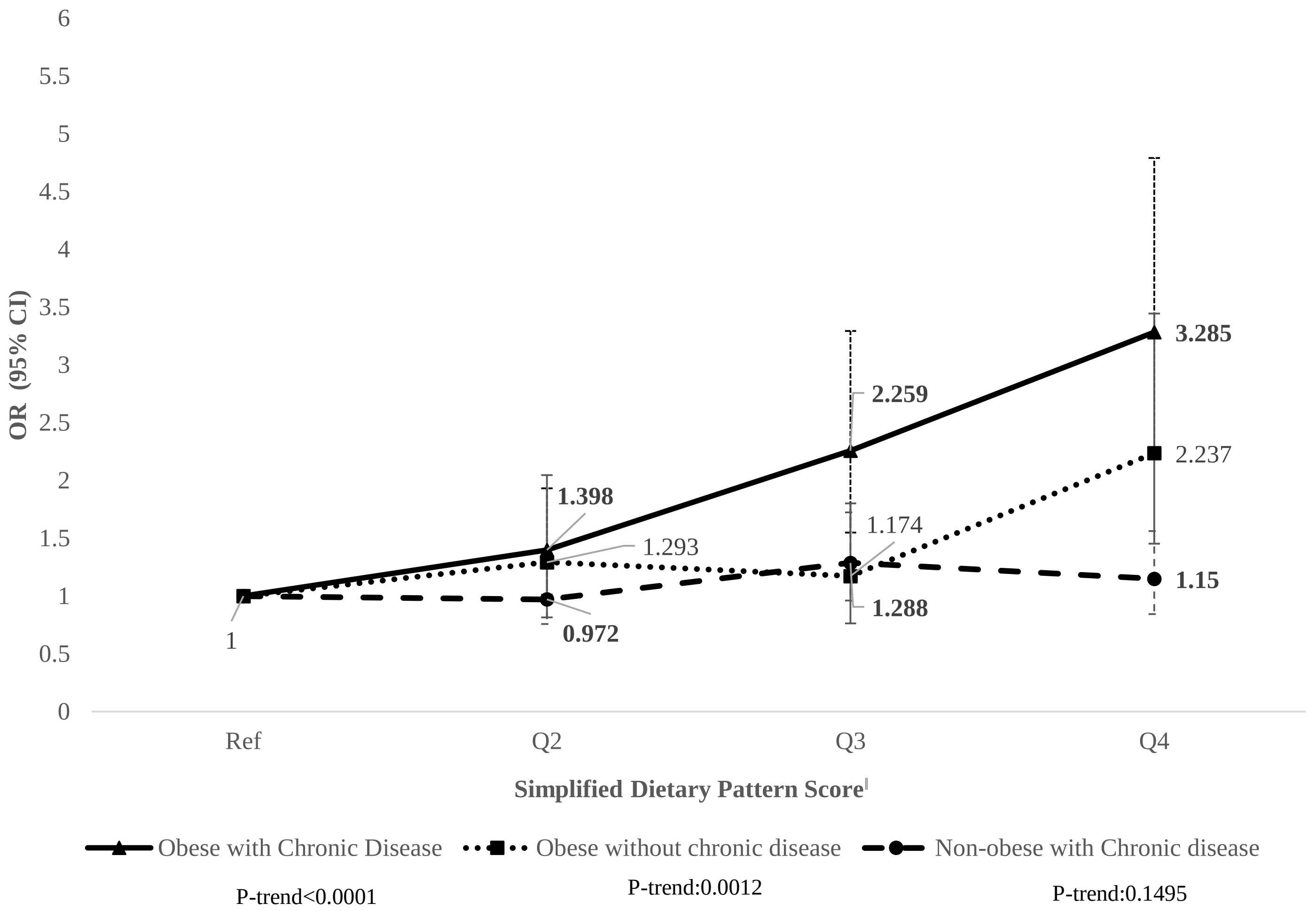


P-trend<0.0001

P-trend<0.0001

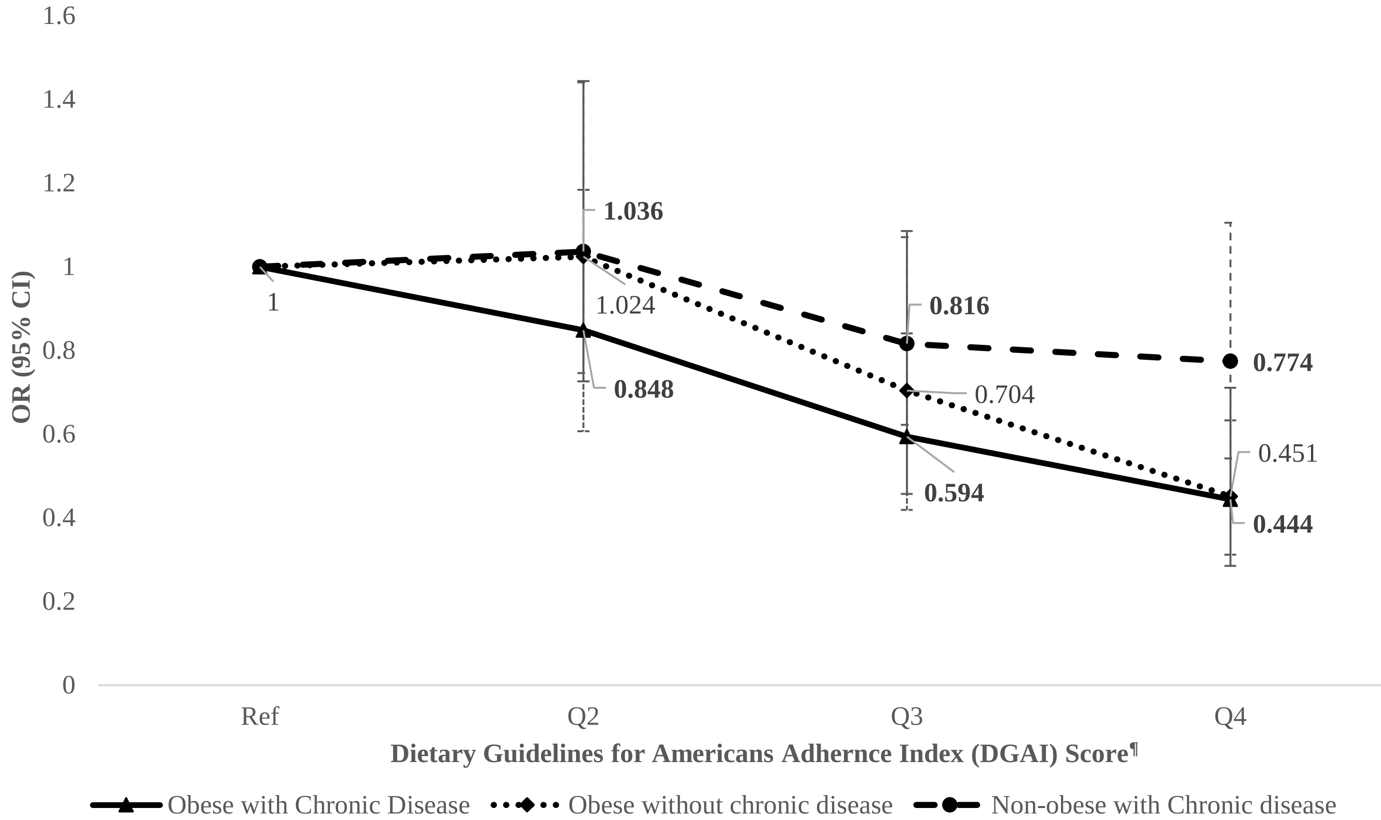
P-trend: 0.1418

b.



6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
OR (95% CI)
3.285
2.259
2.237
1.398
1.293
1.174
1.288
1.15
1
0.972
Ref
Q2
Q3
Q4
Simplified Dietary Pattern Score
Obese with Chronic Disease
Obese without chronic disease
Non-obese with Chronic disease
P-trend<0.0001
P-trend:0.0012
P-trend:0.1495

c.



P-trend<0.0001 P-trend<0.0001 P-trend: 0.0224

[*]Estimates are weighted odds ratios and bootstrapped confidence intervals (Balanced Repeated Replication technique)
[†]Models are adjusted for age, sex, physical activity level, smoking and misreporting status
(under-reporter, plausible reporter and over-reporter) (cut-off for plausible reporting: 0.7≤Energy Intake/Estimated Energy Requirement ≤1.42)
[‡]The p-trend represents the p-value associated with logistic regression coefficient for the dietary pattern score as a continuous variable.
[§]Non-obese without a chronic disease is the reference category.
[ǀ]Sum of standardized intakes of fast foods, carbonated drinks, refined grains, solid fats, processed meats, cheese, baked goods, gravies, sauces and dressings, sugars and syrups (all with +1 weights), and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables and yogurt (all with -1 weights)
[¶]Scores ranged from 0-19 possible points with higher scores indicating more healthful and varied dietary patterns

Supplementary Table 8.1. Food groups used for dietary pattern analyses in the Canadian Community Health Survey, cycle 2.2.

Food Group	Food Items
Fast Foods	Pizza, sandwiches, submarines, hamburgers & cheeseburgers, and hot dog dishes; breakfast combinations (with egg, cheese, ham, etc.); fried or roasted potatoes; frozen dinners
Mixed Ethnic Dishes	Mexican dishes, Chinese dishes and soups
Pasta and Rice Dishes	Pasta, rice and cereal grain dishes
Refined Grains	White bread and breakfast cereal, other breads (rolls, bagels, pita bread, croutons, dumplings, matzo, tortilla, crackers and crispbreads)
Whole Grains	Whole wheat bread, other whole grain bread; whole grain and high fiber breakfast cereal (whole grain, oats and high fibre breakfast cereals)
Pancakes and Waffles	Pancakes and waffles
Baked Goods	Muffins and English muffins; croissants, piecrusts & phyllo dough; biscuits and cookies; squares & bars; cakes, cheesecakes, shortcakes and brownies; sweet rolls and breads; pies (pop tarts) and pie shells; dry mixes (cakes, muffins, pancakes); Danishes, doughnuts and turnovers; donuts; filled crepes, blintzes, cobblers and other pastries
Starchy Vegetables	Potatoes, corn, peas
Orange Vegetables	Red and orange vegetables (carrots, squashes, and tomatoes)
Dark Green Vegetables	Broccoli, lettuces & leafy greens (spinach, mustard greens, etc.)
Other Vegetables and Juices	Beans, cabbage and kale, cauliflower, celery, mushrooms, onion, green onions, leeks, garlic, peppers, other vegetables (cucumber, immature beans, Brussel sprouts, beets, turnips), vegetable juices
Legumes and Soy	Legumes and food made with vegetables proteins (tofu)
Whole Fruits	citrus fruits (oranges, grapefruits, lemons, etc.), apple, banana, cherries, grapes and raisins, melons (cantaloupe, honeydew, watermelon), peaches, nectarines, pears, pineapple, plums and prunes, strawberries, other fruits (blueberries, dates, kiwis, fruit salads, dry fruits etc.)
Fruit Juice	Fruit juice
Whole-Fat Milk	Whole milk
Reduce-Fat and Skim Milk	Skim milk, reduced fat milk (1% and 2%)
Milk Substitutes	Milk substitutes including evaporated milk, condensed milk and other types of milk
Cheese	Cottage and other types of cheeses
Yogurt	Yogurts
Eggs	Eggs and frozen egg substitutes
Fish and Shellfish	Fish and shellfishes
Nuts, Seeds and Nut Butters	Nuts, seeds and nut butters and spreads
Beef, Game and Organ Meats	Beef, liver and liver pate, offal, and game meat
Veal, Lamb and Pork	Veal, lamb, and pork meat
Poultry	Chicken, turkey and other birds
Processed Meat	Sausages (fresh and cured), luncheon meats (canned and cold cuts), cured ham
Sugars and Syrups	Sugars (white and brown), jams, jellies and marmalade, other sugars (syrups, molasses, honey, etc.)

Sweet Snacks	Confectionary (candies, popsicle, sherbert, jello, dessert toppings and pudding mixes, chocolate bar, etc.); frozen dairy products (e.g., ice cream, ice milk);malted milk, instant breakfast; sweet desserts
Salty Snacks	Potato chips, tortilla chips, popcorn, plain & pretzels
Carbonated Drinks	Non-alcoholic beverages (all soft and fruit flavoured drinks)
Alcoholic Beverages	Spirits (gin, whisky, vodka, etc.), liqueurs (mint cream, etc.), wine, beers and coolers
Tea	Tea
Coffee	Coffee
Water	Water (well and mineral)
Solid Fat	Creams (whipping, table, half & half, sour), butter, tub margarine, block margarine, animal fat, shortening
Vegetable Oil	Vegetable Oil
Gravies, Sauces and Dressings	Gravies, sauces (white, béarnaise, soya, tartar, ketchup, etc.), salad dressings (with or without oil)
Seasonings	Seasonings (salt, pepper, vinegar, etc.), spices, others

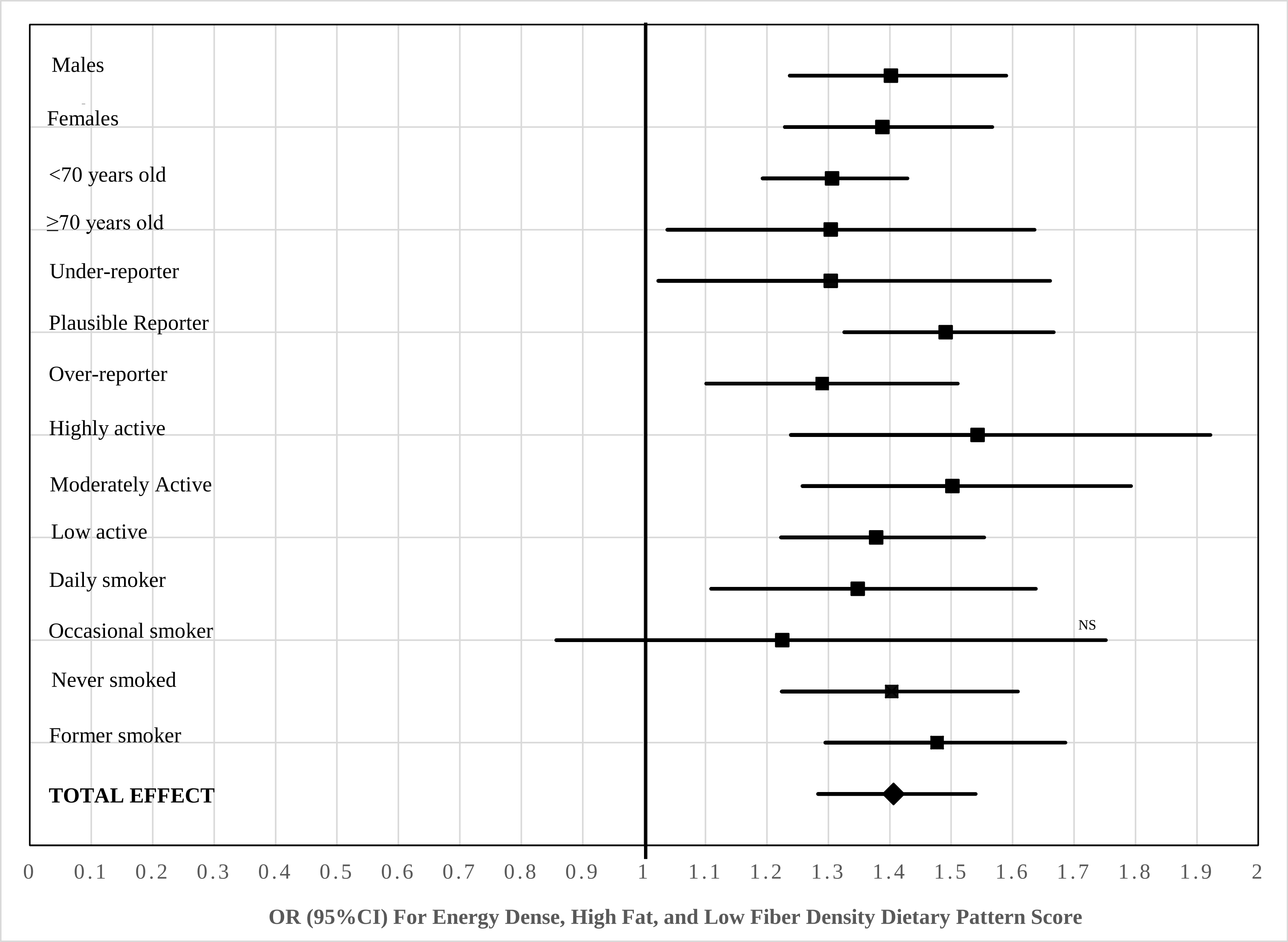
Supplementary Table 8.2. Mean intakes of obesity-related response variables among normal weight, overweight and obese adult participants of the Canadian Community Health Survey, cycle 2.2 (n=11,748)

Response Variables	**Normal weight**	**Overweight**	**Obese**
Energy Density, *kcal/gr*			
Model I[*]	1.9±0.02[‡,§]	1.96±0.02[ǁ]	2.05±0.02
Model II[†]	1.91±0.02[‡,§]	1.97±0.02[ǁ]	2.06±0.03
Energy from Fat, *%*			
Model I[*]	31.22±0.3[§]	31.45±0.37[ǁ]	32.96±0.37
Model II[†]	31.52±0.34[§]	31.77±0.40[ǁ]	33.29±0.39
Fiber Density, *g/1000 kcal*			
Model I[*]	8.57±0.15[§]	8.41±0.16[ǁ]	7.47±0.17
Model II[†]	8.48±0.14[§]	8.31±0.21[ǁ]	7.46±0.21

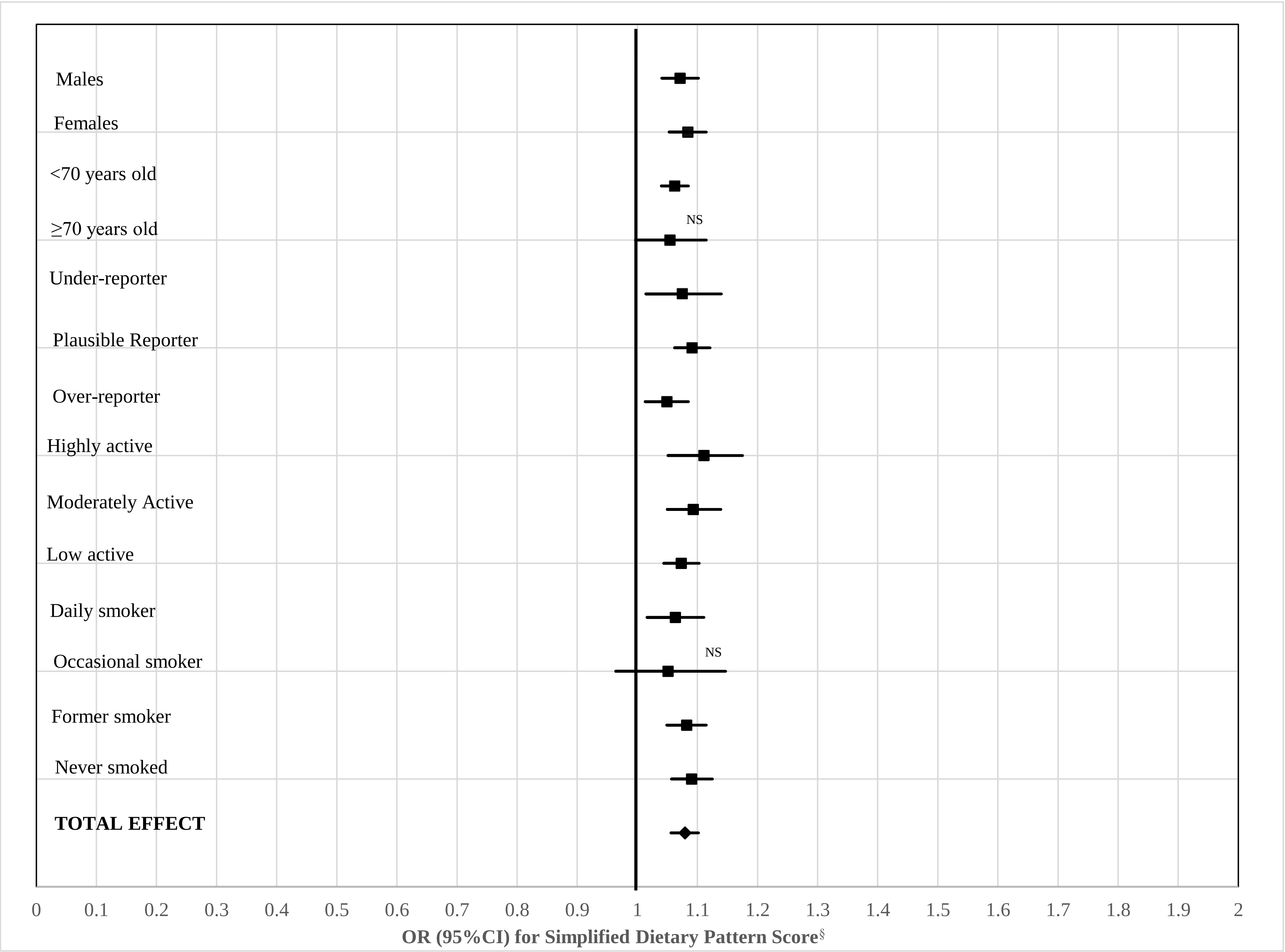
[*]Model I: Adjusted for age, sex and misreporting status (under-reporting, plausible-reporting and over-reporting) (cut-off for plausible reporting: 0.7≤Energy Intake/Estimated Energy Requirement≤1.42)
[†]Model II: Adjusted for variables in Model I as well as physical activity level and smoking status
[‡]Significantly different between normal-weight and overweight ($p<0.02$)
[§]Significantly different between normal-weight and obese ($p<0.001$)
[ǁ]Significantly different between overweight and obese ($p<0.001$)

Supplementary Figure 8.1. Weighted multivariate-adjusted odds ratios (OR) and 95% confidence intervals (CI) for the obesity risk (BMI≥30 kg/m^2) according to a standardized increase (1 SD) in the: a) energy dense, high fat, and low fiber density dietary pattern score derived from the weighted partial least squares (wPLS) (centered and scaled); b) simplified dietary pattern score; and c) 2015 Dietary Guidelines for Americans Adherence Index (DGAI) score among different adult subgroups in the Canadian Community Health Survey, cycle 2.2 (n=11,748)[*,†,‡]

a.

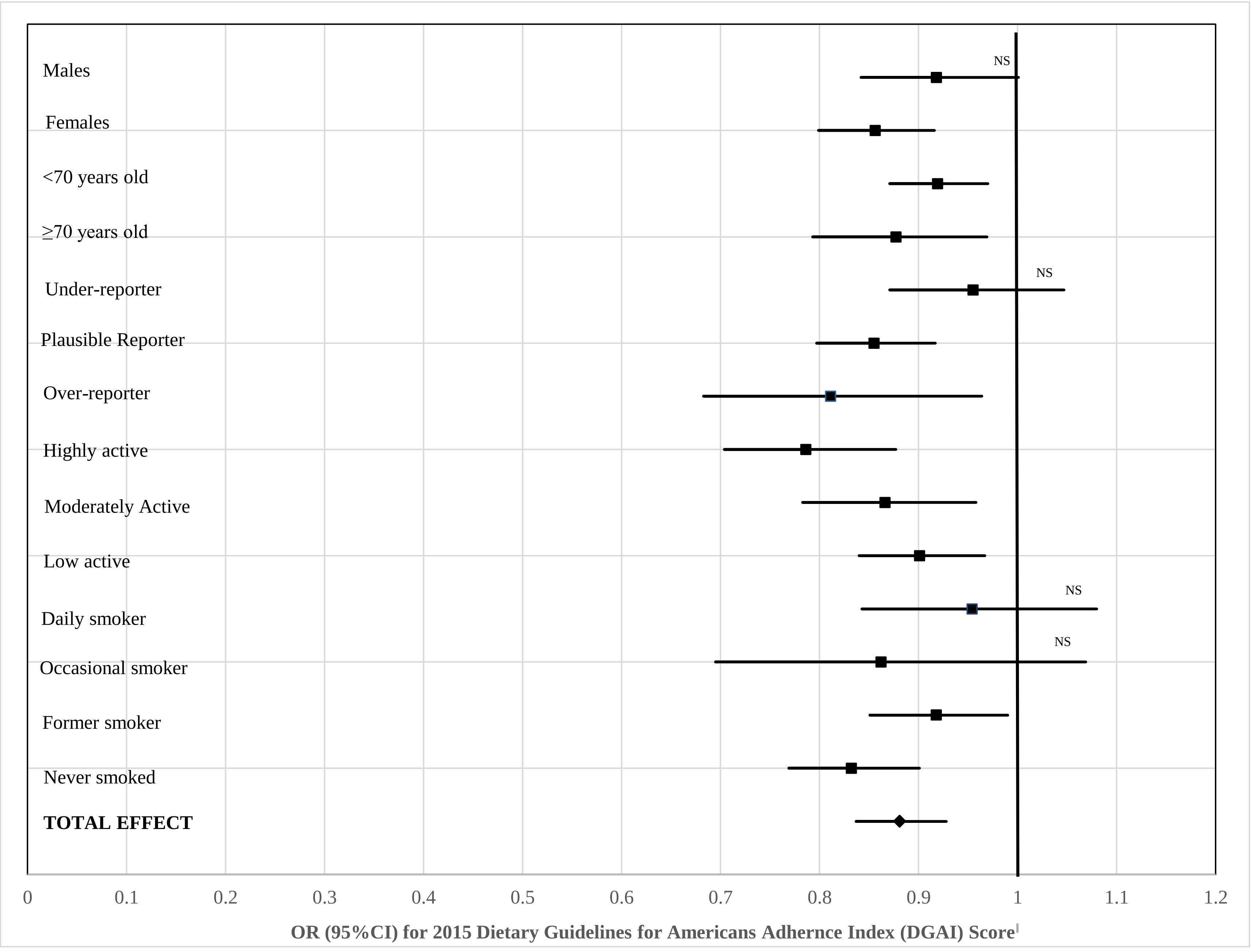


b.



Males
Females
<70 years old
≥70 years old
NS
Under-reporter
Plausible Reporter
Over-reporter
Highly active
Moderately Active
Low active
Daily smoker
Occasional smoker
NS
Former smoker
Never smoked
TOTAL EFFECT
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
OR (95%CI) for Simplified Dietary Pattern Score§

c.


Males
NS
Females
<70 years old
≥70 years old
Under-reporter
NS
Plausible Reporter
Over-reporter
Highly active
Moderately Active
Low active
Daily smoker
NS
Occasional smoker
NS
Former smoker
Never smoked
TOTAL EFFECT
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
OR (95%CI) for 2015 Dietary Guidelines for Americans Adhernce Index (DGAI) Score

NS: Not Significant

[*]Estimates are weighted odds ratios and bootstrapped confidence intervals (Balanced Repeated Replication technique)

[†]Models are adjusted for age, sex, physical activity level, smoking and misreporting status (under-reporter, plausible reporter and over-reporter) (cut-off for plausible reporting: 0.7≤Energy Intake/Estimated Energy Requirement≤1.42), unless when these variables are evaluated as the main subgroup

[‡]The p-trend represents the p-value associated with logistic regression coefficient for the dietary pattern score as a continuous variable. All models are statistically significant unless otherwise noted

[§]Sum of standardized intakes of fast foods, carbonated drinks, refined grains, solid fats, processed meats, cheese, baked goods, gravies, sauces and dressings, sugars and syrups (all with +1 weights), and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables and yogurt (all with -1 weights)

[ǁ]Scores ranged from 0-19 possible points with higher scores indicating more healthful and varied dietary patterns

Chapter 9

9 Discussion

9.1 Overall Recommendation

Findings of this thesis shed light on the importance of considering methodological limitations in nutritional epidemiology, to be able to make use of self-reported national nutrition surveys for generating an evidence-base that could eventually translate into nutrition policies and guidelines for reduction of diet-related chronic diseases.

In contrast to some groups that question the usefulness of nutrition surveys for informing public health policies (89), we recommend that appropriate adjustments for systematic measurement errors be incorporated into analyses of self-reported nutrition data to improve the utility of survey data for capturing diet-disease relationships. In addition, in contrast to the EWCFG 2007 recommendations and the HCST 2014 (which is formulated based on the EWCFG 2007), we recommend that the dietary exposure be treated as a complex multidimensional factor in future development of Canadian dietary guidelines and *a priori* diet quality indexes. By combining comprehensive dietary pattern analyses (Studies 4 and 5) with adjustment for misreporting bias (as described in Study 1) we were able to demonstrate that national nutrition surveys are invaluable resources for capturing diet-disease relationships and for generating comprehensive evidence for developing national nutrition policies and guidelines. Confirmation of these findings in future long-term prospective studies in Canada would provide a stronger platform for development of nutritional policies leading to reduced risk of chronic diseases.

9.2 Summary of Research and Specific Recommendations

Recommendations specific to each of the two main phases conducted in this PhD thesis are given in the following section.

9.2.1 Phase I: Evaluation of different methods to handle misreporting in nutrition surveys

Very recently a controversial commentary was published recognizing dietary misreporting as a potential source of bias in capturing diet-disease relationships (219) . Nutritional studies often rely on self-reported dietary intakes which are subject to misreporting and implausible intakes. Various algorithm-based techniques have been proposed for screening out implausible recalls

(23, 36). However, some authors still mistakenly use the first cut-off point suggested by Goldberg et al. in 1991 to identify misreporters in their studies (34), including Archer et al. in analysis of the NHANES data (85). This is problematic since cut-points should be derived based on the characteristics of the population under study to avoid subject misclassification. Another problem in this research area is that methods of handling implausible recalls, once they are identified, have not been well studied. This has led some authors to conclude that national nutrition surveys have extremely limited ability for explaining the obesity epidemic (89).

In response to this controversy, we conducted the largest known study to compare several different statistical approaches that have been proposed to address misreporting bias in obesity research by examining self-reported dietary intakes among adolescents and adults in the Canadian national nutrition survey (14). We concluded that neglecting energy misreporting rendered the association of dietary exposures with overweight and obesity risk as insignificant or even reversed. "Adjusting for the reporting group" yielded consistent results and provided the maximum sample size while maintaining biological plausibility. Although "exclusion of misreporters" strengthened diet-obesity relationships, we do not recommend using this method due to losing about 40% of the population (misreporters) who are systematically different than the plausible reporters (different lifestyle and higher obesity and chronic disease risk) (14).

These findings may also explain some recent studies that found that the BMI of the US population has increased significantly overtime for a given level of energy intake and physical activity (220), which may be due to the social desirability issue and higher misreporting rates in the modern age. These results may also be a function of other factors significantly modifying how energy intake and expenditure influence body weight over time, or they may be due to biases in reporting of diet and physical activity over time (220). However, given the increasing evidence that multiple factors beyond diet and physical activity are associated with increases in body weight, further investigation of how different factors influence body weight independent of lifestyle factors is warranted.

The results of this study demonstrate to nutrition researchers and policy makers the importance of adjusting for recall plausibility to enhance the usefulness of nutrition surveys for informing public health policy. This study also confirms that inconsistent results in the nutritional epidemiology field are mainly due to using inappropriate statistical techniques for adjusting for measurement errors, rather than inherent flaws in nutrition surveys.

9.2.2 Phase II: Dietary pattern analyses

Countries worldwide have implemented dietary guidelines to promote healthful dietary practices and to prevent chronic diseases. While guidelines are in place, the ability to evaluate actual dietary practices and adherence to guidelines is essential for population nutrition monitoring and for devising of relevant nutrition policies for reduction of chronic diseases. In 2014, Health Canada released the first Canadian nutrient profiling system (*a priori* index), i.e., HCST Tier System, aimed at evaluating the dietary adherence to the EWCFG 2007 in terms of quantity and type of foods recommended (i.e., number of servings from each food group, and within these, the quality of food choices). In response to increasing importance of considering nutritional quality of food choices and totality of dietary intakes in dietary guideline development, we conducted the first studies to evaluate the eating behaviours of Canadians using the HCST 2014, and to gauge the applicability and relevance of this nutrient profiling tool on a population basis (126, 127). Results of these studies showed that the HCST 2014 is an appropriate measure for characterizing dietary intakes of Canadians and therefore can be used for public health initiatives to ensure adherence to the EWCFG 2007 recommendations. However, adherence to this system was not associated with obesity, which may be due to overly focus of the HCST and EWCFG on meeting the DRI nutrient requirements, rather than chronic disease prevention (27). In light of recent improvements and updates in dietary guidelines and strong evidence for the role of dietary patterns in etiology of chronic diseases, findings of this study demonstrate the importance of a paradigm shift from a nutrient-focused to a comprehensive dietary pattern approach for development of the next Canadian food guide in order to reduce the burden of chronic diseases at the population level.

In fact, taking a dietary pattern approach for developing the next version of the EWCFG, similar to that adopted by the HHS/USDA DGA 2015 (67), would be optimal. In Chapter 7 of this thesis, we provided a comprehensive picture of dietary patterns of Canadians and the potential benefits of adherence to the 2015 DGA recommendations, measured by the DGAI (80), for reduction of chronic disease risk in Canada. Our results clearly demonstrated that closer adherence to the 2015 DGA recommendations is associated with nutrient-dense diets and lower risk of obesity with and without an accompanying chronic disease in Canada. Indeed, the underlying premise of the 2015 DGA is ensuring nutrient adequacy and prevention of chronic diseases, which were both confirmed in this research. These results are particularly important as our earlier study (presented in Chapter 5) using the same nationally-representative sample of Canadians was unable to find any significant association between adherence to the Canadian dietary guidelines and risk of obesity (126, 127); resulting in a call for an update of these set of dietary guidelines (27). Given that both nutrients and food groups are the building blocks of the 2015 DGAI, it is recommended that future Canadian dietary guidelines and *a priori* indexes consider both of these elements as part of comprehensive meal patterns. Generally, findings of this research can directly inform nutrition policy makers about the significance and importance of using an energy-based *a priori* diet quality index that considers a variety of foods and nutrients, for nutrition monitoring and eventually developing targeted nutrition policies and public health programs.

Finally, in order to identify the main elements of a dietary pattern that contribute the most to the obesity epidemic in Canada, we conducted a population-based dietary pattern analysis using hybrid dietary pattern derivation technique (Chapter 8). Hybrid methods were proposed by Hoffmann and colleagues in 2004 to attain more focus on variation in selected disease-specific nutrients and energy sources that are shown to be related to the outcome of interest (71). As a result, hybrid methods are theoretically the most valuable techniques for identifying important disease risk factors if evaluated in population-based large-scale studies and with appropriate consideration of methodological limitations. In Chapter 8 we conducted the first nationally-representative study to apply hybrid methods for deriving dietary patterns. In fact, the main methodological challenge we addressed in this study was modifying the PLS algorithm, which currently does not accept population weights, to incorporate sampling survey and bootstrapping weights. Using sampling survey weights and bootstrapping the variances are essential requirements of working with national nutrition data to ensure that results of study would be representative of target population. Results of this study (Chapter 8) found that fast foods, carbonated drinks, refined grains, solid fat, processed meat, cheese, baked goods, gravies, sauces and dressings, and sugars and syrups were positive determinants and whole fruits, dark green vegetables, other vegetables and juices, orange vegetables, and yogurt were negative determinants of an energy-dense, high-fat and low-fiber dietary pattern, which was associated with 2-3 times higher risk of obesity among Canadians. Findings of this study also questions the underlying assumption of equal weights for different food groups in dietary pattern analysis and recommends that certain elements of a dietary pattern may contribute more to the overall healthfulness of diet and its association with chronic diseases. This recommendation is in line with those of a previous study which concluded that not all dietary components have the same predictive value in identifying diet-disease relationships, which is a novel concept in nutritional epidemiology (170).

9.3 Overall Conclusions and Future directions

This thesis provides the first Canadian evidence to support future development of evidence-based national nutrition guidelines and policies through conducting series of comprehensive epidemiological studies each addressing a distinct research gap. Findings of this thesis demonstrate how combination of appropriate methodological techniques for handling systematic measurement error and derivation of multidimensional dietary patterns can enhance the usefulness of national nutrition surveys for capturing the relationship between dietary exposures and disease outcomes, which can eventually translate into effective nutrition guidelines and policies. Indeed, identifying dietary patterns is the first step in developing dietary guidelines in many countries, including the United States and Australia (33, 67). This thesis provides the first application of Canadian and American *a priori* dietary quality indexes as well as a hybrid technique for capturing dietary patterns of Canadians.

Generally, findings of the first phase of this thesis support the need to account for systematic misreporting error in nutrition surveys and when conducting dietary pattern analyses using self-reported nutrition data. In fact, to ensure that results of dietary pattern analyses in this thesis would not be influenced by differential misreporting error, we identified and used an adjustment technique for handling dietary misreporting in all analyses. Future studies that evaluate sensitivity and specificity of different statistical techniques against hard outcomes and reference biomarkers will further advance our knowledge of gold standard methods for handling measurement errors in nutritional epidemiology. Another important factor to consider in nutrition surveys and analyses is the population under study, which can affect sources of measurement error. For example, misreporting may be more of an issue among proxy-reported dietary recalls (children), while memory errors may be a great challenge for the elderly population. Considering the population under study is therefore an area that also needs to be further investigated for development of methods for handling misreporting. However, one should remember that detecting a “true” association with absolute certainty is almost impossible in nutritional epidemiology in light of current methods. Careful planning, analysis and interpretation of results are therefore the keys to ensure that estimated values are as close to reality as possible. Some of the areas recently identified as important for reducing measurement errors include using of technology for dietary assessment (not feasible in large-scale nationally-representative surveys) and expanding food composition databases (221).

In Chapters 5, the Canadian HCST 2014 was used to score diet quality and capture its association with obesity risk (126, 127). We concluded that there is an urgent need for development of a more encompassing nutrient profiling system in Canada, in place of the HCST 2014; one that includes both nutrients and dietary components. Indeed, analysis of the current EWCFG 2007 illustrates that Health Canada should take an approach similar to those taken by the DGA and the Australian Dietary Guidelines (25, 33) to encourage consumption of healthy foods rather than focusing on avoiding nutritional inadequacies, as the majority of modern-day diet-related chronic diseases in developed countries are a result of "overconsumption" rather than deficient intakes (27). In the next revision of the EWCFG, food intake patterns should be modelled based on the foods to encourage and foods to limit to focus on the totality of dietary intakes in the etiology of chronic diseases. We also recommend that the next version of the EWCFG includes "other" foods (e.g., added sugar, saturated fat, alcohol) and identify a cut-point for consumption of these foods based on the modelling phases to account for about 20-30% of daily calories that are being consumed from these food items in Canada. Finally, considering the multiethnicity of the Canadian population, national nutrition guidelines should include ethnic food behaviours, similar to the range of food patterns proposed in the Australian Dietary Guidelines (156).

To help inform the development of the next Canadian food guide, we conducted two large-scale independent dietary pattern studies. In Chapter 7, we accounted for the limitations of the HCST 2014 by updating an energy-based *a priori* dietary quality index (2015 DGAI) and validating it for use among the Canadian population. Our findings demonstrated strong associations between the 2015 DGAI score and diet quality and reduced risk of chronic diseases in Canada, which is in contrast to the association of the HCST 2014 and obesity. Owing to the similarity of the North American diet, we suggest that the 2015 DGAI may be used for population nutrition surveillance in Canada, with stronger predictive ability than the HCST 2014. These results need to be confirmed in future large-scale longitudinal surveys.

To complement the dietary pattern analysis using *a priori* method in Chapter 7, we used hybrid (energy-dense, high-fat and low-fiber) and simplified dietary pattern techniques to derive dietary patterns associated with obesity risk. Our findings demonstrated significant associations between dietary patterns and obesity risk with or without an accompanying chronic disease regardless of the method used for deriving dietary patterns. As demonstrated by the differential odds ratios, future studies should explore the characteristics, risk factors, and dietary patterns of participants with different obesity phenotypes (with and without a chronic disease) in order to potentially inform specific dietary guidelines for these vulnerable groups. Improving and standardizing the dietary pattern methodology for use in large-scale national nutrition surveys are also warranted to be able to identify important elements of a dietary pattern contributing the most to the chronic disease risk. Finally, since individual dietary patterns tend to have a long-term stability, more extensive longitudinal dietary pattern analyses linked to biomarkers and hard outcomes at the population level are required to comprehensively examine the complex association of dietary intakes and disease outcomes and to develop evidence-based nutritional guidelines for reduction of chronic diseases.

Overall, findings of this thesis demonstrated that appropriate adjustment for the error structure in national nutrition survey handled the misreporting bias adequately, enabled comprehensive analyses of dietary patterns at the national population level and helped determined important components of Canadian diet that need to be targeted in the next Canadian food guide for reduction of diet-related chronic diseases. Together the five studies in this thesis confirm the invaluable potential of national nutrition survey data for informing evidence-based national nutrition policies and guidelines, provided that appropriate methodological techniques are used for analyzing them.

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