

**An investigation of body fat accrual in an ethnically diverse cohort of British
Columbian children and youth: patterns, obesity classification, and determinants**

by

Jennifer McConnell-Nzunga
B.A., Kansas Wesleyan University, 2010
M.H.H.S., Youngstown State University, 2013

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

in Social Dimensions of Health

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Abstract

Obesity during childhood and adolescence is a serious public health concern in Canada and globally. Obesity is a complex disease with genetic, environmental, social, and behavioural determinants. However, our understanding of obesity and its development is limited by a reliance on proxy measurements of adiposity such as body mass index (BMI) and cross-sectional study designs that limit our ability to assess temporality. In this dissertation, I present the first set of body fat percent (BF%) accrual and velocity percentile curves for Canadian children and youth, investigate the relationship between BMI- and BF%-based definitions of obesity, and examine the longitudinal influence of sedentary time, moderate-to-vigorous physical activity (MVPA) and caloric intake on the development of BF%.

My analyses are based on the UBC Healthy Bones III Study (HBSIII), a mixed longitudinal study of boys and girls aged 8-12 years at baseline, measured between 1999 and 2012. In HBSIII, adiposity was measured directly as BF% from total body dual energy x-ray absorptiometry (DXA) scans and MVPA and sedentary time were measured objectively using accelerometers.

For the first study in my dissertation, I used generalized additive models for location scale and shape (GAMLSS) to develop sex- and ethnic-specific BF% accrual and velocity percentile curves. I present separate curves for Asian and Caucasian boys and girls aged 9-19 years at the 3rd, 10th, 25th, 50th, 75th, 95th, and 97th centiles. In this descriptive study, I found materially different shaped BF% percentile curves for Asian and Caucasian girls but not for boys.

Second, I examined the relationship between BMI- and BF%-based definitions of obesity for Asian and Caucasian boys and girls aged 9-19 years. I used multivariable regression models, sensitivity and specificity analysis, receiver operating characteristic (ROC) curves, and Youden's Index to explore this relationship. I found that BMI identified <50% of those classified with obesity based on BF%, and that classification performance of BMI differed significantly by age and sex subgroups for Asian and Caucasians.

In my third analysis, I explored the longitudinal relationship between BF% and sedentary time, MVPA, and caloric intake as boys and girls mature. I fit polynomial multilevel models using MO (years from age at peak height velocity, APHV) as the time variable. Rate of change in BF% across maturity differed between boys and girls and differences in MVPA, sedentary time, and caloric intake between individuals influenced BF% at APHV (MO=0) and rate of change in BF% across maturity.

Together, these studies advance our understanding of how body fat accrues as children and youth mature, and highlight the heterogeneity in predictors of adiposity and adiposity measurement accuracy across age, sex, and ethnic groups.

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List of abbreviations

Abbreviation	Term
APHV	Age at peak height velocity
AUC	Area under the curve
BC	British Columbia
BF%	Body fat percent
BIA	Bioelectrical impedance analysis
BMI	Body mass index
CPM	Counts per minute
DXA	Dual energy X-ray absorptiometry
FFM	Fat-free mass
FFMI	Fat-free mass index
FM	Fat mass
FMI	Fat mass index
GAMLSS	Generalized additive models for location scale and shape
HBSIII	Health Bones Study III
LMS	Lambda-Mu-Sigma
MO	Maturity offset
MVPA	Moderate-to-vigorous physical activity
ROC	Receiver operating characteristic

SED	Sedentary time
SES	Socioeconomic status
UBC	University of British Columbia

Acknowledgments

I would like to express my sincerest gratitude to my supervisor Dr. Patti-Jean Naylor; thank you for your unwavering support throughout my PhD studies and research, and for your patience, encouragement, and friendship. Your mentorship throughout the past 4 years has been pivotal in my development as a researcher, and a professional. I am grateful for the wealth of opportunities you allowed me to be a part of, from IPAL to the Early Years and everything in between. These experiences broadened my interests and provided me with a chance to gain important skills that I will need to be successful in my next chapter. Your energy, optimism, and dedication are truly inspiring.

I would also like to thank the rest of my committee for their insightful comments and encouragement, but also for the hard questions that pushed me outside of my comfort zone and helped me to grow. Dr. Heather Macdonald, your feedback, insight, and attention-to-detail has driven me to develop as a writer and a researcher. I have learned a lot from you and you've inspired me to strive for a level of excellence I didn't know I could reach. Dr. Scott Hofer, your encouragement and engagement during the hours spent talking through my statistical problems was pivotal for my success. We pushed the limits of my statistical knowledge and confidence in these analyses and you helped to make that experience enjoyable and rewarding. Dr. Ryan Rhodes, your feedback and insight on the many drafts of these papers helped me to develop well-thought out, thorough manuscripts.

Special thanks also go to Dr. Heather McKay for allowing me to use the HBSIII data for these analyses. I would not have been able to conduct these important

investigations without your support and pivotal work leading the HBSIII studies. I am also very grateful for the thoughtful feedback you provided on these papers over the last year. The ability to learn from such a talented writer and researcher has been truly beneficial to me. I would also like to thank Drs. Lindsay Nettlefold and Leigh Gabel for their support when I encountered data or analysis hurdles. I would also like to thank the many other individuals on the UBC HBSIII team that I did not get the pleasure to meet but without your hard work and dedication this dissertation would not have been possible.

Last but not least I would like to thank my friends and family for being there for me when I needed to talk or vent about things that didn't always make sense to you and conversely, for understanding when I was too busy to reach out as often as I should. Although most of you are thousands of kilometers away, you could always make me feel a little closer to home after a good chat. To my wonderful husband Raphael, you should get an honorary degree for the support and love you've shown me throughout this process, even if you did make me plan a wedding in the middle of it. I can't wait to see where this next chapter takes us and look forward to tackling it with you.

Dedication

This dissertation is dedicated to my mother who inspired me to try and make a difference in the world and most importantly to “live well, laugh often, and love much”.

Preface

This dissertation is an original intellectual product of the author, Jennifer McConnell-Nzunga. Chapters 3-5 of this dissertation are anticipated to be stand-alone manuscripts in the peer-reviewed academic literature in future. I submitted Chapter 4 to *Measurement in Physical Education and Exercise Science* and I am revising the manuscript for second review. I provide details of my contributions and those of my collaborators for each Chapter below. Additionally, I detail other peer-reviewed research I have collaborated on during my doctoral studies.

This dissertation is based on the University of British Columbia (UBC) Healthy Bones III Study (HBSIII). The HBSIII was conceived of and designed by Professor Heather McKay (UBC) and received ethics approved from the UBC Clinical Research Ethics Board (H15-01194, H07-02013, H2-70537). The University of Victoria Research Ethics Office approved the use of these data for my studies (#16-044). Data collection was finished before I began my doctoral studies in 2013 so I was not involved in collecting any of the HBSIII data. I led statistical analysis of the longitudinal HBSIII data, including developing the research questions and designing and conducting the analyses in this dissertation.

Chapter 3: A version of this material is in preparation for publication (1). As lead author, I was responsible for defining the research question, conducting the statistical analyses, and drafting the manuscript. All data were collected, cleaned, and processed by the HBSIII study team. Dr. Hofer provided statistical consult and reviewed the manuscript. Drs. McKay, Macdonald, Rhodes, and Naylor provided detailed feedback and edits on the manuscript. I presented this work as a pecha-kucha style oral

presentation at the Canadian Obesity Network (2) and was awarded the honour of top pecha-kucha presentation at the conference.

1. McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., Hofer, S.M., and McKay, H. Body fat accrual trajectories for Asian and Caucasian-Canadian children and youth: A longitudinal DXA-based study. (in preparation).
2. McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., and McKay, H. (2017). Body Fat Percentile Curves for Children and Youth of Asian and European Ancestry. Presented to the Canadian Obesity Summit. Banff, Alberta, Canada.

Chapter 4: A version of this material was submitted to Measurement in Physical Education and Exercise Science (1). As lead author, I was responsible for defining the research question, conducting the statistical analyses and drafting the manuscript. All data were collected, cleaned, and processed by the HBSIII study team. Dr. Hofer provided statistical assistance. Drs. McKay, Macdonald, Rhodes, Hofer, and Naylor provided detailed feedback and edits on the manuscript. Additionally, a preliminary version of this work was peer-reviewed for conference presentation (2).

1. McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., Hofer, S.M., and McKay, H. Classification of obesity varies between BMI and direct measures of body fat in boys and girls of Asian and European ancestry. Measurement in

Physical Education and Exercise Science. (Submitted on 12/03/2017, Under review).

2. McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., and McKay, H. (2016). Classification of obesity varies between measures of BMI and direct measures of body fat in Asian and White boys and girls. Presented to the XIII International Congress on Obesity. Vancouver, B.C., Canada.

Chapter 5: A version of this material is in preparation for publication (1). As lead author, I was responsible for defining the research questions, conducting the statistical analyses, and drafting the manuscript. All data were collected, cleaned, and processed by the HBSIII study team. Drs. Hofer, and Macdonald provided statistical consult. Drs. McKay, Macdonald, Rhodes, Hofer, and Naylor provided detailed feedback and edits on all versions of the manuscript. Also, a preliminary, cross-sectional version of this work was peer-reviewed for conference presentation (2).

1. McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., Hofer, S.M., and McKay, H. Is adiposity predicted by physical activity, sedentary time, or caloric intake as boys and girls mature?: A 4-year mixed-longitudinal DXA-based study. (In preparation)
1. McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., and McKay, H. Diet and physical activity predictors of body fat percent vary by sex in a

sample of Canadian children, youth, and young adults. (2017). Presented to International Society of Behavioral Nutrition and Physical Activity. Victoria, BC, Canada.

I conducted an additional analysis using the HBSIII study data that is not part of this dissertation. As lead author, I was responsible for defining the research questions, conducting the statistical analyses, and drafting the abstract and poster presentation. Drs. McKay, Rhodes, Nettlefold, Wharf-Higgins and Naylor provided detailed feedback and edits on all versions of the abstract. The analysis was presented as follows:

1. McConnell, J. S., Naylor, P.J., Nettlefold, L., McKay, H., Rhodes, R., and Wharf-Higgins, J. (2015). Investigating the Social and Behavioural Determinants of Weight Status in a Cohort of Canadian Children Using Direct and Self-Report Measures. Presented to The Canadian Obesity Summit. Toronto, Ontario, Canada.

Outside of this dissertation work, during my doctoral studies I was involved in designing, piloting, and expanding the Intergenerational Physical Activity Leadership (IPAL) program in collaboration with Dr. Naylor. Study of the IPAL project has been published as a peer-reviewed academic manuscript (1). Additionally, I presented the preliminary results of the pilot study of this project (2), the design and framework of the study (3), and the final results of this research (4) as cited below.

2. McConnell, J. & Naylor, P.J. (2015). Feasibility of an Intergenerational Physical Activity Leadership Program. *Journal of Intergenerational Relationships*, 14:3
3. McConnell, J. S. (2014). The Intergenerational Physical Activity Leadership (IPAL) Program. Poster presented to The Global Summit on the Physical Activity of Children. Toronto, ON, Canada.
4. McConnell, J. S. (2015). Physical Activity – Let’s Make it Intergenerational! Presented to the School of Exercise Science, Physical and Health Education’s 2015 IdeaFest event titled: Exercise is my Medicine. Victoria, B.C., Canada.
5. McConnell, J. S. (2015). Feasibility of an Intergenerational Physical Activity Leadership Intervention. Presented to the International Society of Behavioral Nutrition and Physical Activity. Edinburgh, Scotland, UK.

I have also had the privilege of collaborating on other child physical activity and healthy eating research and peer-reviewed manuscripts during my doctoral studies. As first author (1), second author (2), and fourth author (3), I analyzed the data and co-wrote the manuscript (1), reviewed the analysis and co-wrote the manuscript (2), and conducted the literature review, reviewed the analysis, and edited the manuscript (3) respectively.

1. McConnell, J., Frazer, A., Berg, S., Labrie, T., & Zebedee, J., Naylor, P.J. (2014). Got Health?: A Student-Led Inquiry Youth Engagement Project. *Journal of Child*

& Adolescent Behaviour, 2:153.

2. Naylor, P.J., McConnell, J. Rhodes, R.E., Barr, S., Gherent, I. (2014). Efficacy of a Minimal Dose School Fruit and Vegetable Snack Intervention. *Journal of Food and Nutrition Disorders*, 3:4
3. Naylor, P.J., Tomlin, D, Rhodes, R.E., McConnell, J. (2014). Screen Smart: Evaluation of a brief school facilitated and family focused intervention to encourage children to manage their screen-time. *Journal of Child & Adolescent Behaviour*, 2:1.

Chapter 1 : Introduction, literature review, rationale, objectives & hypotheses

1.1 Introduction

Childhood obesity is one of the most serious Canadian and global public health issues of the 21st century (Bancej et al., 2015; World Health Organization, 2015). In 2012-2013, 14.3% of Canadian children and adolescents 6-17 years old were classified with obesity based on World Health Organization (WHO) body mass index (BMI) cut-offs (Bancej et al., 2015)¹. This prevalence of obesity is concerning given that children with obesity have significantly greater odds of raised diastolic blood pressure, raised systolic blood pressure (Freedman, Dietz, Srinivasan, & Berenson, 1999), raised LDL cholesterol, low HDL cholesterol, raised triglycerides, metabolic disorders (Cook, Weitzman, Auinger, Nguyen, & Dietz, 2003; Weiss et al., 2004), psychosocial disorders (Britz et al., 2000; Erickson, Robinson, Haydel, & Killen, 2000; Strauss & Pollack, 2003), gastrointestinal disorders (Kinugasa et al., 1984; Murray et al., 2003), pulmonary complications (Luder, Melnik, & DiMaio, 1998; Rodriguez, Winkleby, Ahn, Sundquist, & Kraemer, 2002) and high fasting insulin concentration (Freedman et al., 1999). Obesity also tracks strongly from childhood and adolescence into adulthood, especially where obesity is more severe and present at an older age (Whitaker, Wright, Pepe, Seidel, & Dietz,

It should be noted that people-first language has been widely adopted for most chronic diseases and disabilities and will be used throughout this dissertation (ex. not referring to individuals as obese but as having obesity). Obesity is recognized as a disease by the Canadian Medical Society (Parsons, Power, Logan, & Summerbell, 1999; Saunders, 2011) and the use of people-first language is the official stance of the Canadian Obesity Network (Rich, 2015), the Obesity Action Coalition (Canadian Obesity Summit, 2015), and the Obesity Society (Obesity Action Coalition, 2015). Not only is "put people first, not their disability" a rule of APA style (The Obesity Society, 2015), it is also important in reducing stigma and promoting respect. Research shows that describing someone as obese can cause discrimination, and influence how likely the person is to seek medical care and how the person feels about his or her condition (The American Psychological Association, 2015).

1997). Beyond health implications, as excess bodyweight persists into adulthood, it can affect economic earnings, educational attainment, and quality of life over time (Puhl & Heuer, 2009). Based on the current childhood obesity prevalence in Canada and the associated risk of adverse outcomes across the lifespan it is imperative that we a) accurately identify individuals with, or at risk of developing obesity and b) understand the predictors and determinants of this disease.

Body fat is the tissue component primarily responsible for adverse chronic disease outcomes of obesity (Greenberg & Obin, 2006; Landgraf et al., 2015). Objectively measured BF% values ranging from 20-28% for boys and 30-34% for girls aged 5-18 years are associated with a variety of adverse health outcomes including cardiovascular disease risk factors, high blood pressure, and high cholesterol across ethnically diverse samples from Australia, the United States (U.S.), and Japan (Dwyer & Blizzard, 1996; Going et al., 2011; Mueller, Harrist, Doyle, & Labarthe, 2004; Washino, Takada, Nagashima, & Iwata, 1999; Williams et al., 1992). As such, objective measures of body fat are critical for assessing adiposity and understanding the childhood obesity epidemic (Prentice & Jebb, 2001). However, most childhood obesity research is based on proxy measures of obesity such as BMI that do not discriminate between fat mass (FM) and fat free mass (FFM). Although BMI is strongly associated with total and percent body fat in children and adolescents (Pietrobelli et al., 1998), relationships between BMI and dual energy X-ray absorptiometry (DXA)-derived body fat measures can vary with age, sex, and ethnicity (Shaw, Crabtree, Kibirige, & Fordham, 2007). Specifically, Asian children and youth have lower BMI but greater body fat percent (BF%) compared with children of European ancestry (Freedman et al., 2008) and are at risk of adverse health effects at a lower BMI and BF% value than those of European ancestry.

To advance the study of childhood and adolescent obesity, it is also critical to understand the pattern and determinants of body fat accrual. Childhood obesity is the outcome of several modifiable and non-modifiable dynamically interactive factors operating via metabolic, genetic, social, environmental and behavioural pathways over time (Ang, Wee, Poh, & Ismail, 2013; Canadian UNICEF Committee, 2009; Saunders, 2011). Contemporary lifestyle changes to modifiable risk factors including unhealthy dietary habits (Epstein et al., 2001) (such as sugar-sweetened beverage consumption (Ludwig, Peterson, & Gortmaker, 2001)), increased sedentary behaviours (Tremblay et al., 2011), and lower quality of sleep are strong determinants of childhood obesity (Chaput, Brunet, & Tremblay, 2006). There is also modest support for the role of total energy intake (EI) (Huang, Howarth, Lin, Roberts, & McCrory, 2004) and physical activity in the development of obesity (Poitras et al., 2016; Saunders, 2011). While it is clear that many social and behavioural determinants are implicated in the development and persistence of obesity for children and adolescents, gaps and challenges remain. For example, most childhood obesity interventions have modest or no effect in reducing BMI or prevalence of obesity by BMI (Campbell, Waters, O'Meara, & Summerbell, 2001; Kamath et al., 2008), indicating the need for improved understanding of the determinants and patterns of obesity development in order to better target intervention and treatment strategies.

To accurately capture the pattern of obesity development over time and investigate potential determinants of obesity development, there is a need for well-designed longitudinal studies that allow us to discern the sequence of events in the development of obesity and delineate within- and between-person differences in its determinants (Pettigrew, 1990). Longitudinal study designs, in combination with objective measurements of body fat and its determinants are necessary in a field where primarily cross-sectional studies and proxy

measurements of obesity fall short. The rich data housed in the University of British Columbia (UBC) Pediatric Bone and Physical Activity (PBPA) Database provides a critical and rare opportunity to address the gaps and challenges highlighted above, and contribute meaningfully to the understanding of childhood and adolescent obesity. Among many measurements described in detail in Chapter 2, the PBPA Database includes objectively-measured body fat from DXA scans, objectively-measured physical activity from Actigraph accelerometers, and 14 years of measurements across 1,071 participants from the Healthy Bones III Study (HBSIII). These data allow for sophisticated examination of the development of body fat over time and its determinants and enable further evaluation of obesity measurement techniques/methods. Therefore, in this dissertation I aim to: 1) describe the pattern of BF% accrual and BF% velocity in childhood and adolescence between sexes and across ethnic groups, 2) examine the relationship between BMI- and BF%-based definitions of obesity across sex and ethnic groups, and 3) investigate longitudinal determinants of BF% during childhood and adolescence. I extend previous studies that used cross-sectional designs, primarily proxy measures of obesity (e.g. BMI), and self-reported behaviours as predictors. To achieve these aims, I used objectively measured BF% collected using DXA scans, and moderate-to-vigorous physical activity (MVPA) and sedentary time collected using accelerometry. In addition, I used multilevel models to account for the longitudinal nature of my data, which permits investigation of inter- and intra-individual variation across time.

I begin my dissertation with two chapters that include a review of relevant literature and a description of the methods I used in my research, followed by three research chapters (Chapters 3-5). In Chapter 3, I examine the body fat accrual trajectories for Asian and Caucasian boys and girls. In Chapter 4, I describe the relationship between BMI- and BF%-based definitions of

obesity for Asian and Caucasian boys and girls. Finally, in Chapter 5, I investigate longitudinal associations between MVPA, sedentary time, estimated dietary calories and BF% in boys and girls. I conclude this dissertation with an integrated discussion in Chapter 6.

1.2 Literature review

I begin this chapter by defining obesity and describing the methods used to measure and define obesity in this dissertation. Next, I review the literature concerning the potential predictors of obesity and BF% accrual (sex, age and maturity, ethnicity, energy intake, physical activity and sedentary time) that I will investigate in Chapter 5. Where possible I focus on studies that employed objective measures of body fat but refer to studies using proxy measurements of obesity when necessary given the constraints of the literature. Finally, I define the rationale, objectives and hypotheses for the three studies comprising Chapters 3-5 of this dissertation.

1.2.1 Defining and measuring obesity and body fat

1.2.1.1. Definition

An individual is considered overweight when they weigh more than what is considered healthy for their given height. This excess weight could be due to any component of body composition such as muscle, bone, or fat . Obesity is defined as having excess adiposity or fat that increases the risk of impaired health, although what constitutes excess fat in children and youth is, as of yet, not agreed upon (Lakshman, Elks, & Ong, 2012). Adiposity is commonly assessed using proxy anthropometric measures such as BMI, waist circumference, and skinfold thickness. Objective measures such as bioelectrical impedance analysis (BIA), DXA or magnetic resonance imaging (MRI) scans, among others, are used less frequently. In this chapter and dissertation, my focus will be two-fold. First, I focus on BMI as a proxy measure of obesity and

discuss common cut-offs used to define obesity and associated health outcomes. Second, I focus on DXA-derived measurements of body fat. However, due to the lack of established cut-offs for objectively-measured body fat in children and youth and paucity of evidence linking body fat to health outcomes, I also evaluate current literature based on other direct body fat measures.

1.2.1.2 Body mass index

The National Institutes of Health issued the first obesity classifications based on BMI in 1985 and since then, BMI is the most commonly used measurement tool to classify and report on population- and individual-level weight status including underweight, normal, overweight, and obese (National Institutes of Health, 1985). BMI classification systems (Centers for Disease Control and Prevention (CDC), World Health Organization (WHO), and International Obesity Task Force (IOTF), described in detail below) use different definitions for weight status categories but all are based on the standard BMI calculation of body mass divided by height squared ($BMI = \frac{\text{body weight (kg)}}{\text{height (m)}^2}$).

Currently, researchers and clinicians commonly use one of three BMI-based definitions of overweight and obesity for children and adolescents: CDC, IOTF, and WHO. The CDC growth charts were produced in the U.S. in 2000 based on national survey data collected between 1963 and 1994 (Kuczmarski, Ogden, & Guo, 2001). The CDC growth charts contain growth curves for infants 0 to 36 months, and BMI-for-age growth curves for individuals 2-20 years old. Using the BMI-for-age curves, individuals between the 85th and 95th percentiles are classified as ‘overweight’ and those above the 95th percentile as ‘obese’ (Ogden & Flegal, 2010).

The CDC charts are most applicable to children and young adults in the U.S.; therefore, in 2000 the IOTF convened an expert committee to develop BMI cut-offs that represented more diverse populations. The IOTF BMI curves were based on observations from large national

studies in Brazil, Great Britain, Hong Kong, the Netherlands, Singapore, and the U.S for individuals 2 to 18 years old (Cole, 2000). As health risks of excess weight were not as clearly established for children and adolescents the IOTF group developed BMI curves for boys and girls that intersected with the established adult BMI cut-points of 25.0 kg/m² and 30.0 kg/m² for overweight and obesity, respectively. These cut-points were strongly correlated with adverse health outcomes; average all-cause mortality increases by 30% for every 5kg/m² above 25 kg/m² in adults (Prospective Studies Collaboration). Therefore, the IOTF definitions or cut-points for overweight and obesity in children by sex are based on BMI curves that pass through an adult BMI of 25 kg/m² and 30 kg/m² at age 18 years.

In 2006, the WHO released BMI growth curves for children under age five (WHO Multicentre Growth Reference Study Group, 2006). These were based on longitudinal data from children in Brazil, Ghana, India, Norway, Oman, and the U.S. that were raised in conditions considered the “gold standard” for optimal growth (e.g. no known health or environmental constraints to growth, exclusive or predominant breastfeeding for at least 4 months, introduction of complementary foods by 6 months of age, and continued partial breastfeeding to at least 12 months of age, no maternal smoking before or after delivery, single term birth, absence of significant morbidity, and living in socio-economic conditions favourable to growth with mobility < 20% (De Onis et al., 2004)) (WHO Multicentre Growth Reference Study Group, 2006). In 2007, the WHO added growth reference curves for children and youth aged 5-19 years that transitioned smoothly from the 0-5-year growth curves previously published. Classification of overweight and obese for the second set of growth curves was based on one and two standard deviations (SD) above the mean, respectively. These SD-based definitions of overweight and obesity also aligned closely with the adult cut-offs of 25 kg/m² and 30 kg/m² (de Onis et al.,

2007). In 2010, the Dietitians of Canada recommended the WHO cut-offs for use in clinical and research settings in Canada, and then redesigned the charts in 2014 (primarily cosmetic adjustments) to facilitate clinician uptake (Dieticians of Canada, 2014).

Use of BMI is ubiquitous in Canadian obesity research. In their recent scoping review of studies published between 2002-2012, Patton & McPherson found that BMI was the most common anthropometric measurement used with Canadian children and youth (44/50 studies) whereas BF% measures by BIA or skinfold thickness were used less frequently (12/50 studies) (Patton & McPherson, 2013). Although common, BMI has many limitations. First, there are multiple BMI-derived definitions or cut-points for obesity, complicating cross-population comparisons. For instance, estimates of overweight and obesity prevalence varied substantively in the 2004 Canadian Community Health Survey and the 1978/79 Canadian Health Survey across the WHO, IOTF and CDC cut-offs (Shields and Tremblay, 2010). Using the 2004 data, the combined prevalence of overweight and obesity was 35% based on WHO cut-offs, 26% based on IOTF cut-offs, and 28% based on CDC cut-offs. Differences in estimates between the 1978/79 and 2004 data were similar based on the three definitions but the relative increase in prevalence of overweight and obesity was greater when the IOTF cut-offs were used (Shields & Tremblay, 2010). Second, BMI is a proxy measure of adiposity and does not discriminate between fat mass and fat-free mass, which includes muscle, bone, water, and internal organs. BMI may under or overestimate actual obesity and health risk as a result of inter-individual differences in these tissue components. In addition, fat is the primary tissue identified as influencing the onset of negative health effects of overweight and obesity in adults (evidence is emerging but far less substantive in children (Landgraf et al., 2015; Singer, 2017)). Use of BMI may therefore introduce greater error into identification of at-risk populations.

The association between BMI and BF% varies by sex, obesity status, maturity, and ethnicity². The validity of BMI can be assessed using tests for sensitivity and specificity. Sensitivity is the rate of true positives identified by the screening test; how many people with the disease are correctly identified as having the disease. Specificity is the rate of true negatives identified by the screening test; how many people without the disease are correctly identified (Parikh, Mathai, Parikh, Sekhar, & Thomas, 2008). A recent systematic review and meta-analysis comparing BMI cut-offs to objective body fat measures (DXA, air displacement plethysmography, hydrostatic weighing, BIA) reported pooled sensitivity of 0.73 and specificity of 0.93 (sensitivity for males = 0.76 and females =0.71; specificity for males =0.94 and females =0.95) with race, obesity definition using BMI, reference criteria of BMI and the reference standard method to measure adiposity explaining a moderate amount of the observed heterogeneity between studies ($I^2 = 48\%$) (Javed et al., 2015). The association between adiposity and BMI also differed by obesity status whereby BMI was more strongly correlated with fat mass index (FMI) in children > 85th percentile of BMI-for-age but similarly associated with FMI and fat-free mass index (FFMI) for children with a BMI < 50th percentile (Table 1.1) (Freedman et al., 2004).

² The terms race and ethnicity are both social constructs and have some overlap (Kyle & Puhl, 2014; Puhl, Peterson, & Luedicke, 2013). These terms are therefore often used interchangeably when in fact there are important differences between the two. Historically, race was associated with biology, but there is little variation in genetic composition between geographically separate groups (American Anthropological Association, 1998). The concept of race should be established more socially as a way to think about population groups that might look different and have different ancestral roots, reducing the emphasis on biological factors (Dunn & Kuper, 1975). Ethnicity refers to the shared characteristics of a population group, including geographic and ancestral origins, cultural traditions, language, and religion. Ethnicity is extremely fluid and individuals often self-identify into these groups based on changing social and political context, definitions, understandings, and perceptions (Bhopal, 2004).

Table 1.1. Correlation coefficients for body mass index levels and fat and fat-free mass by sex and age. Adapted from Freedman, D. S., Wang, J., Maynard, L. M., Thornton, J. C., Mei, Z., Pierson, R. N., Jr., Dietz, W. H., et al. (2004). Relation of BMI to fat and fat-free mass among children and adolescents. *International Journal of Obesity and Related Metabolic Disorders*, 29(1), 1-8.

Age (years)	Boys				Girls			
	Overall correlation	BMI-for-age			Overall correlation	BMI-for-age		
		<50th percentile	50-84th percentile	>85th percentile		<50th percentile	50-84th percentile	>85th percentile
9-11								
FMI (kg/m ²)	0.95	0.45	0.43	0.95	0.95	0.56	0.77	0.93
FFMI (kg/m ²)	0.66	0.56	0.27	0.59	0.72	0.67	-0.05	0.53
12-14								
FMI (kg/m ²)	0.93	0.45	0.53	0.85	0.97	0.56	0.61	0.96
FFMI (kg/m ²)	0.65	0.69	0.21	0.38	0.71	0.58	0.36	0.55
15-18								
FMI (kg/m ²)	0.93	0.44	0.52	0.95	0.96	0.65	0.7	0.89
FFMI (kg/m ²)	0.64	0.78	0.36	0.21	0.76	0.67	0.18	0.69

Note: BMI = body mass index, FMI = fat mass index, FFMI = fat free mass index. Pearson correlation coefficients adjusted for race (four categories) and age, between BMI and the specified characteristic. Sample sizes within categories of sex, age, and BMI-for-age ranged from 38 to 66.

The BMI-BF% relationship also varies by ethnicity; in a mixed race sample of children and youth aged 3-18 years from the U.S., (Ellis, Abrams, & Wong, 1999) at the same BMI, black girls had a lower BF% and Hispanic girls had a higher BF% as compared white girls, but these differences were not significant for boys. Similarly, Asian children living in the U.S. have lower BMIs but greater BF% compared with Caucasians (Freedman et al., 2008) and Mohawk children

in the U.S. have significantly more centrally distributed body fat (measured using waist to hip ratio) compared with Caucasian children (Goran et al., 1995).

Further, obesity classification differs between sexes depending on whether BMI or objective measures are used to assess adiposity. As children mature, muscle (or lean) mass contributes more to boys' total body mass whereas FM contributes more to girls' total body mass. These differences in fat and lean mass are not reflected in BMI curves, which show similar patterns for boys and girls in adolescence (McCarthy, Cole, Fry, Jebb, & Prentice, 2006), and explain the heightened sex difference and heterogeneity in the relationship between BMI and BF% as children age (Taylor, Grant, Williams, & Goulding, 2010). As children age more mature boys have a lower BF% and more mature girls have a higher BF% compared with less mature children at a similar BMI (Daniels, Khoury, & Morrison, 1997a). A longitudinal study of youth measured at ages 8, 10 and 12 years found that between ages 8 and 12 years BMI increased linearly in boys and girls, but between ages 10 and 12 years BF% (by DXA) remained unchanged. During the second two years of the study, fat mass and lean mass (by DXA) increased at approximately the same rate, which contributed to the increase in BMI but not BF% (Telford, Cunningham, & Abhayaratna, 2014). Similarly, an increase in BMI percentile without a corresponding decrease in BF% (by hydrodensitometry) was reported in 13 to 18 year old boys who were part of a 10-year longitudinal study (Demerath et al., 2006). As is evident in these studies, the disconnect between BMI and body fat highlights importance of maturational status and timing. The relationship between BF% and BMI clearly varies by age, sex, ethnicity, and maturity status rendering BMI an inconsistent proxy measure of obesity for children and adolescents, and especially for repeated measures unless maturation is controlled for (Flegal et

al., 2009; Telford et al., 2014). Thus, objective measures such as DXA are essential tools in understanding the development of childhood obesity and its determinants.

1.2.1.3. Dual energy X-ray absorptiometry

Body composition can be objectively measured using DXA. DXA can assess total and regional lean and fat tissues often reported as FM and FFM for the total body, arms, legs, and trunk (Daniels, Khoury, & Morrison, 2000; Freedman, Ogden, Berenson, & Horlick, 2005; Mazess, Barden, Bisek, & Hanson, 1990). DXA scans are quick (5-10 minutes) and incur a very low dose of radiation; less than 1/100th the amount received in one chest x-ray (Goran, 1997).

Using the compartment model, DXA partitions the body into compartments of tissues of constant densities (lean, fat and bone mass). These tissues or compartments are then quantified based on calculations of the differential absorption of photons emitted at two energy levels. Bone edge detection and tissue thickness algorithms as well as assumptions of the level of body hydration are used to convert the absorption data into values of mass for bone, fat, and lean tissue components across the whole body or within sub-regions (Helba & Binkovitz, 2009).

Although DXA is the gold standard for assessing adiposity in children and youth, it not without limitations. Fat mass can be overestimated in thick tissue; tissue greater than 20–25 cm thick increases attenuation of low-energy photons and results in an overestimation of fat mass by up to 4% and an underestimation of fat free mass up to 6% (Jebb, Goldberg, & Elia, 1992; Laskey, Lytle, Flaxman, & Barber, 1992). Body hydration may also influence results of a DXA scan. Hydration of fat-free tissues typically varies from 67% to 85% (Moore & Boyden, 1963); however, most DXA algorithms assume a constant hydration level of 73%. Therefore, hydration above this level leads to overestimation fat mass (Laskey, 1996).

Reproducibility of a measurement tool is often determined using the coefficient of variation (%CV). Precision of DXA reproducibility (at 1 SD) is 1.4–2% for FM and 1.1–1.5% for FFM in pediatric and young adult populations (Margulies et al., 2005; Mazess et al., 1990; Njeh, Samat, Nightingale, McNeil, & Boivin, 1997). Further, DXA measurements of FM and FFM were valid compared to chemical analysis of pig carcasses in the pediatric weight range ($r = 0.90$ – 1.0) (Elowsson et al., 1998) and reliable in test re-test studies in children ($ICC = 0.998$) (Gutin et al., 1996). DXA was validated against MRI for longitudinal assessment of FM and FFM in children and adolescents across the Tanner stages of maturation (Bridge et al., 2011), as well as with the criterion 4-compartment model whereby BF% by DXA correlated strongly with BF% predicted in children and adolescents ($R^2 = 0.85 - 0.90$) (Sopher et al., 2004; Wong et al., 2002). Despite being a valid and reliable measurement tool, comparisons of DXA-derived body composition measurements across studies may be limited by variability in DXA models (e.g., Hologic vs Lunar devices) and analysis software (Telford et al., 2014; Telford et al., 2008).

When using objectively measured body composition measures from DXA to assess adiposity, absolute values of FM or FFM must account for changes expected as children grow and mature. As such, indexes that control for height, such as FMI and FFMI (Carter, Taylor, Williams, & Taylor, 2011; Demerath et al., 2006), or indices that control for body weight, such as BF% (Going et al., 2011; Telford et al., 2014), are commonly used.

The weight normalized variable BF%, which is a measure of kilograms of fat mass adjusted for weight ($BF\% = \frac{fat\ mass\ (kg)}{weight\ (kg)}$), confers greater risk of adverse health outcomes above a certain threshold in children and adolescents (Dwyer & Blizzard, 1996; Going et al., 2011; McCarthy et al., 2006; Mueller et al., 2004; Washino et al., 1999; Williams et al., 1992). Unfortunately, this threshold is not clearly defined, as a variety of different thresholds based on

BF%, or BF percentile have been used. Due to the differential changes in total and regional BF% with age, sex, ethnicity, and maturity status determining cut-off thresholds for adverse health risk is difficult in children (Laurson, Eisenmann, & Welk, 2011).

For example, in a study of over 1800 children aged 9-15 years BF% (by skinfold thickness measurements) $\geq 20\%$ in boys and $\geq 30\%$ in girls was associated with elevated levels of high density lipoprotein cholesterol and systolic blood pressure, both of which are associated with increased risk of coronary heart disease as an adult (Dwyer & Blizzard, 1996; Newman III et al., 1986; PDAY Research Group, 1990). Similarly, the prevalence of adverse cardiovascular disease risk factors in a study of over 12,000 boys and girls 6-18 years old was significantly higher in boys with BF% (measured by skinfold thickness measurements) $\geq 20\%$ and girls with BF% $\geq 30\%$ (Going et al. (2011). Additionally, a study of over 1200 boys and girls 9 and 10 years old found that BF% (measured by bioelectrical impedance analysis) $> 23\%$ was significantly related to the probability of a high risk atherosclerogenic index score, a marker for future, potential coronary heart disease (Washino et al., 1999). Also, a study of nearly 3,500 boys and girls 5-18 years old found that BF% (measured by skinfold thickness measurements) $\geq 25\%$ in boys and $\geq 30\%$ in girls was associated with elevated SBP, diastolic blood pressure, and unfavourable lipoprotein ratios (Williams et al., 1992). Lastly, a study of nearly 700 8-17 year olds suggested the 85th percentile be used as a cut-off for excess BF% (measured by bioelectrical impedance analysis (BIA)) based on increased cardiovascular risk factors from blood pressures, total serum cholesterol values, and lipoprotein ratios; the 85th percentile equates to a BF% of 28.25% to 21.65% for boys 8.5 to 17.5 years old, respectively, and a BF% of 32.74% to 33.57% for girls 8.5 to 17.5 years old, respectively (Mueller et al., 2004).

Despite the paucity of health indicators related to BF%, reference datasets are available for BF% in children and youth from BIA measures in U.S. (Chumlea et al., 2002; Mueller et al., 2004) and U.K. (McCarthy et al., 2006) populations and from sum of six skinfold thickness measurements for U.S. (Laurson et al., 2011) and Spanish populations (Moreno et al., 2005) (Table 1.1). These reference values are designed primarily for comparison and identifying trends, but they provide context not only for the results in Chapter 3-6 of this dissertation, but also for many studies that use percentile prevalence matching to define obesity (often at the 95th percentile) (Flegal et al., 2010; Freedman, Ogden, Blanck, Borrud, & Dietz, 2013; Freedman et al., 2009; Mei et al., 2002; Zimmermann, Gubeli, Puntener, & Molinari, 2004).

Table 1.2. Reference values for body fat percent at the 85th and 95th percentiles for boys and girls 9 – 18 years old.

	Age (Years)	McCarthy et al., 2006 ¹		Mueller et al., 2004 ¹ *		Laurson et al., 2011 ²	
		85th	95th	85th	95th	85th	95th
Girls	9	27.2	31.2	32.64	37.45	28.0	35.6
	10	28.2	32.2	32.46	37.11	30.1	37.9
	11	28.8	32.8	32.25	36.69	31.6	39.4
	12	29.1	33.1	32.07	36.32	32.6	40.3
	13	29.4	33.3	31.97	36.11	33.5	40.8
	14	29.6	33.6	32.02	36.16	34.1	41.1
	15	29.9	33.8	32.26	36.6	34.6	41.2
	16	30.1	34.1	32.76	37.54	35	41.2
	17	30.4	34.4	33.57	39.08	35.5	41.5
	18	30.8	34.8	n/a	n/a	36.3	42.2
Boys	9	22.2	26.8	31.68	39.68	26.6	36.4
	10	22.8	27.9	32.89	39.91	29.2	40.4
	11	23	28.3	32.38	39.03	31	43.3
	12	22.7	27.9	30.66	37.33	31.4	44.2
	13	22	27	28.24	35.13	30.5	43.3
	14	21.3	25.9	25.62	32.73	28.8	41.2
	15	20.7	25	23.31	30.42	27.3	39.3
	16	20.3	24.3	21.82	28.52	27.3	39.5
	17	20.1	23.9	21.65	27.33	28.5	41.3
	18	20.1	23.6	n/a	n/a	30.3	44.1

* Note: Mueller et al. reported values for half-year age groupings (e.g., 8.5 years old, 9.5 years old); I placed these values in the table by base year (e.g., 9.5 years is in row 9).

1. BF% measured using BIA.

2. BF% measured from the sum of six skinfold thickness measurements.

Although DXA scans provide valid and reliable measures of adiposity, there is a lack of meaningful reference metrics for development of body composition and fat distribution throughout maturation and across ethnic groups and specifically for Canadian children. There is also a need to better understand the risks for adverse health outcomes based on different trajectories of BF% development and distribution and how these risks may differ across populations and stages of maturation (Goran, 1997; McCarthy et al., 2006).

1.2.2. Non-modifiable factors affecting overweight and obesity in children

1.2.2.1. Sex and gender

According to the Canadian Institutes of Health Research, (Canadian Institutes of Health Research, 2015) sex refers to biological attributes and is primarily associated with physical and physiological features such as chromosomes, gene expression, hormone levels and function, and reproductive/sexual anatomy. Sex is most often categorized as female or male but the biological attributes and expression that make up sex can vary. Gender indicates the socially constructed roles, behaviours, expressions, and identities of women, men, and gender-diverse people (American Psychological Association, 2015). Gender influences perception of self and others, actions and interactions, and the allocation of power and resources in society. Gender is similarly most often conceptualized in a binary way (woman/man) but there is substantial diversity in how gender is understood, experienced, and expressed by individuals and groups. Gender and sex are highly interrelated, and there is no simple method to integrate sex and gender in health research or to account for the complex interrelationships between them and other factors or determinants of health (Canadian Institutes of Health Research, 2015). Based on this understanding, I use the

terms sex and gender with fidelity to the original work when discussing previous research. The construct of biological sex is of particular interest for the body of research in this dissertation due to the manifestation and focus on biological maturation throughout the study period.

The sex of an individual is associated with the social and behavioural determinants of obesity and development of body fat over time. The social determinants of health influence population health through income, social status, social support networks, education, employment, working conditions, social environments, physical environments, personal health practices, coping skills, healthy child development, gender and culture (Public Health Agency of Canada, 2015).

Focusing on health behaviours, sex is associated with different rates of physical activity and sedentary behaviour as well as dietary habits in children and youth. In terms of physical activity, a comprehensive review of 108 studies of correlates of physical activity published between 1970 and 1998 identified 40 variables for children aged 3-12 years and 48 variables for adolescents aged 13-18 years and found that male sex was consistently significantly positively associated with physical activity in both age groups (Sallis, Prochaska, & Taylor, 2000). A second summary of 7 systematic reviews of physical activity published after the year 2000 found that male sex was a consistent positive determinant of physical activity for children aged 4–9 years and was also a correlate of physical activity in other age groups (Bauman et al., 2012).

While Canadian girls and boys aged 6-19 years spend similar amounts of time in sedentary activities (8.7 and 8.5 hours per day, respectively) (Colley et al., 2011), there are sex differences in the type of sedentary activities pursued. For example, a study of U.S. adolescents aged 11 to 15 years also found that total minutes of leisure-time sedentary behaviour did not differ significantly between boys and girls (286 minutes per day and 300 minutes per day,

respectively), but despite spending similar amounts of time watching TV, boys spent more time playing computer games and girls spent more time listening to music and talking on the phone (Norman, Schmid, Sallis, Calfas, & Patrick, 2005).

Important sex differences are also apparent in dietary behaviours during childhood and adolescence that in turn, influence energy intake. To illustrate, a 2007 study of rural Ontario school children found that boys consumed significantly more servings of grain and meat and consumed more energy, protein, carbohydrate, calcium, iron, phosphorus, and sodium than girls (Galloway, 2007). Similarly, a 2009 study of food preferences 1,800 youth in Ohio found that boys preferred significantly more meat, fish, and poultry foods compared with girls, and girls preferred significantly more fruits and vegetables compared with boys (Caine-Bish & Scheule, 2009). A 2008 study of grade 5 students in Alberta also supported these sex differences in dietary behaviours; compared with girls, boys consumed more fast-food, were more likely to get 30% or more of their energy from dietary fat, and were less likely than girls to get the recommended 6 or more servings of fruits and vegetables per day (Simen-Kapeu & Veugelers, 2010).

Occurring in tandem with these social and behavioural determinants, there are also important sex differences in development of BF% during growth. Puberty initiates changes to hormones that influence the amount and distribution of adipose tissue during puberty (cortisol, insulin, growth hormone, and the sex steroids (Roemmich & Rogol, 1999)) whereby boys gain muscle mass and lose fat mass and girls gain more fat mass (Rogol, Roemmich, & Clark, 2002). Specifically, in boys, BF% increases before puberty then declines from about 15% to 10%, on average, as linear growth in height increases. In girls, BF% is stable pre puberty then increases

from 17% to 22%, on average, between the ages of 10 and 15, respectively (Figure 1.1) (Cheek, 1968; Malina, Bouchard, & Bar-Or, 2004).

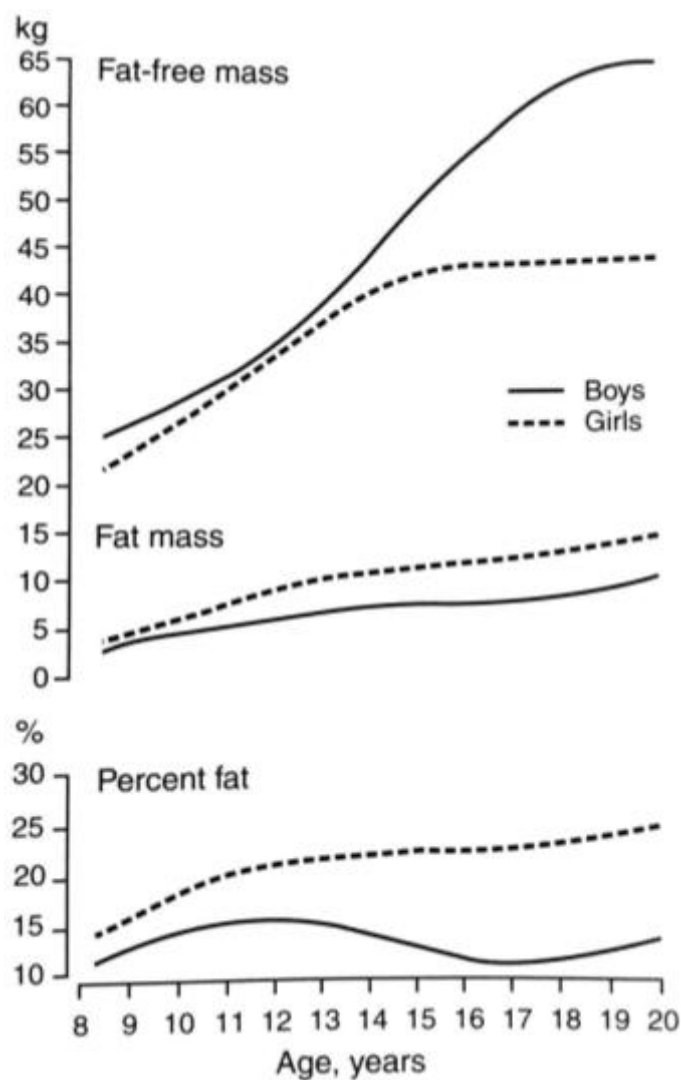


Figure 1.1. Changes in body composition from late childhood to young adulthood. Reprinted from Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, Maturation, and Physical Activity* (2 ed.): Human Kinetics. Curves are based on a sample of 3,667 boys and girls aged 8-20 years pooled from 32 studies. Data are comparable to representative US samples from the 1980s (Malina, 1989; Malina, Bouchard, & Beunen, 1988).

The trajectory of obesity over time may also be different between sexes as approximately 30% of adult obesity may begin in adolescence for females and approximately 10% of adult obesity may begin in adolescence for males, and this difference was influenced by a stronger effect of lower education attainment and lower social class during childhood on adult BMI for females in this study (Braddon, Rodgers, Wadsworth, & Davies, 1986). The dynamic interdependence between factors causing obesity is apparent, and age and maturity are similarly interrelated.

1.2.2.2. Age and maturity

In order to study the determinants of obesity and the development of BF% over time, we must consider the natural trajectory of change in body composition, growth patterns and possible critical periods for development of overweight and obesity that exist from infancy to adolescence. Age at onset is a key determinant of whether childhood overweight or obesity will persist through to adolescence and into adulthood (Dietz, 1994). The three critical periods of increased risk for persistence of and adverse health outcomes due to overweight and obesity are the prenatal period, the period known as “adiposity rebound”, and adolescence as shown in Figure 1.2. Of interest in this dissertation is adolescence.

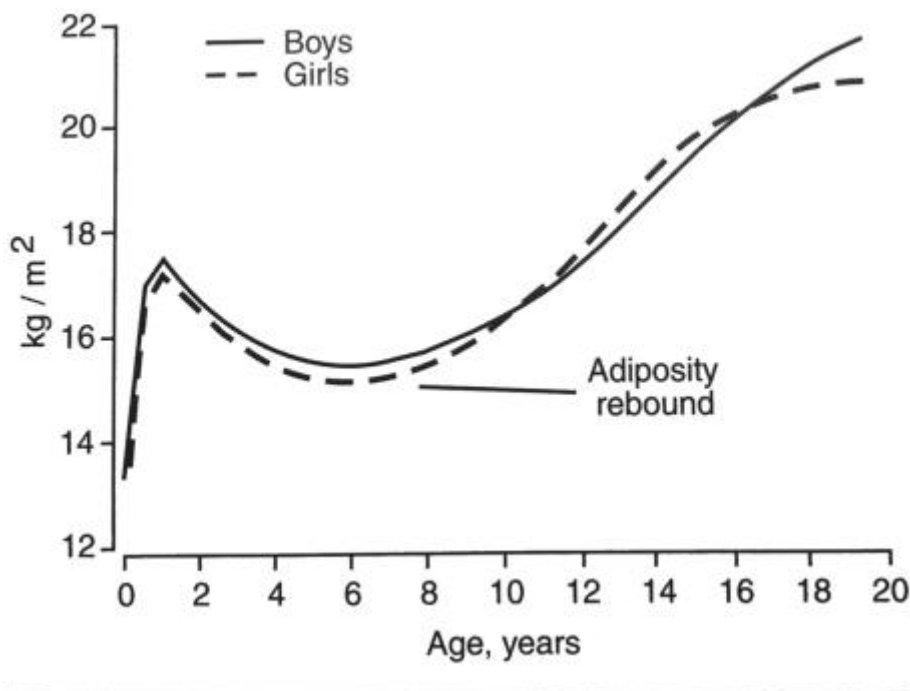


Figure 1.2. Distance curves for the body mass index (BMI) in French children from birth to 21 years of age. Reprinted from Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, Maturation, and Physical Activity* (2 ed.): Human Kinetics.

Adolescence is the stage of physical, cognitive and social maturation between childhood and adulthood (Lerner & Steinberg, 2004) and is the last critical period for development of obesity before adulthood. Although the processes of growth and maturation are interrelated, growth refers to a change in size, body composition, and various systems of the body that is measurable, whereas maturation refers to the progression towards the mature adult state (Manna, 2014). As mentioned above, approximately 30% of adult obesity may begin in adolescence for females and 10% for males (Braddon et al., 1986). During adolescence, changes occur in the quantity and location of body fat (Must, Jacques, Dallal, Bajema, & Dietz, 1992; Strauss, 2000). For example, body fat becomes more centrally distributed during adolescence for boys and girls

(although more rapidly for boys) (Mueller, 1982) and centrally distributed fat is related to chronic disease risk factors such as hyperinsulinemia in adolescence (Freedman et al., 1987). Due to the changes in the quantity and location of body fat from childhood through adolescence, researchers must consider maturity or biological age (years from age at peak height velocity (APHV), a measure of somatic maturity) and not just chronological age. Assessment of both the tempo and timing of maturation is vital in studies of growth and development in children (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). In longitudinal studies with sufficient anthropometric measurements, maturation can be determined using APHV (Malina et al., 2004). Average APHV is 11.5 years for girls and 13.6 years for boys, and as such, aligning children by chronological age could result in comparing boys and girls at very different biological ages (Figure 1.2) (Moore et al., 2015). Importantly, biological age is differentially related to the association between BMI and BF% where more mature boys have a lower BF% and more mature girls have a higher BF% compared with less mature children at a similar BMI (Daniels et al., 1997a).

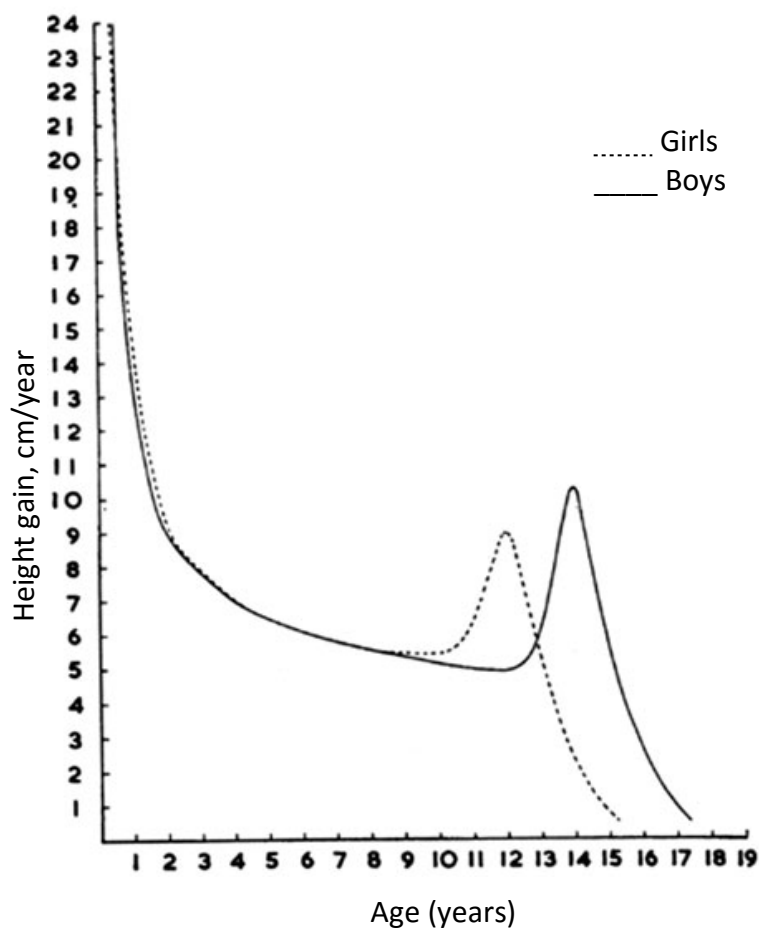


Figure 1.3. Typical individual velocity curves for height (centimetres per year) in boys and girls. Reprinted from Tanner, J. M., Whitehouse, R. H., & Takaishi, M. (1966). Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. I. *Archives of Disease in Childhood*, 41(219), 454.

As a measure of somatic maturity, APHV identifies the age at maximum velocity in statural growth, which occurs when an individual reaches a maturational point equivalent to 92% of adult stature (Bailey, Baxter-Jones, Mirwald, & Faulkner, 2003). APHV is most accurately determined in longitudinal studies that acquire serial measurements of height at regular intervals

during the pubertal period. For example, boys need a height measurement before age 11.5 years and after age 16.5 years with at least five measurements during this period and girls need a height measure before 11.0 years and after 13.0 years, with at least four measurements during this period (Hauspie, Das, Preece, & Tanner, 1980; Largo, Gasser, Prader, Stuetzle, & Huber, 1978; Mirwald & Bailey, 1986; Roy, Sempe, Orssaud, & Pedron, 1972; Roy, 1971; Tanner, Whitehouse, Marubini, & Resele, 1976; Taranger & Hägg, 1980). Statistical modeling is then used to develop individual growth trajectories and identify APHV and the magnitude of PHV. In cross-sectional studies, APHV can be reliably predicted in boys and girls based on single measures of stature, trunk length (sitting height), leg length, body mass, and chronological age (Mirwald et al., 2002). In an effort to externally validate the Mirwald equations and address potential overfitting and bias, Moore and colleagues recently redeveloped the sex-specific prediction equations, and concluded that the equations could be simplified without a meaningful increase in standard error. The redeveloped models included age \times sitting height for boys and age \times height for girls (Moore et al., 2015). Importantly, both models were calibrated using only Caucasian children. However, the HBSIII research group also developed equations. Prediction of APHV is affordable, quick, non-invasive, safe, and can be used to compare boys and girls (Baxter-Jones, Eisenmann, & Sherar, 2005). Once calculated, individuals can be aligned on maturity offset (MO) or years from APHV, where MO=0 represents APHV.

1.2.2.3. Ethnicity

Ethnic disparities in obesity are apparent across the lifespan (Wang & Beydoun, 2007) In 2004, the combined percentage of those with overweight and obesity aged 2-17 years old in Canada was 28% for white youth, 29% for black, 18% for Southeast and East Asian, 41% for

off-reserve aboriginal, and 27% for youth classified as other (Shields, 2006). Closely tied to socioeconomic status (SES) and operating through many of the same pathways, ethnic disparities in obesity prevalence are related to differences in diet and physical activity behaviours, differential access to pregnancy or infant health care, and effects of cumulative disadvantage or chronic stressors that influence intergenerational transmission of obesity within ethnic groups, especially those in poverty (Geronimus, 1992).

Ethnic disparities in risk factors for obesity are apparent during the prenatal period and during infancy, childhood and adolescence (Kimbrow, Brooks-Gunn, & McLanahan, 2007; Reilly et al., 2005). When compared with Caucasian children, minority children in the U.S. that were followed from the prenatal period to age four were more likely to have a low birth weight for gestational age, more likely to be born to a mother with gestational diabetes, more likely to have greater rapid weight gain in infancy, more likely to have televisions in their bedrooms, have a greater intake of sugar-sweetened beverages and fast food, and were less likely to sleep at least 12 hours a day in infancy. Adjustment for SES and parental BMI pre-pregnancy did not attenuate these relationships (Taveras, Gillman, Kleinman, Rich-Edwards, & Rifas-Shiman, 2010).

Importantly, using BMI as a proxy for obesity when comparing youth across ethnicities is problematic because there are differences in regional fat deposition and correlations between BMI and measured body fat between ethnic groups. This is illustrated by a U.S. study that compared European American, African American and Hispanic children; Hispanic children aged 7-12 years had the greatest trunk, intra-abdominal and subcutaneous abdominal adipose tissue (by DXA), followed by European Americans and African American children (Casazza, Beasley, & Fernandez, 2011). Ethnic differences in (BMI-BF% relationship) were also apparent in a cross-national comparison of 6 year-old children in India and the U.K; Indian children living in

India had a smaller BMI and WC compared with Caucasian children in the U.K., yet the Indian children had a greater BF% (measured by DXA) (Lakshmi et al., 2012). Similarly, in a U.S. study, Asian adults (Chinese, Japanese, Korean, and Filipino) have lower BMIs but greater BF% compared with Caucasians (Wang et al., 1994). In addition to differences in body composition there are also differential health risks associated with obesity across ethnic groups. Asians are at risk of adverse health effects at a lower BMI and BF% value than those of European ancestry. Asian Indian children in the U.K. are more insulin resistant than children of European ancestry at the same BF% U.S.(Lakshmi et al., 2012), and Asian children have adverse total cholesterol levels at the same BMI as those of European ancestry (Holmes, LaHurd, Wasson, McClarin, & Dabney, 2015). The heterogeneity in risk is apparent across the lifespan as adults of South Asian and Chinese ancestry can develop type 2 diabetes and chronic heart disease at a lower BMI and at an earlier age than those of European ancestry (Chiu, Austin, Manuel, Shah, & Tu, 2011; Misra & Khurana, 2011).

1.2.3. Modifiable factors affecting overweight and obesity in children

1.2.3.1 Diet

Changes in dietary habits are implicated in the rising prevalence of childhood obesity (Frazao, 1999) because dietary intake contributes to the EI (energy intake) side of the energy balance equation (energy balance = energy intake – energy expenditure) and is a modifiable behaviour. In this dissertation, I focus on total EI although I acknowledge the potential contribution of other components of EI such as calcium intake (Skinner, Bounds, Carruth, & Ziegler, 2003), sugar-sweetened beverages (Malik, Schulze, & Hu, 2006) and dietary fat intake (Gillis, Kennedy, Gillis, & Bar-Or, 2002).

1.2.3.1.1. Total energy intake

The relationship between EI and weight status in children and adolescents varies in the literature and evidence to support this relationship comes mostly from cross-sectional studies. For example, in a cross-sectional study of 181 Canadian children aged 4-16 years, girls and boys with obesity had significantly greater total EI (approximately 400 calories per day) than their peers without obesity suggesting a clear association (Gillis et al., 2002). Similarly, in a sample of over 10,000 U.S. boys and girls between 9-14 years old followed up after 1 year an increase of 100 calories a day was associated with a significant increase in BMI (girls: $.0059 \pm .0027 \text{ kg/m}^2$ per increase of 100 kcal/day; boys: $.0082 \pm .0030 \text{ kg/m}^2$) (Berkey et al., 2000). Conversely, in a study of nearly 900 U.S. boys and girls aged 11-15 years old, higher caloric intake reported from 24 hour recalls was associated with decreased odds of overweight and obesity by BMI in girls (OR = 0.99; P = .03) and boys (OR = 0.98; P <.001) (Nielsen, Siega-Riz, & Popkin, 2002). A study of Spanish adolescents 15-17 years old measuring caloric intake using a prospective food log, as well as a retrospective food frequency questionnaire reported no difference in caloric intake between normal weight and overweight and obese (BMI) participants (Ortega et al., 2007).

Data on the trends in EI in children over time are similarly unclear. Results from the 1970-1972 Nutrition Canada Survey (National Health and Welfare, 1977) and the 2004 Canadian Community Health Survey (Statistics Canada, 2004) show that caloric intake decreased between the two survey cycles for males 12-64 years old and remained the same for females (Garriguet, 2004). While comparison of self-report 24 hour recall data in the U.S. from national surveys in 1977-1978 and 1996 found that total EI of children and adolescents increased by an average of 118 calories per day (Nielsen, Siega-Riz, & Popkin, 2002). In contrast, analysis of other national

U.S. survey data from 1970 and 1994, and an additional study that examined 10 year olds in 1973 and 1994 both found that total EI in youth was stable between measurement occasions (Nicklas, Elkasabany, Srinivasan, & Berenson, 2001; Troiano, Briefel, Carroll, & Bialostosky, 2000). Considering that participants in the more recent surveys had greater BMIs than participants in the earlier surveys, EI is clearly not the only factor contributing to obesity and the energy expenditure side of the equation is also important.

1.2.3.2. Physical activity

It is concerning that most Canadian children and adolescents are not meeting current guidelines for physical activity (Colley et al., 2011). Physical activity makes up the only discretionary and modifiable part of energy expenditure (EE) and has a positive effect on basal metabolic rate or resting energy expenditure (Tremblay et al., 1985). Physically active individuals may also have a reduced risk for obesity due to greater appetite control and better sensitivity to overall EI compared with sedentary individuals (Martins, Truby, & Morgan, 2007).

As with diet, the literature surrounding the association between physical activity and weight or adiposity is inconsistent. This is clearly illustrated in a review of longitudinal studies of physical activity and weight and adiposity in children and adolescents (Must & Tybor, 2005). Must & Tybor assessed 17 studies on 16 cohorts and reported that six studies did not find a significant relationship between physical activity and relative weight or adiposity. Two studies reported significant negative associations between physical activity and weight or adiposity in girls only. Seven studies found a significant negative relationship between physical activity and weight or adiposity. One study found a significant positive relationship between physical activity and adiposity and another found a positive association in overweight children between physical activity and BMI, fat mass, and fat-free mass but not BF%. The review found inconsistent

associations between physical activity and weight or adiposity but also drew attention to the inconsistencies in the way PA, weight, and adiposity variables were measured. Nearly half of the studies measured physical activity by self-report, one used parental report, two studies used accelerometry, and one study used heart rate telemetry and direct observation. Also, most studies assessed weight status by BMI with some using subscapular skinfold thickness, triceps skinfolds, sum of skinfolds, BIA, waist circumference, and DXA. Many studies used some combination of more than one of these measurements. Variability in these measurement tools makes it difficult to compare results across studies and develop a consensus from the literature.

Similarly, a recent systematic review of physical activity and health outcomes in children and youth identified 72 studies that focused on adiposity and extracted 78 favourable results (negative association between physical activity and adiposity measures), 71 null results and 9 unfavourable results (positive association between physical activity and adiposity measures). The authors included all intensities of physical activity as long as physical activity was objectively measured. Adiposity was assessed using BMI, sum of skinfold thickness, and bioelectrical impedance (Poitras et al., 2016).

Improved understanding of the correlates and determinants of physical activity is imperative for the study of obesity. A review of reviews identified 11 determinants and 39 correlates of physical activity in children, and 7 determinants and 51 correlates in adolescents (Bauman et al., 2012)³. In children, male gender, previous physical activity and self-efficacy were consistent positive determinants of physical activity, and gender, enjoyment of physical activity, intention towards physical activity, time outdoors, previous physical activity, healthy diet, family support, parental marital status, and self-efficacy towards physical activity were

³ Determinants are causal factors whose variation is followed systematically by variations in the outcome. Correlates are factors that demonstrate reproducible associations or predictive relationships (Bhopal, 2004).

consistent positive determinants. Barriers to physical activity were the only inverse correlate for children. In adolescents, consistent determinants included self-efficacy, perceived ability to be physically active, previous physical activity, support for physical activity, and Caucasian ethnicity. Consistent positive correlates for adolescents included male gender, SES, parental education, parental marital status, perceived competence, self-efficacy, body image, attitude, enjoyment of physical activity, family support, intention towards physical activity, self-motivation, perceived benefits, physical education class or school sports team, organized competitive sports, community sports, alcohol use, parental physical activity, sibling physical activity, direct parental help, support from friends or significant others, and parental attitudes. Correlates with consistent negative relationships for adolescents included smoking, lack of time, and barriers to physical activity (Bauman et al., 2012).

These findings speak to the complex relationship between physical activity behaviours and obesity, as high prevalence of obesity can be a contributing factor to and a consequence of low total physical activity (Bauman et al., 2012). A longitudinal study of over 200 British elementary school aged children measured annually between ages 7 and 10 years found that BF% (by DXA) at age 7 predicted a decrease of 4 minutes per day in MVPA (by accelerometry) over time. In addition, higher physical activity levels at age 7 did not predict a decrease in BF% over time (Metcalf et al., 2011). Low levels of physical activity are often accompanied by high levels of time spent in sedentary activities (Epstein, Paluch, Consalvi, Riordan, & Scholl, 2002; Robinson, 1998), which poses an independent risk for obesity and adverse health outcomes (Tremblay et al., 2011)

1.2.3.3. Sedentary behaviour

Canadian children and youth are accumulating unhealthy levels of sedentary time; boys

spend an average of 8.5 hours/day and girls spend an average of 8.7 hours/day in sedentary activities (Colley et al., 2013). The alarmingly high prevalence of sedentary behaviour in Canadian children and youth is worrisome considering the adverse health outcomes associated with sedentary behaviour (Chinapaw, Proper, Brug, Van Mechelen, & Singh, 2011). A systematic review of 232 studies on sedentary behaviour and health outcomes in children and youth aged 5-17 years included 14 Canadian studies. Body composition was assessed in 170/232 of those studies (Tremblay et al., 2011). Seven of the eight randomized controlled trials showed that decreases in sedentary time resulted in decreases in body weight. Of the intervention studies, most reported decreases in body weight or weight status with decreased sedentary time, although three studies decreased sedentary time and found no change in weight status. Nineteen longitudinal studies found that individuals that watched greater amounts of television at baseline had a greater increase in weight or adiposity over time; however, nine longitudinal studies found no relationship between sedentary behaviours and weight or adiposity. Within the 119 cross-sectional studies reviewed, 94 reported that increased sedentary behaviour was associated with increased weight or adiposity; however, 25 found no relationship between sedentary behaviours and weight or adiposity (Tremblay et al., 2011). These findings were largely replicated in a more recent systematic review of sedentary time and health indicators in children and youth including body composition (Carson et al., 2016). Carson and colleagues identified 162 studies that examined body composition as an outcome, and overall, increased frequency or duration of screen time was associated with unfavourable body composition as measured primarily by BMI or waist circumference. Accelerometry-derived sedentary time had mostly null associations and self-reported reading or doing homework had inconsistent associations with body composition outcomes.

Although sedentary behaviours don't affect the EE side of the energy balance equation (Pearson, Braithwaite, Biddle, van Sluijs, & Atkin, 2014) they may negatively affect coupling of EE and EI (Mayer, Roy, & Mitra, 1956) and may increase EI; in school-aged children each hour spent watching television was associated with a 167 calorie increase in EI (Wiecha et al., 2006). It is important to consider that the stronger associations reported between sedentary behaviour and weight than between physical activity and weight may reflect greater measurement accuracy of children's sedentary behaviour. In young children, sedentary behaviours occur over longer periods and are easier to assess than physical activity, which often occurs in small bursts throughout the day (Rennie, Johnson, & Jebb, 2005; Wareham & Rennie, 1998).

1.3 Rationale, objectives, and hypotheses

1.3.1. Rationale

Due to the high prevalence of Canadian children with overweight and obesity (Roberts, Shields, De Groh, Aziz, & Gilbert, 2012), the tracking of obesity through childhood, adolescence, and adulthood (Whitaker et al., 1997), and the associated adverse health outcomes (Cook et al., 2003; Weiss et al., 2004), improved understanding of obesity development to better inform prevention, intervention, and treatment efforts is imperative. There is a complex relationship between overweight or obesity and age, maturity, sex, ethnicity, physical activity, sedentary behaviour, and dietary habits that warrants further investigation (Ang et al., 2013; Saunders, 2011). Mapping the development of BF% accrual and BF% velocity trajectories as children and youth age is a fundamental building block currently missing in the study of obesity in Canadian children and youth. A deeper understanding of the development of body fat provides

the context to examine how we measure and define obesity and how these definitions affect its measurement in different groups. Bringing the work full circle, from the study of body fat development and examination of how we define obesity, we must then assess potential determinants of body fat development in children and youth as they mature. Due to the paucity of Canadian longitudinal studies and of longitudinal studies that specifically incorporate objective measures of body fat and physical activity, the body of research in my dissertation serves to fill a gap where proxy measures (BMI), subjective recalls (self-report), and correlational (cross-sectional) study designs fall short.

The purpose of my dissertation is therefore threefold: a) to develop BF% accrual distance and velocity curves in Canadian children and adolescents across sex and ethnic groups, b) to examine the association between BF% and BMI in different ethnicity-sex groups, and c) to investigate the relationship between demographic, physical activity, and diet variables and BF% over time. I describe the rationale, research questions, objectives, and hypotheses for the three studies that comprise my dissertation, below.

1.3.1.2. Body fat accrual trajectories for Asian and Caucasian-Canadian children and youth: A longitudinal DXA-based study

Rationale

Understanding the development of specific elements of body composition (i.e., total fat mass, regional fat mass, and BF%) over time is necessary to identify body composition abnormalities in children arising from a wide variety of individual characteristics, social determinants, medical conditions and chronic diseases (Bishop et al., 2008). Nationally representative body composition reference values exist for some countries and subgroups (Fan et

al., 2014; Kelly, Wilson, & Heymsfield, 2009; Sala, Webber, Morrison, Beaumont, & Barr, 2007). Body composition percentile curves are limited for Canadian children and adolescents and to date, no study has used objective measures of BF% or generalized additive models for location scale and shape (GAMLSS) methods (described in greater detail below) which are currently considered the gold standard method to model growth curves (R. A. Rigby & D. M. Stasinopoulos, 2005). GAMLSS models are an extension of the Lambda-Mu-Sigma (LMS) method with an additional parameter to adjust for kurtosis. The LMS method was historically popular for this kind of investigation because it is capable of handling skewness in the underlying reference data and the resulting curves contain the information to generate any centile curve (Cole, 1990; Fan et al., 2014; Kelly et al., 2009; Pan & Cole, 2004). GAMLSS is a more sophisticated method that represents more recent advances in analysis.

There currently exist two published Canadian reference datasets for body composition in children and adolescents. The first includes normative DXA-derived FM and FFM values based on data obtained from 179 white children and adolescents (91 girls and 88 boys) aged 3 to 18 years from Ontario (Sala et al., 2007). The second includes DXA-derived whole body and regional FM and FFM obtained from 234 Caucasian children and adolescents (124 girls and 110 boys) aged 8-16 years from the University of Saskatchewan Pediatric Bone Mineral Accrual Study (Faulkner et al., 1993). My analysis expands upon the foundation laid by these studies by including a larger, more diverse sample, that is more representative of BC and the metro-Vancouver area, specifically, and using BF% as the primary outcome.

Objective

1) To develop sex- and ethnic-specific BF% percentile distance and velocity curves for Asian and European (Reference) children at the 3rd, 10th, 25th, 50th, 75th, 90th and 97th centiles using the GAMLSS method.

1.3.1.2.2. Classification of obesity varies between BMI and direct measures of body fat in boys and girls of Asian and European ancestry

Rationale

Although BMI is the most common measure of adiposity used in obesity research it is a proxy measure of obesity and does not discriminate between fat mass and fat free mass. Further, BMI does not estimate BF% equally for various ethnic and sex groups (Daniels et al., 1997a). For example, Asian children living in the U.S. have lower BMIs but greater BF% compared with Caucasians (Freedman et al., 2008) and adults of South Asian and Chinese ancestry can develop type 2 diabetes and chronic heart disease at a lower BMI value and an earlier age than those of European ancestry (Chiu et al., 2011; Ekoé, Rewers, Williams, & Zimmet, 2008; Misra & Khurana, 2011). Because of these complex relationships between BMI and BF%, East and Southeast Asian children aged 2 to 17 years that typically have the lowest prevalence of overweight (12%) and obesity (6%) by BMI in Canada (Shields, 2006) may still be at risk as adults.

Sex differences in obesity classification between objective measures and BMI exist in childhood because as children mature a higher proportion of total body mass is comprised of FFM in boys and FM in girls. These differences are not reflected in BMI curves, which show similar patterns for boys and girls in adolescence (McCarthy et al., 2006) and result in an

increased sex difference in the relationship between BMI and BF% as children age (Taylor et al., 2010).

Due to the popularity of BMI as a proxy measure of obesity, assessment of the relationship between BMI and BF% across age, sex, and the two largest ethnic groups in BC (Asian and North American/European ancestry) (Statistics Canada, 2009) has the potential to improve detection of obesity and thus reduce the risk of future chronic disease. In this analysis, I investigate the ability of BMI to correctly classify children and adolescents based on BF%-based definitions of obesity using receiver operating characteristic (ROC) curves. The areas under each ROC curve (AUC) and their 95% confidence intervals can be estimated to compare the relative ability of BMI to estimate a high BF% (Rahman & Berenson, 2010; Taylor, Falorni, Jones, & Goulding, 2002; Taylor, Jones, Williams, & Goulding, 2002).

Objectives

- 1) Examine how BMI classifications using WHO cut-offs categorize children and youth aged 9 to 18 years compared with objective measures of BF% by DXA.
- 2) Investigate how age, sex, and ethnicity (Asian vs Caucasian) influence classification of obesity by BMI and BF%.

Hypotheses

- 1) BMI will agree with BF% better in Caucasian than in Asian participants.
- 2) BMI will agree with BF% better in girls than in boys.

1.3.1.2.3. Is adiposity predicted by physical activity, sedentary time, or caloric intake as boys and girls mature?: A 4-year mixed-longitudinal DXA-based study

Rationale

Overweight and obesity develop over time, and the most appropriate approach to capture this development is a longitudinal study where it is possible to discern the sequence of events as well as within- and between-person differences (Pettigrew, 1990). Most longitudinal studies of obesity in Canadian children and adolescents are based on national survey and self-report data (Carter, Dubois, Tremblay, Taljaard, & Jones, 2012; Oliver & Hayes, 2008; Tremblay & Willms, 2000; Tremblay & Willms, 2003) and none of have used DXA-derived body composition and objectively-measured physical activity. In addition, to my knowledge no studies to date have adjusted for maturation which contributes to sex differences in the development of BF%.

Through this analysis I not only address the lack of objective measures in longitudinal studies but also further the body of research by controlling for maturity in individuals. Using 4 years of longitudinal measurements I will model BF% and select determinants in 312 boys and girls using multilevel models with years from APHV (MO) as the time variable. Time-varying predictor variables include MVPA and sedentary time (by accelerometry) and estimated caloric intake. Time invariant predictor variables include sex and ethnicity (Asian, Caucasian, other).

Objective

- 1) To evaluate patterns in the associations between MVPA, sedentary time, dietary calories and BF% as boys and girls mature.

Hypotheses

- 1) MVPA will negatively predict development of BF% in boys and girls.
- 2) Sedentary time and caloric intake will positively predict BF% in boys and girls.

Chapter 2 : Methods

In this chapter I describe the study design, relevant measurements from HBSIII, and the statistical methods I used in Chapters 3-6. I was not involved in collecting the HBSIII data; however, I developed the research questions and designed and conducted the analyses in this dissertation. The University of Victoria Research Ethics Office approved my studies (#16-044, Appendix 1).

2.1. Study design and sample

Participants in this study were part of the University of British Columbia's HBSIII mixed longitudinal study, which includes data gathered from three school-based studies: Healthy Bones Study (HBS) and Bounce at the Bell, Action Schools!BC, and a new 2009 cohort (Figure 2.1 shows measurement timeline and cohort introduction). I provide a brief overview of each cohort in Section 2.1.1. Participants in HBSIII now comprise the UBC PBPA database, which includes data for girls (n=556) and boys (n=515) aged 8 to 12 years at baseline and categorized as Asian (n = 533), Caucasian (n = 412), or "Other" (n = 126). In this dissertation, I utilize data obtained between September 1999 and June 2012.

2.1.1. Healthy Bones and Bounce at the Bell

HBS was a cluster randomized controlled school-based intervention that employed DXA to investigate the effects of a 20-month exercise intervention on bone mass accrual. Participants (n=383) were recruited from grade 4, 5 and 6 classes from 14 elementary schools in Vancouver

and Richmond, BC in the fall of 1999 (MacKelvie, McKay, Khan, & Crocker, 2001; MacKelvie, McKay, Petit, Moran, & Khan, 2002; MacKelvie, Petit, Khan, Beck, & McKay, 2004). The HBS intervention consisted of 10-12 minutes of high-impact, weight-bearing exercise performed twice per week during physical education class and once per week in the classroom or outdoors. The intervention took place over 2 academic years, resulting in 2, 7-month intervention periods. Intervention and control schools participated in physical education mandated by the school board (40 minutes of physical education twice per week). Participants from intervention and control schools were invited to attend annual assessments in the spring of each year until 2011.

Bounce at the Bell was a companion study to HBS and investigated the effect of frequent bouts of jumping exercises on change in bone mass across 8 months. Participants (n=51) were recruited in the fall of 2000 from grade 4 and 5 classes in 3 elementary schools in Richmond, BC (McKay et al., 2005). The intervention involved 10 counter-movement jumps 3 times per day (morning, noon, and end of day bell; ~3 minutes per day of jumping) as well as physical education class twice per week. Participants were invited to attend annual assessments each spring until 2011.

2.1.2. Action Schools! BC

The Action Schools! BC (AS!BC) study cohort (n=515) was recruited in 2003 from grade 4 and 5 classes in 10 schools in Vancouver and Richmond, BC (Macdonald, Kontulainen, Khan, & McKay, 2007). AS!BC was a 16-month cluster randomized controlled school-based intervention that investigated the effect of a novel active school model on children's bone mass and strength. Based on principles of health promotion, the flexible AS!BC model helps schools develop individualized action plans to promote evidence-based, best-practice healthy living

activities (Naylor, Macdonald, Reed, & McKay, 2006). Participating schools were oriented to the program in the spring of 2003 before summer holidays, then when school returned in the fall of 2003 the intervention schools completed an 8-month active intervention. Participants were invited to attend annual assessments each spring until 2011. The AS!BC, HBS, and Bounce at the Bell cohorts were combined in 2006 because the measurement protocols were nearly identical. Importantly, none of the intervention studies (HBSII, Bounce at the Bell or AS! BC) resulted in significant differences in BF% or BMI between the intervention and control groups (McKay et al., 2014; McKay et al., 2005).

2.1.3. New cohort

In the fall of 2009, a third cohort was recruited (n=120) from grade 4 and 5 classes in 5 schools in Vancouver and Richmond, BC. This newest cohort was recruited to study bone microstructural changes from pre-puberty through young adulthood using more advanced imaging technology (high-resolution peripheral quantitative computed tomography, HR-pQCT) that had recently become available. This cohort was followed annually until 2012.

In my analyses, I include relevant data from all cohorts. Written informed consent from the parents or legal guardians, written assent from participants younger than 18 years of age and informed consent from participants 18 years of age and older was obtained. The University of British Columbia's Clinical Research Ethics Board approved all of the studies (H15-01194, H07-02013, H2-70537).

2.1.4. Recruitment

The HBS and AS!BC studies employed similar recruitment methods. Briefly, the recruitment team made presentations to school principals at district meetings and principals volunteered their schools to participate. At the volunteer schools, the recruitment team presented to grade 4, 5, and 6 teachers and also gave information letters and consent forms to teachers to send home with students. Consent and assent were obtained for the follow-up studies for HBS participants in 2001, 2003, 2006 and 2009 and for AS!BC participants in 2004, 2006, 2007 and 2009. The new cohort was recruited similarly; information letters and consent forms (Appendix A) were distributed in the classroom and consent and assent was obtained in 2009.

Concerning retention, the study team used several incentives over the 12-year study period, including distributing items at assessments (i.e., snacks, stickers, pencils, socks, Frisbees, \$20). Detailed individual and group (data de-identified, collapsed and reported by age and sex) results were mailed to each participant (Appendix B) leading up to the next years' data collection. Mail-outs included a note reminding them of the upcoming data collection and a picture of their whole-body skeleton from DXA.

2.1.5 Data collection overview

The research coordinator contacted the teachers of HBSIII participants that were attending elementary schools, and arranged for participants from each class to be picked up at the school door to travel to the lab in groups of 5 (plus a research assistant as chaperone). The driver and research assistant accompanied participants to the measurement site from the school. Participants that were attending secondary schools were contacted by the research coordinator via telephone. When possible, group measurement sessions were arranged (up to 6 participants/session) for students attending the same secondary school (participants attended 41

different secondary schools across the study period). Participants were transported to the Bone Health Research Lab at Vancouver General Hospital (VGH) (and in 2012 to the Centre for Hip Health and Mobility at VGH) by minivan. Participants who already graduated secondary school were contacted individually to schedule assessment by the research coordinator. Participants rotated through 6 stations at the lab where they were assessed on: anthropometry (5 min), questionnaires (30 min), jumping mechanography (15 min), DXA (20 min), HR-pQCT (20 min) and pQCT (10 min). Prior to data collection all research team members attended a full-day training session conducted by the research coordinator to learn measurement protocols. All research team members were trained to correctly administer questionnaires and conduct anthropometry. To maintain quality assurance, team members practiced measurements during the training session and were trained on the ethics of data collection. Trained technicians/measurers conducted imaging procedures.

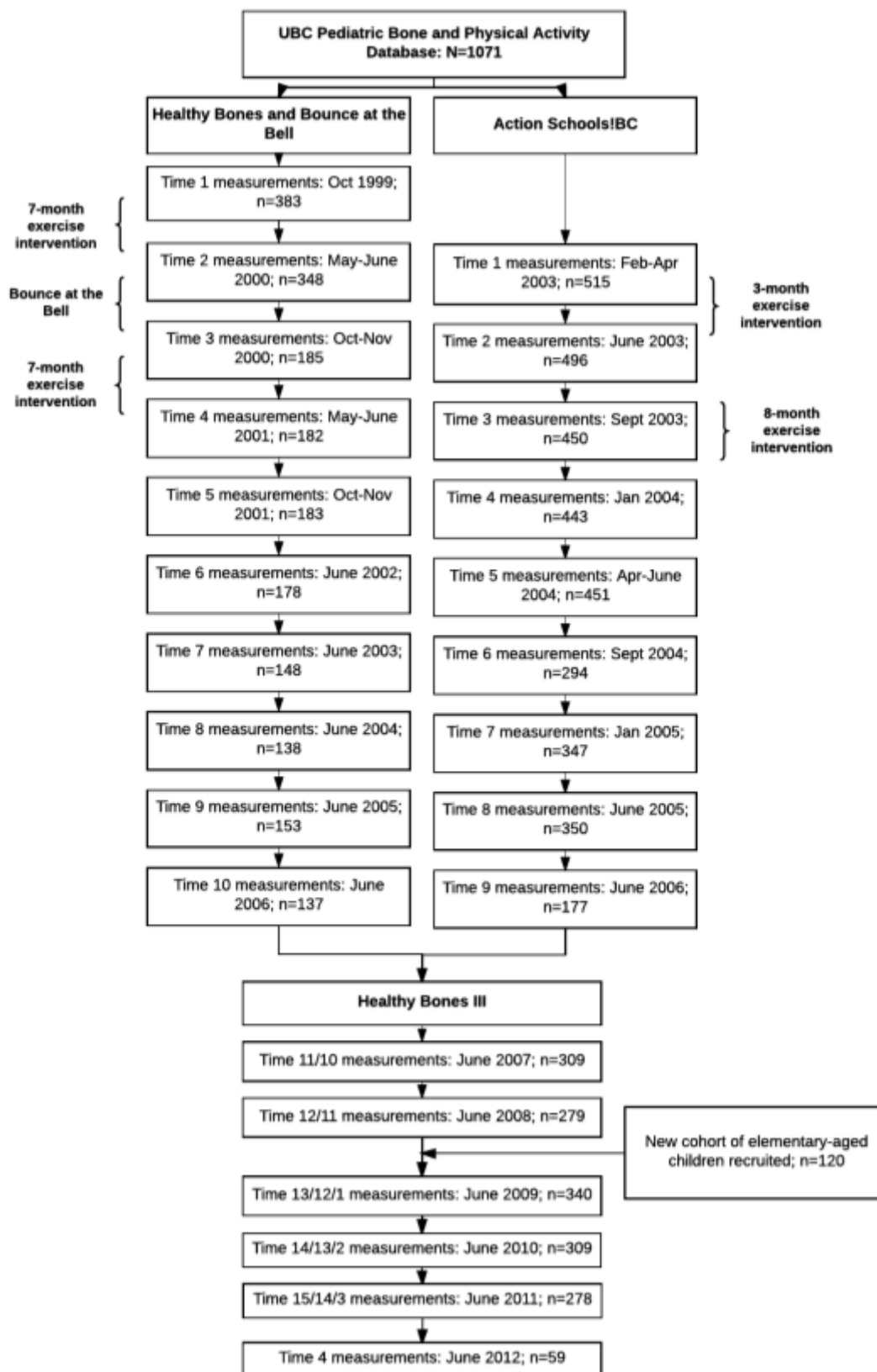


Figure 2.1. Overview of the Healthy Bones III Study.

2.2 Anthropometry

Anthropometry included height (cm), sitting height (cm), and body weight (kg). Height and sitting height were measured twice to the nearest millimetre using a customized, wall-mounted stadiometer from 1999 to 2002 and using a Seca wall-mounted stadiometer (model 242, Hanover, MD, USA) from 2003 to 2012 and stretch-stature techniques. Height was assessed with the participant's head positioned in the Frankfort plane, heels flat on the floor, shoes off, and gentle traction applied to the participant's mastoid process (MacDougall, Wenger, & Green, 1991). Body weight was measured twice to the nearest 0.1 kg using an electronic scale (Seca, Hanover, Maryland, USA). Participants removed heavy clothes and shoes before being weighed. If height or body weight measures differed by more than 0.4 cm or 0.2 kg, respectively, a third measure was taken. The average of the two closest values or the median of three equidistant values was used for analysis (MacKelvie et al., 2001). In the laboratory, reproducibility (CV%) was < 0.3% for all anthropometry measures.

Height and body weight were used to calculate BMI at every visit from 1999-2011 (HBS), 2003-2011 (AS! BC pilot), and 2009-2012 (2009 cohort) resulting in 6721 observations from 1071 participants. BMI was calculated as body weight divided by height squared ($BMI = \frac{\text{body weight (kg)}}{\text{height (m)}^2}$).

2.3 DXA

Total body fat mass (FM, kg) and bone mineral-free lean mass (LM, kg) were obtained from DXA total body scans (QDR 4500W; Hologic, Waltham, MA, USA) and from these scans

BF% was calculated as $F\% = \frac{\text{fat mass (kg)}}{\text{body weight (kg)}}$.

Trained technicians scanned all participants using standard acquisition procedures (Hologic Inc., 2002) (Figure 2.2). Participants were asked to lay down on the scanning table with their arms by their sides, palms on the table with a space between the hands and the thighs. The technician rotated the participant's feet so the toes were touching and heels were apart. The technician wrapped a Velcro strap around the participant's feet to ensure they remained stationary for the duration of the 6-minute scan, then ensured proper alignment of each participant within the scan limit border lines. As technicians varied between studies, all were trained and evaluated against an established criterion standard (unpublished data).

A spine phantom and anthropomorphic phantom were scanned daily and weekly to assess quality of the DXA system. In the lab, for adults, the %CV with repositioning was 1.9% for fat mass and 0.33% for lean mass. Precision of total body fat and lean mass measures was not determined in children and adolescents in an effort to limit unnecessary exposure to ionizing radiation (Hologic Inc., 2002; Hoy, 2010). DXA scans were performed at every lab visit from 1999-2011 (HBS), 2003-2011 (AS! BC pilot), 2009-2012 (2009 cohort) resulting in 5296 observations from 1071 participants.

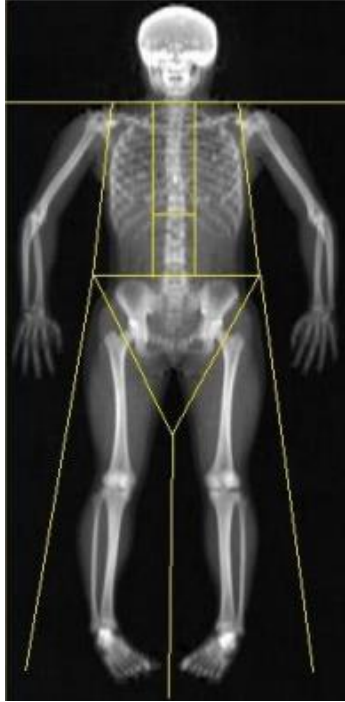


Figure 2.2. Sample image of an analyzed total body DXA scan of a 12-year old girl.

2.4 Measurement of Selected Factors Affecting Overweight and Obesity in Children in the HBSIII

2.4.1. Health history questionnaire

At baseline, parents or guardians completed a health history questionnaire for their child (HBS: 1999, Bounce at the Bell: 2000, AS!BC: 2003, new cohort: 2009) and participants completed a shorter version at subsequent annual visits (Appendix 2). Age, sex, and ethnicity were gathered from the health history questionnaire.

2.4.1.1. Sex and Chronological age

Sex was collected at baseline for each cohort from the Health History Questionnaire and recorded as a binary variable (boy / girl). Also from the Health History Questionnaire, chronological age (years) was calculated as (measurement date – birth date)/365.25.

2.4.1.2. Biological age

APHV, (years) was calculated as an estimate of biological maturity. APHV was estimated using Baxter-Jones et al.'s, (2011) method whereby peak height velocity is calculated by fitting an interpolating cubic spline to each participant's height velocity data. Height velocities are calculated by dividing the difference between the annual distance measurements by the age increment for each participant. A cubic spline fit is then applied to the whole-year velocity values for each participant. The spline is interpolating polynomials, which uses information from neighbouring data points to determine a degree of global smoothness. The cubic spline maintains the integrity of the data without altering the underlying growth characteristics (Baxter-Jones et al., 2011). APHV was identified for 266 of 1071 participants (113 boys, 153 girls). Boys required a height measurement before age 11.5 years and after age 16.5 years with at least five measurements during this period. Girls needed a height measure before 11.0 years and after 13.0 years, with at least four measurements during this period (Hauspie et al., 1980; Largo et al., 1978; Mirwald & Bailey, 1986; Roy et al., 1972; Roy, 1971; Tanner et al., 1976; Taranger & Hägg, 1980)).

For individuals without estimated APHV due to missing or mistimed measurements, I estimated MO with a recalibrated version of the Mirwald prediction equation (Mirwald et al., 2002; Moore et al., 2015). The simplified Mirwald equation uses age and height measurements for girls and age and sitting height measurements for boys. In the calibration sample, predicted APHV explained approximately 90% of the variance in actual APHV (Moore et al., 2015). The published equations were developed from data from white participants only; however, the

HBSIII research group also developed equations for Asian boys and girls (unpublished data). As such, I used the published equations to predict APHV in Reference and Other participants and ethnic-specific equations for Asian participants. The APHV prediction equations are as follows (age in years and height and sitting height in cm):

1. Reference/Other boys: $(-8.128741 + (0.0070346 \times \text{age} \times \text{sitting height}))$
2. Asian boys: $(-8.128741 + 0.7482624) + (0.0070346 \times \text{age} \times \text{sitting height})$
3. Reference/Other girls: $-7.709133 + (0.0042232 \times \text{age} \times \text{height})$
4. Asian girls: $(-7.709133 + 0.7303442) + (0.0042232 \times \text{age} \times \text{height})$

I used anthropometry data from the measurement occasion closest to 11.6 years for girls and 13.5 years for boys (reported average APHV) to estimate MO (Gabel, 2017; Moore et al., 2015).

I then calculated MO in years as chronological age-APHV resulting in a continuous measure of biological age where MO=0 at APHV.

2.4.1.3. Ethnicity

Ethnicity was gathered from the health history questionnaire. Parents or guardians were asked to indicate their own birthplace and the birthplace of their parents as well as self-report their own and their child's ethnicity. Participants were classified as "Asian" if both parents or three of four grandparents were born in Hong Kong, China, Japan, Taiwan, Philippines, Korea or India, of European Ancestry, referred to as the "Reference group" if both parents or three of four grandparents were born in North America or Europe and "Other" if ethnicity was: African, Arab, Caribbean, Oceania, Aboriginal, Latin, Central, South American and mixed ethnicity.

Although I recognize the limitations of the social construct of ethnicity and the vast heterogeneity within commonly used subgroups (Kaplan & Bennett, 2003) I believe ethnicity is

important to examine as it is associated with disparities in outcomes such as obesity (Flores et al., 2001; Krieger, Williams, & Zierler, 1999; Laveist, 1996), which have substantive implications for public health action.

2.4.1.4. Caloric intake

From 2003-2010 diet was estimated using a validated 24-Hour food recall questionnaire (Lytle, Murray, Perry, & Eldridge, 1998; Mullenbach, Kushi, Jacobson, Prineas, & Sinaiko, 1992). Trained researchers administered the 24-Hour Food Recall to participants; the interviews lasted 10-20 minutes. The data were then entered into Food Processor SQL for Kids (Food Processor SQL, 2008). Of interest from the 24-hour recall are values for total caloric intake (kcal).

2.4.1.5. Physical activity and sedentary time

Starting in 2008, accelerometers (ActiGraph GT1M, Pensacola, Florida, USA) were used to objectively measure physical activity and sedentary behaviour with a 15-sec epoch. The GT1M is a small, uniaxial accelerometer that detects vertical accelerations of 0.05-2.00 g. The signal is band filtered to the frequency range of 0.25-2.50 Hz to exclude non-human movement. Accelerometers were attached to an elastic belt and worn at the hip with the accelerometer positioned at the iliac crest. Participants were asked to wear the accelerometer during waking hours for seven consecutive days and to remove only for sleeping, bathing and swimming. Participants were given a log sheet to record accelerometer on and off times each day.

All accelerometry data were analyzed using KineSoft software (v3.3.75; KineSoft, Loughborough, UK). Accelerometer files were screened and participants were included in the dataset if they had at least 10 hours of data on three or more days (Mattocks et al., 2008). The outcome values were derived using age specific accelerometer cut-points that are based on age-related differences in resting metabolism and energy use. The Evenson cut-points were used to classify the raw accelerometer data into sedentary for < 100 cpm and MVPA for ≥ 2296 cpm (Troost, Loprinzi, Moore, & Pfeiffer, 2011). Non-wear time was defined as periods of continuous zeros greater than 30 minutes as these were considered biologically implausible (Esliger, Copeland, Barnes, & Tremblay, 2005). I excluded these data from my analysis.

2.5. Statistical analysis

In this section, I provide an overview of the statistical analyses I performed in this dissertation. I conducted analyses using SPSS 23 (IBM Corp., 2013, 2015), MPlus v.8 (Muthén & Muthén, 2017), and R version 1.0.143 for Macintosh (RStudio Team, 2015). Variables were visually examined for cross-sectional analyses using histograms and scatterplots and with scatterplots of predictors against BF% and against MO for longitudinal analysis. I conducted diagnostics for the models and statistical procedures using best practices in the literature and I describe these in detail in Chapters 3-5.

Briefly, in Chapter 3, I used SPSS 23 (IBM Corp., 2013, 2015) to run descriptive analyses and R to develop generalized models for location, scale, and shape (GAMLSS) and plot BF% accrual and velocity by sex-and-ethnic-specific percentiles (Robert A Rigby & D Mikis Stasinopoulos, 2005). I used Microsoft Excel (Microsoft Corp., 2016) to graph the percentile curves. In Chapter 4, I investigated the relationship between BMI- and BF%-based definitions of

obesity across sex and ethnic groups. I used SPSS 23 to conduct descriptive analyses, run Cochrane-Orcutt multivariable regression models to control for auto-correlated data, develop receiver operating characteristic (ROC) curves, calculate sensitivity and specificity values, and derive Youden's index (IBM Corp., 2013, 2015). In Chapter 5, I used SPSS to conduct descriptive statistics and MPlus to generate multilevel models to investigate the relationship between BF% and MVPA, sedentary time, and daily caloric intake across maturity.

Chapter 3 : Body fat accrual trajectories for Asian and Caucasian-Canadian children and youth: A longitudinal DXA-based study

3.1. Abstract⁴

Growth reference data first emerged in the 19th century as means, SDs and centiles (distance data) and later via Tanner and Whitehouse as velocity (rate of change) data.

Given the current focus of science and society on obesity it seems imperative to accurately map body fat accrual in children and youth. Body fat accrual trajectories can be used to monitor trends in the proportion of total body mass comprised of fat and identify potential health risks. Therefore, 14 years of mixed-longitudinal data were used to develop sex- and ethnic-specific BF (%) centile distance and velocity curves by chronological age for boys and girls of Asian and European ancestry who lived in BC, Canada. Importantly, the longitudinal reference data fill an obvious gap, as similar data are currently nonexistent in the published literature.

4,572 observations from 944 participants aged age 9-19 years (y) (female=487; Asian=532) in the UBC Pediatric Bone and Physical Activity database were utilized. BF% was determined from whole body scans acquired using dual energy X-ray absorptiometry. Sex and ethnic-specific BF% percentile distance and velocity curves were created for Asian and

⁴ A version of this material is in preparation for publication: McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., Hofer, S.M., and McKay, H. Body fat accrual trajectories for Asian and Caucasian-Canadian children and youth: A longitudinal DXA-based study. (in preparation). I presented a version of this work at the Canadian Obesity Network: McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., and McKay, H. (2017). Body Fat Percentile Curves for Children and Youth of Asian and European Ancestry. Presented to the Canadian Obesity Summit. Banff, Alberta, Canada.

European (Reference) children at the 3rd, 10th, 25th, 50th, 75th, 90th and 97th centiles using the GAMLSS method in R.

Centile distance curves for Asian and Reference participants were of similar shape for girls but not boys. Differences in velocity centile curves between ethnicities were apparent for boys only.

In conclusion, while acknowledging several limitations, the BF% distance and velocity centile reference curves I developed for Asian and Caucasian children and youth living in British Columbia may be used to investigate geographic differences in fat mass and fat mass accrual across Canada. Distance and velocity curves can also be used to monitor fat mass accrual trends in British Columbian children and youth and to identify when an individual veers from an average body fat accrual trajectory. Given what has been termed the ‘obesity epidemic’ (WHO Multicentre Growth Reference Study Group, 2006) the dearth of objectively acquired, longitudinal fat mass data is surprising. Thus, the data in this study begin to fill this key gap in the published literature.

Keywords: body fat percent, obesity, ethnicity, youth, percentiles

3.2. Introduction

Overweight and obesity among children and youth is a global 21st century public health problem (World Health Organization, 2015). In the US, obesity has reached “epidemic proportions” as over thirty percent of children are either overweight or have obesity (Ogden, Carroll, & Flegal, 2008). The physical and psychological health consequences of having obesity are substantial (Dehghan, Akhtar-Danesh, & Merchant, 2005).

Given the substantive public health and economic implications of childhood obesity in Canada we must better understand and monitor this multi-faceted health problem, (Bancej et al., 2015; Nadeau et al., 2013). Further, it seems imperative to also recognize and act upon the associated adverse health effects suffered by children and adolescents with obesity (Freedman et al., 1999; Weiss et al., 2004). In Canada, 12 to 14% of children and adolescents aged 5-17 years are considered obese (Canadian Health Measures Survey data and World Health Organization (WHO) BMI cut-offs) (Roberts et al., 2012).

The trajectory of childhood obesity is largely unknown, as long-term prospective data have not been available to map how body fat (measured directly) is accrued. In Canada, reference curves for body composition were developed using cross-sectional anthropometry data including waist circumference (Katzmarzyk, 2004), skinfold thickness (Kuhle, Ashley-Martin, Maguire, & Hamilton, 2016), and BMI, waist circumference, waist-to-height ratio, and sum of 5 skinfolds (Kuhle, Maguire, Ata, & Hamilton, 2015). However, the myriad problems associated with using cross-sectional data to represent longitudinal change in growth parameters (Farrington, 1991), acquiring quality anthropometry (especially skinfolds) over time (Reilly, Wilson, & Durnin, 1995) and the application of various prediction equations to estimate body fat

(Rodriguez et al., 2005), are well known. For example, BMI does not discriminate between fat mass and fat-free mass (Prentice & Jebb, 2001).

More recently, data derived from DXA total body scans was validated against the 4-compartment criterion measure of BF% and found to provide accurate and reliable measures of total body fat mass in children and youth (Sopher et al., 2004). However, as height and weight are more feasible to obtain, BMI is still most commonly used to construct growth reference charts (Hill & Trowbridge, 1998). This poses a problem as the association between BMI and DXA-derived body fat varies with age, sex, and ethnicity (Shaw et al., 2007). To illustrate, Asian children and youth have low BMI but higher BF% compared with Caucasian children. As Asian children are at apparently greater risk of adverse health effects relative to their body fat it seems essential for BF% be accurately represented (Freedman et al., 2008).

BF% percentile curves exist for a variety of populations and sub-populations (Fan et al., 2014; Kim, Yun, Jang, & Oh, 2013; Laurson et al., 2011; McCarthy et al., 2006; Mueller et al., 2004; Pramanik, Chowdhury, & Das; Sung et al., 2009). However, there is a need to examine the development of BF% through distance curves (by percentile) for Canadian children and youth using direct measures of BF% (from DXA). In addition, velocity curves allow for the identification of normal patterns, as well as anomalies in those typical patterns (rate) in terms of tissue accrual. As there is a scarcity of longitudinal data acquired from Canadian children and youth, BF (%) velocity curves have not been constructed.

Therefore, using data from a 14-year mixed longitudinal study I aimed to address these knowledge gaps. Specifically, I aimed to develop sex- and ethnic-specific BF (%) centile distance and velocity curves by chronological age for boys and girls of Asian or European ancestry who lived in British Columbia, Canada.

3.3. Methods

I provide a detailed description of study design and methods for data collection in Chapter 2 and a brief overview below.

3.3.1. Study population

The sample included 944 male (48%) and female (52%) participants aged 9-19 years who participated in University of British Columbia (UBC)'s Healthy Bones III study (HBSIII) (Figure 3.1). HBSIII is a mixed longitudinal study that includes four cohorts of children and adolescents from previous school-based studies (HBS, Bounce at the Bell, Action Schools! BC pilot, 2009 cohort). Participants were measured beginning in 1999, generating between 1 and 17 measurements per person with most (16%) contributing 3 measurements for a total of 4,572 observations (Table 3.1).

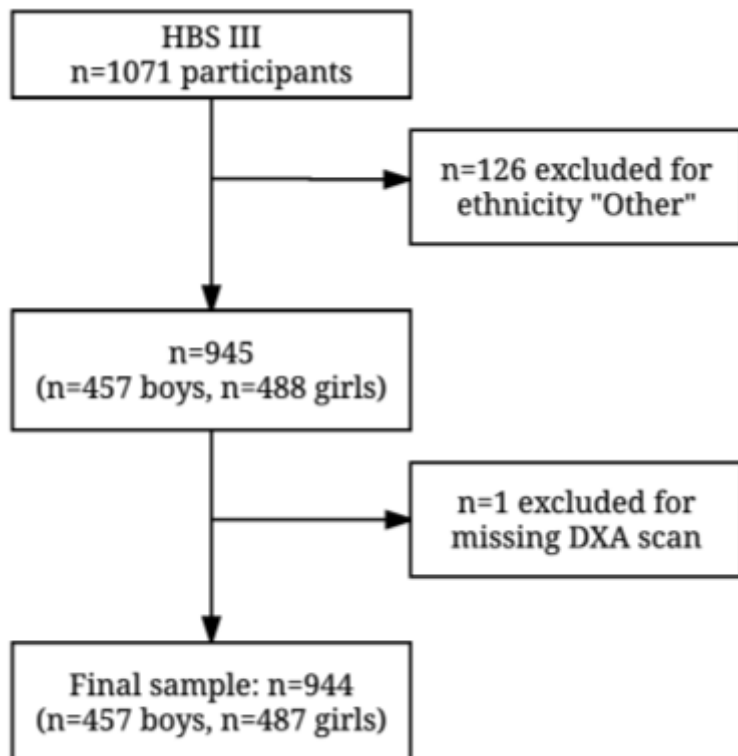


Figure 3.1. Participant inclusion diagram. HBSIII = Health Bones Study III; DXA = Dual energy x-ray absorptiometry.

3.3.2. Measures

3.3.2.1. Body fat percent

Using values obtained from total body DXA scans (QDR 4500W; Hologic, Waltham, MA, USA), BF% was calculated as $F\% = \frac{\text{fat mass (kg)}}{\text{body weight (kg)}} \cdot 100$.

3.3.2.2. Demographics

Sex, ethnicity, and age were determined using a questionnaire, completed by parents at baseline. Individuals were classified as Asian if both parents or three of four grandparents were born in Hong Kong, China, Japan, Taiwan, Philippines, Korea or India, and European, referred to as “reference” if both parents or three of four grandparents were born in North America or

Europe. Participants of mixed or other ethnicities (e.g. African, mixed-race, First Nations) were classified as “Other” and excluded due to inadequate sample size to generate distance and velocity curves. Sex was indicated as boy or girl and date of birth was used to calculate chronological age (years) as $((\text{measurement date} - \text{date of birth}) / 365.25)$.

3.3.3. Statistical analysis

I performed all analyses using RStudio version 0.99.896 for Macintosh (RStudio Team, 2015). I used Generalized Models for Location, Scale and Shape (GAMLSS) (Robert A Rigby & D Mikis Stasinopoulos, 2005) to model sex- and ethnic-specific BF% distance and velocity curves with percentiles. I plotted velocity curves using the Box-Cox Power Exponential (BCPE), and Box-Cox t (BCT) distributions. BCPE is a generalization of the LMS method (Cole, 1990) expanded for data with abnormal kurtosis and skewness and an exponential power distribution (Rigby & Stasinopoulos, 2004). BCT is also a generalization of the LMS method (Cole, 1990), but is expanded for data with skewness, leptokurtosis, and a t distribution (Rigby & Stasinopoulos, 2006). To avoid unusual behaviour of the spline functions near the end of the age range, participants aged 8-23 years were included in the models as this modification produces smoother curves (Kuhle et al., 2016). To adjust for positive and negative BF% velocity values that cannot be accepted in BCPE or BCT distributions, I added a constant value of 100 to BF% velocity values prior to modelling and removed the constant from predicted centile values displayed in Tables Table 3.2 -Table 3.13.

I developed the models based on published centile estimation procedures (Rigby & Stasinopoulos, 2014) similar to recently published anthropometric centile curves for children (Kuhle et al., 2016). First, I used the LMS function to select an appropriate power transformation

for age and fit a family of distributions ("BCCG", "BCPE", "BCT") to the response variables BF% and BF% velocity. Each parameter (μ (mean), σ (variance), v (skewness), and τ (kurtosis)) was fitted using the p-spline function, automatically selecting the smoothing parameters using internal maximum likelihood estimation. I then compared the distributions using generalised Akaike information criterion (GAIC) and selected the best fit. Next, I fitted the chosen distribution family (BCPE and BCT in all groups in this analysis) and age transformation as a GAMLSS model (Robert A Rigby & D Mikis Stasinopoulos, 2005). To check goodness of fit for each model component, I developed residual quantile plots (worm plots) (Buuren & Fredriks, 2001) for nine age groups. I then extracted parameter values from the GAMLSS model for BF% percentiles across ages 9-19 years and for BF% velocity percentiles for ages 10-19 years. Lastly, I used Microsoft Excel (Microsoft Corp., 2016) to plot smoothed percentile curves for the 3rd, 10th, 25th, 50th, 75th, 90th and 97th centiles and generate graphs to compare percentiles between ethnic groups (Figure 3.2 Figure 3.3).

3.4. Results

I provide characteristics of the sample in Table 3.1 for the 944 participants in the study who were aged 9-19 years, 52% were female (n=487) and 56% were of Asian ancestry (n=532). Participants were measured 1-17 times with 16.3% contributing 3 measurements; I included 4,572 total observations (50% male, 50% female; 50% Asian and 50% Reference) in this analysis.

I present the parameter values (μ , σ , v , τ) and BF% distance and velocity values that represent the 3rd, 10th, 25th, 50th, 75th, 90th, and 97th percentiles by age, sex and ethnicity in Tables 3.2 -Table 3.13. Model diagnostics and worm plots showed an adequate fit for all models.

3.4.1. Body fat accrual (from distance curves)

3.4.1.1. Boys

For Reference boys, values that represented each BF% distance centile increased until age 12 to 13 years, then decreased through age 19 years. The difference between centile-specific BF% values at age 9 and age 19 years ranged from -4.6% for boys at the 3rd centile to -8.4% for boys at the 75th centile.

For Asian boys, values that represented each BF% distance centile increased until age 12 to 13 years, then decreased through age 19 years. The trajectories of the 97th and 90th distance centiles exhibited a plateau around age 16 before declining again through age 19 years.

3.4.1.2. Girls

For Reference girls, BF% values at or below the 50th centile were largely consistent from age 9 through to age 13 years. Values at the 75th through 97th centiles decreased between ages 9 and 13 years, then increased through age 19 years. BF% values for girls at the 3rd through 50th centile increased from ages 9-19 years (a difference of 4.7% at the 10th centile and 2.3% at the 50th centile).

For Asian girls, BF% values at or below the 50th centile were largely consistent from ages 9-13 years while centiles above the 50th decreased during this time. BF% at all centiles increased from about age 14 to 16 years. Centiles at the 50th and above continued to increase through age 19 years whereas centiles below the 50th flattened by age 17 years. At the 75th centile, BF% values changed less than 0.5% between ages 9-19 years and at the 10th centile, values rose by 5.3% between age 9 and 19 years.

3.4.2. Body fat percent velocity

3.4.2.1. Boys

For Reference boys, BF% velocity values across all centiles declined from age 9 years, reached a minimum between ages 13-14 years and then increased until age 19 years. The 3rd and 10th centiles for boys remained negative at all ages; the 25th and 50th centile velocity values began positive then became negative between ages 11 and 13 years. At the 75th, 90th, and 97th centiles, velocity values were all positive between age 10 and 19 years.

For Asian boys, BF% velocity values across all centiles decreased from age 9 years, reached a minimum between ages 13-14 years and then increased until age 19 years. Near age 16, the rate of increase slowed for all centiles for 1-2 years, with the greatest plateaus appearing at the highest centiles. BF% velocity values at the 3rd centile remained negative at all ages while the 25th, 50th, and 75th centile velocity centiles displayed both positive and negative values. At the 90th and 97th centiles, velocity values were all positive between age 10 and 19 years.

3.4.2.2. Girls

Results for BF% velocity for Asian and Reference girls were nearly identical and as such I describe them together. Below the 50th centile, BF% velocity values were negative but increased from 10 to 15 years of age. BF% velocity values for girls at the 50th centile and above were positive and decreased from 10 to 15 years of age. For girls, all velocity centile curves remained relatively flat from age 16 to 19 years.

3.5. Discussion

I used a large mixed longitudinal dataset to address the absence of sex- and ethnicity-specific distance and velocity reference curves for body fat (%) for Canadian youth in the published literature. Specifically, I modelled BF% distance and velocity centile curves for an ethnically diverse sample of Canadian children and youth aged 9 to 19 years. I extend the current literature, with BF% from DXA total body scans gathered longitudinally across 10 years of adolescent growth separately for these Asian and Caucasian-Canadian children and youth. In future, these reference curves might be used to investigate differences in BF% in youth across different geographic regions in Canada or to monitor trends in BF% accrual among children and youth in British Columbia.

It should be noted that the ethnic diversity in our sample is unique; children and youth of Asian ancestry and those of European ancestry are equally represented. However, this diverse sample limits comparisons of these BF% centile curves with those of previous studies that included only one ethnic group (K. Kim et al., 2013; McCarthy et al., 2006; Sung et al., 2009) or a nationally representative sample of black, Hispanic and/or Asian children and reference groups (Laurson et al., 2011; Mueller et al., 2004; Weber, Moore, Leonard, & Zemel, 2013). Therefore, I discuss the findings by ethnic group, below.

3.5.2. Patterns of body fat accrual

BF% centile distance curves for boys and girls reflect fat mass accrual across designated time points during child and adolescent growth. At puberty, sex-specific changes occur whereby boys accrue muscle mass and lose fat mass and girls accrue relatively more fat mass, on average (Malina et al., 2004; Rogol et al., 2002). Specifically, in boys, BF% increases before puberty then declines from 17.8% to 11.2%, on average, as growth in height increases. In girls, BF% is

stable pre puberty then increases from 16.6% to 23.5%, on average, between the ages of 10 and 15, respectively (Cheek, 1968). The trajectory of obesity over time may also be different between sexes, as approximately 30% of adult obesity may begin in adolescence for females and approximately 10% of adult obesity may begin in adolescence for males (Braddon et al., 1986). In the HBSIII cohort, I observed these general trends whereby there was a steady increase in BF% and BF% accrual for girls after age 12 and a decrease for these parameters for boys at age 13-14. Comparing the children in this study specifically with the early growth work by Cheek (1968), I found that HBSIII boys follow the described trajectory of BF% at the 25th centile, which is not average as Cheek's work suggests. Similarly, HBSIII girls follow Cheek's described trajectory between the 10th and 25th centiles from 10 to 15 years old. This stark reduction between what Cheek found as average and I observed as much lower than the 50th centile is an artifact of the secular trend of increasing obesity prevalence.

Rate of change in body composition throughout childhood is a significant contributor to adult fat mass. Previous research found that rapid gain in BMI before the age of 2 years increased adult fat-free body mass without increased fat mass accumulation, but rapid gain in BMI at 7 and 11 years old resulted in significantly ($p < .001$) larger increases in adult fat mass (Barker, Osmond, Forsen, Kajantie, & Eriksson, 2005). Although this study used BMI as a proxy measure of adiposity, it provides impetus for our important investigation into the velocity of BF% as children and youth age.

3.5.2.1. Reference children

As no BF% centile reference curves currently exist for Canadian youth, I compared my results to BF% centiles developed for children from the U.S. (Fan et al., 2014) and the United Kingdom (U.K.) (McCarthy et al., 2006). Compared with my data, BF% reference values for

U.S. children were greater for girls and similar for boys at most ages across centiles. For example, at age 18 years, Reference girls in the HBSIII cohort had a BF% of 34.5% at the 90th centile whereas the U.S. girls had a value of 37.3% at age 17.5 years. At age 10, HBSIII Reference boys at the 50th centile had a BF% value of 21.6%, which was similar to the BF% value of 21.2% at the 50th centile at age 10.5 years in U.S. boys.

In contrast, girls from the U.K. had lower BF% values at all centiles from ages 9 through 18 years as compared with HBSIII girls. Boys from the U.K. who fell below the 50th centile had similar BF% values to Canadian boys at age 9 years; however, by age 18 years BF% values were lower for boys in this study. For boys above the 50th centile the opposite was true; BF% values for boys in this study were higher at age 9 and remained higher at age 18 years, compared with U.K. boys.

Comparing the U.S. and U.K. studies to my study is challenging due to variability in modelling approaches (LMS in U.S. and U.K. studies compared with GAMLSS in our study), and measures of BF% (BIA in the U.K., DXA scans in the U.S.) over different measurement intervals (2-years in the U.S., 1-year in the U.K.). Importantly, there were different BMI-based trends for obesity at the population level across countries when data were collected (approximately 17% in the U.S. (Ogden et al., 2008), 8%-14% in Canada (Roberts et al., 2012; Shields, 2006), about 6% in the U.K. (Stamatakis, Primatesta, Chinn, Rona, & Falaschetti, 2005)). Finally, sampling strategies also differed considerably in that the U.S. used a national representative sample for their analyses while U.K. researchers and HBSIII accessed convenience samples.

3.5.2.2. Asian children

Based on parent and grandparent birthplace the Asian participants' primary ancestry was from Hong Kong (28% of the sample), China (29% of the sample), Japan (1% of the sample), Taiwan (4% of the sample), Philippines (8% of the sample), Korea (2% of the sample) or India (10% of the sample). I acknowledge that this allocation limits the social construct of ethnicity and the heterogeneity within these subgroups (Kaplan & Bennett, 2003). Therefore, I examined how my findings compared with BF% centiles developed for Asian children aged 6-18 years living in Hong Kong (Sung et al., 2009) and aged 10-18 years living in Korea (K. Kim et al., 2013). I could find no centile reference curves for Asian children living anywhere in North America.

Given the tremendous environmental differences between these groups, the heterogeneity in BF% between Asian-Canadian, Hong Kong Chinese and Korean children is not surprising. Boys from Hong Kong had lower BF% values compared with HBSIII boys at age 10, but higher BF% at age 18 across all centiles. Girls in Hong Kong appeared to have lower BF% values at age 10 and 19 across all centiles compared with girls in this study. Differences in the shape of the curves between Asian-Canadian and Hong Kong Chinese children were most apparent at puberty where the Asian-Canadian sample displayed a distinct change as youth developed but the Hong Kong Chinese curves were much flatter and consistent with no real adjustment at puberty. This is of note given that 28% of the Asian-Canadian sample in HBSIII were of Hong Kong Chinese origin. Asian-Canadian and Korean girls had similar BF% values but Korean boys had greater BF% compared with Asian-Canadian boys at all ages and centiles.

Studies differed in modelling approaches (LMS compared with GAMLSS in our study), and as LMS curves do not permit modelling of kurtosis, predicted BF% values could be affected

(Borghetti et al., 2006). Also, use of different BF% measurement tools (BIA in the U.K., DXA scans in the U.S.) limits comparison between studies as BIA measurements can vary based on hydration, ethnic group, and obesity status (Goran, 1997; Meyer et al., 2011).

Further, studies differed in the centile values reported (5th, 10th, 25th, 50th, 75th, 85th, and 95th for the Hong Kong study, 15th, 25th, 50th, 75th, 85th, and 95th for the Korean study, and 3rd, 10th, 25th, 50th, 75th, 90th, and 97th for this study). Finally, both comparison studies provided BF% values in figures rather than tables. Thus, it was challenging to directly compare values across groups.

Together, these results shed light on the tremendous variability in how centile curves are developed and, potentially, in BF% between children and adolescents of different ethnicities and those from a similar ethnicity but different geographical regions. Thus, it seems prudent to use the same ethnic-specific reference curves over time to evaluate the status of body fat and body fat accrual in children and youth. There is a dearth of longitudinal demographic data from children and youth of Asian ancestry living in Western countries such as Canada. It seems important that future studies address this.

3.5.2.3. The utility of reference percentile curves

The idea of growth charts has been around since the late 18th century when Count De Montbeillard acquired height measures from his son every six months from birth to age 18 years, and used them to produce the first growth chart (Tanner, 1990). Growth reference data first emerged in the 19th century as means, SDs and centiles and later as height and weight velocities from Tanner and Whitehouse (Tanner, Whitehouse, & Takaishi, 1966). Since then, assessment of growth and development using reference data has become a part of standard health and clinical practice (Cole, 2012).

Based on centile-tracking (Tanner, 1963), centiles may facilitate detection of individual abnormalities in growth trajectories across a range of tissues. This includes BF% trajectories as they relate to healthy weight. Centile charts also provide a crude prediction of BF% values as maturity progresses, assuming constant lifestyle behaviours (Wells, 2014). However, clearly established thresholds for BF% that relate to adverse health outcomes have yet to be established for children and youth. BF% values ranging from 20-29% for boys and 30-34% for girls were associated with a variety of adverse health outcomes (Dwyer & Blizzard, 1996; Going et al., 2011; Mueller et al., 2004; Washino et al., 1999; Williams et al., 1992). In adults, BF values of 25% for men and 35% for women are commonly used as ‘healthy’ thresholds (De Lorenzo et al., 2003; Organization, 1995; Romero-Corral et al., 2008), as they were associated with greater cardio-metabolic risk (Phillips et al., 2013). To illustrate the findings from the BF% accrual distance charts for the HBSIII cohort, I compared BF% values for an 18-year old Asian boy and a Reference boy in my study to the common adult male cut-off of 25% BF. I also compared BF% values for an 18-year old Asian and Reference girl in my study to the common adult female cut-off of 35% BF. Based on the BF% curves developed from the HBSIII cohort, Asian girls with 35% BF would fall at the 84th centile and Asian boys with 25% BF at the 90th centile while Reference girls at 35% BF would fall at the 91st centile and Reference boys at 25% BF at the 90th centile, on those curves. Thus, Asian and Reference boys reach the BF% value that corresponds to risk-based adult cut-offs at the same centile whereas Asian girls reached this 7 centile points lower than Reference girls. This provides a snapshot of the distribution of BF% in the HBSIII sample and illustrates differences in how BF% may be classified differently on different centile curves. I also highlight the finding that Asian girls in BC may be at risk of reaching greater BF% values at a lower centile than Reference girls.

3.5.3. Body fat velocity

The velocity at which total body mass is accrued during childhood and adolescence is associated with fat mass at adulthood (Cheng et al., 2015). Thus, BF% velocity charts developed using longitudinal data can be used to map rate of BF accrual, identify when a child departs from a 'healthy' accrual trajectory and potentially identify growth disorders ahead of charts developed using distance data (Dieticians of Canada, 2014; Kuczmarski et al., 2002). However, as velocity does not track across an anticipated trajectory in children and youth, BF% velocity curves provide different information than do BF% distance centile curves (Healy, Yang, Tanner, & Zumrawi, 1988). To illustrate, a child that tracked along the 3rd centile for BF% velocity from age 8-19 years would have lower BF% at age 19 than at age 8. As such, velocity centile curves should be used in conjunction with absolute BF% values plotted on centile distance curves (Tanner, 1952; World Health Organization, 2009).

Longitudinal studies tracking body fat accrual of children and youth across four or more years are rare. To our knowledge, only one study to date reported BF% velocity in children or youth (Lloyd, Chinchilli, Egli, Rollings, & Kulin, 1998). In this 6-year longitudinal study of Caucasian girls aged 11-18 years in the U.S., mean BF% velocity was approximately 3%/year at age 12 and just above 0%/year at age 18. This aligns with the 75th centile for BF% accrual velocity at age 12 and the 50th centile at age 18 for Reference girls in my study. This crude comparison suggests that girls in my study were accruing BF at a slower rate at age 12 compared with same age girls in the U.S., but at a similar rate at age 18.

Given the substantial focus of science and society on obesity and its determinants, the lack of BF (by DXA) accrual data is surprising. Longer-term prospective data and further study

are needed to map when children depart from a healthy weight and enter an overweight or ‘obesity’ trajectory. Our study begins to fill this gap in longitudinal BF data.

I note several limitations of this study. First, BF% as derived from a total body DXA scan includes fat mass in the numerator and denominator. This can pose a statistical problem as individuals with obesity could experience large changes in fat mass with only small changes in BF% (Wells, 2000). Second, there are currently no BF% growth standards for children and youth, nor are there clinical cut-offs for BF% related to adverse health outcomes. Thus, there is limited health context to interpret data plotted on the distance and velocity centile values that I developed. Third, the data utilized comprise a convenience sample of healthy children and youth from BC, Canada, which limits the external validity and generalizability of my findings to other populations.

Importantly, there are a number of strengths of my study. These include the mixed longitudinal design, objectively-measured body fat using whole-body DXA and use of GAMLSS modelling to derive centile curves for BF% and BF% accrual velocity. Importantly, the multi-ethnic cohort and mixed longitudinal design allowed me to develop BF% velocity curves for both Asian and Reference children and youth for the first time. Previous studies employed the LMS method to generate reference data. However, the newer GAMLSS approach I used to develop BF% distance and velocity curves permits modelling of kurtosis (Borghini et al., 2006). Finally, I studied Reference children of European ancestry and Asian children, as compared with previous studies that investigated Reference (referred to as White or Caucasian in previous studies) children and sometimes other ethnicities (Black, Hispanic) but not Asian children.

In conclusion, while acknowledging several limitations, the BF% distance and velocity centile reference curves I developed for Asian- and Reference-Canadian children and youth may

be used to investigate geographic differences in BF% and BF% accrual across Canada. Distance and velocity curves can also be used to monitor BF% accrual trends in British Columbian children and youth and to identify when an individual veers from an average BF% accrual trajectory. In light of the current 'obesity epidemic' (WHO Multicentre Growth Reference Study Group), the dearth of objectively acquired, longitudinal body fat data is unfortunate. There is an urgent need for large samples of longitudinal data so as to establish 'healthy' and 'unhealthy' BF% accrual trajectories. Monitoring BF% accrual in diverse groups of children and youth from early childhood through adulthood would enhance our understanding of whether or how BF% accrual is associated with an array of health problems, the association between BF% and total body mass and how the contribution of body fat to total body mass tracks over the life course.

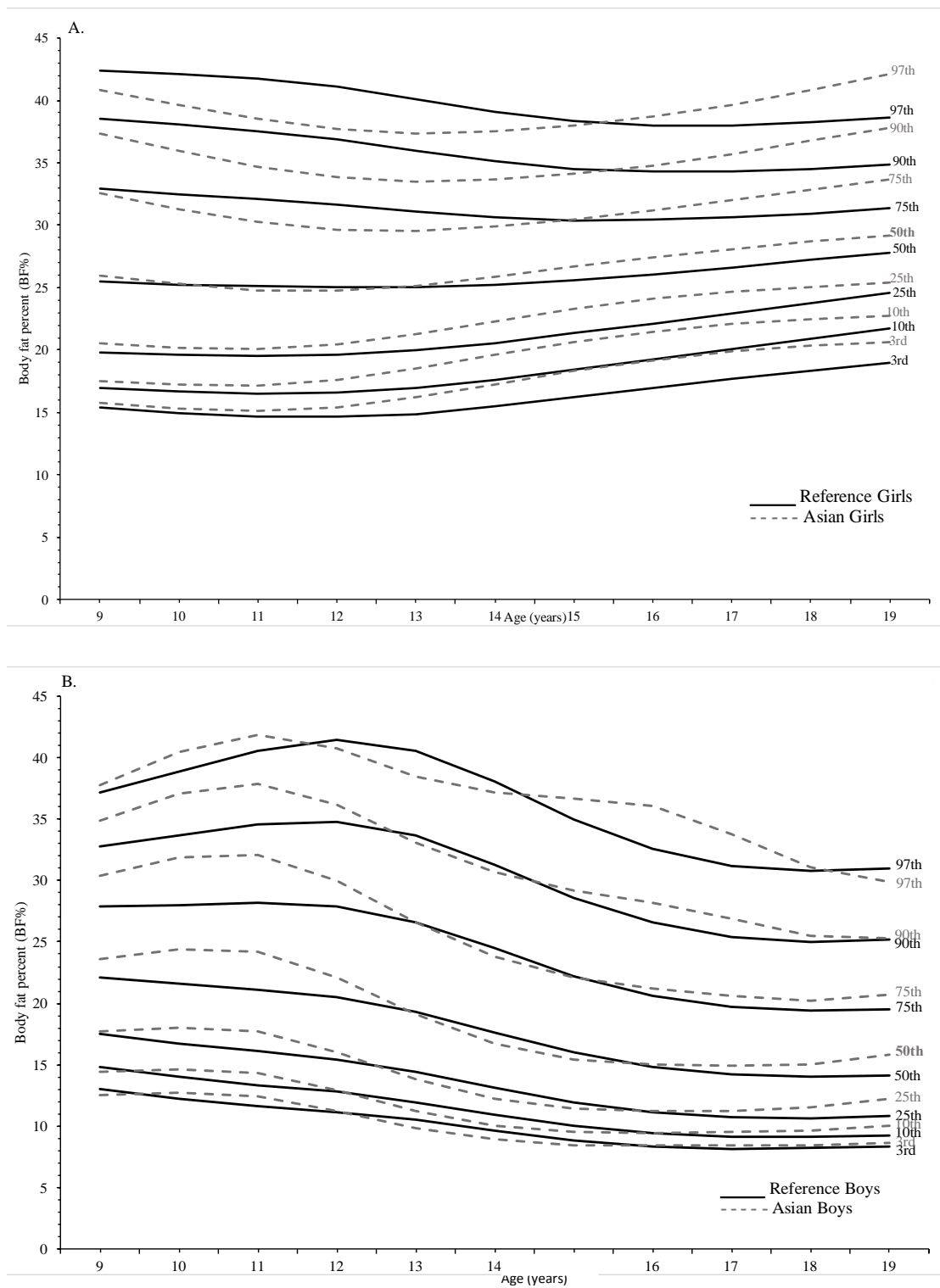


Figure 3.2. Distance curves that illustrate body fat percent (BF%) values at the 3rd, 10th, 25th, 50th, 75th, 90th, and 97th centile for A) Reference (solid line) and Asian (dashed line) girls and B) Reference (solid line) and Asian (dashed line) boys.

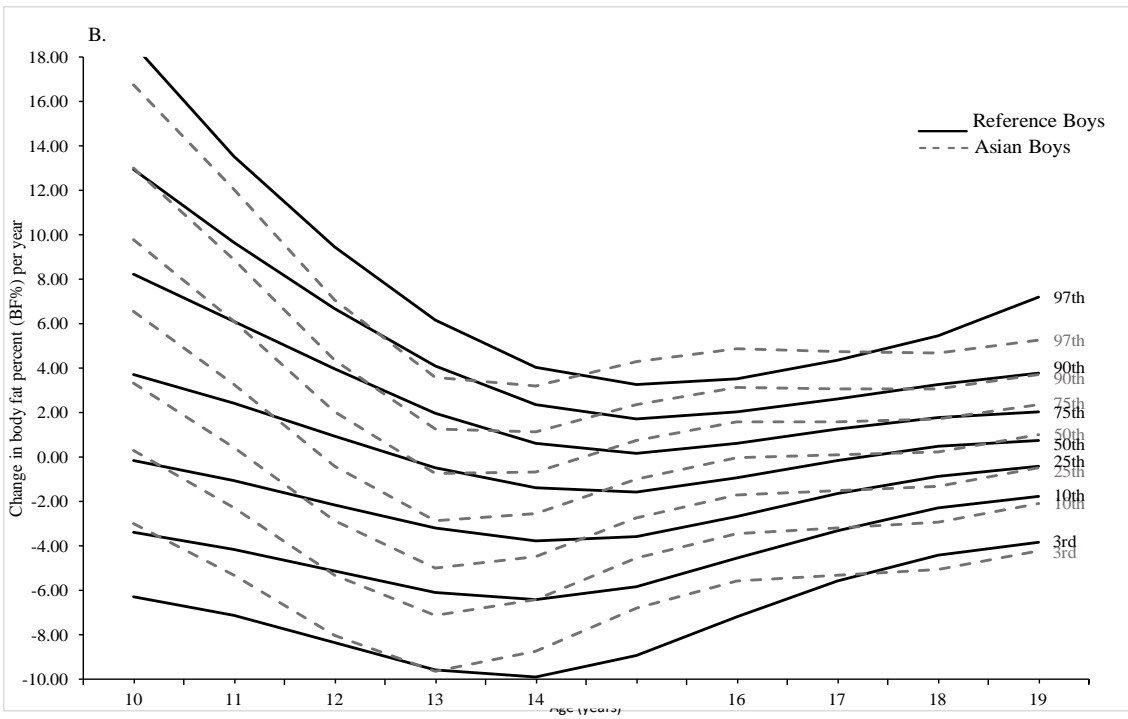
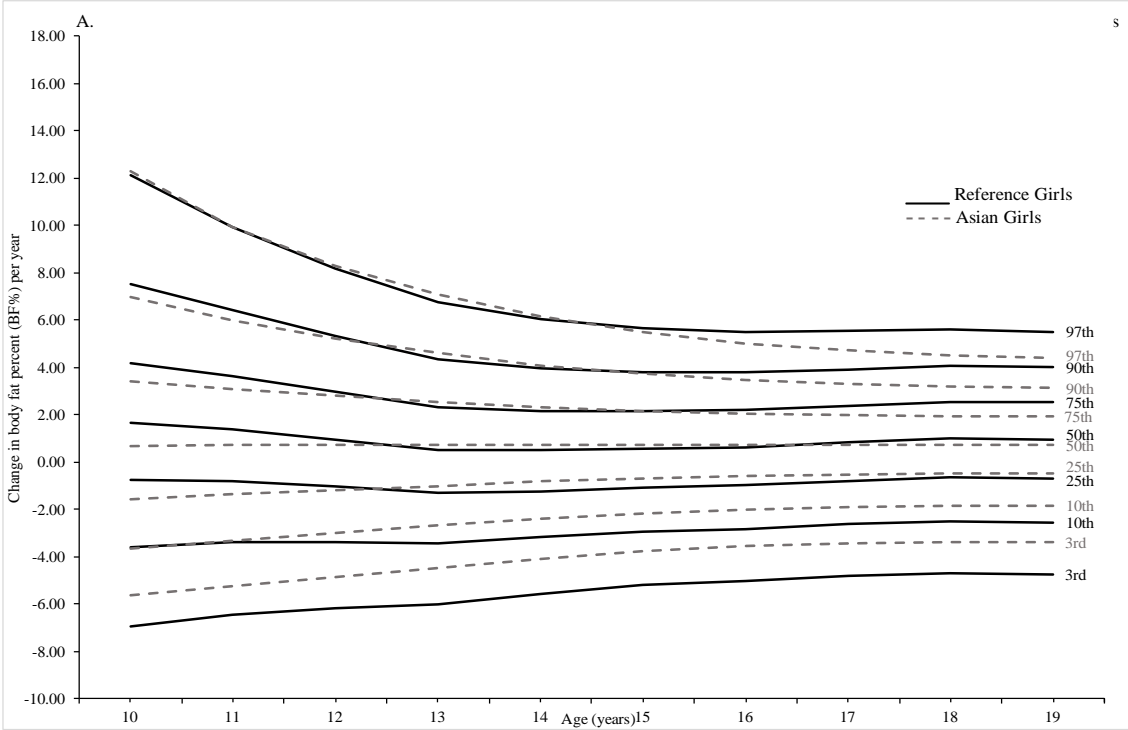


Figure 3.3. Body fat percent (BF%) velocity (change in BF% / year) values at the 3rd, 10th, 25th, 50th, 75th, 90th, and 97th centile for A) Reference (solid line) and Asian (dashed line) girls and B) Reference (solid line) and Asian (dashed line) boys.

Table 3.1. Number of observations for Asian, Reference and all boys and girls by age in the HBSIII cohort.

	Boys			Girls		
	Asian	Reference	All boys	Asian	Reference	All girls
n	1141	1145	2286	1173	1113	2286
Age (years) *	12.8 (2.5)	13.2 (2.6)	13.0 (2.6)	12.6 (2.5)	13.2 (2.7)	12.9 (2.6)
<i>Number of observations by age</i>						
9	85	68	153	99	72	171
10	232	200	432	249	190	439
11	251	207	458	259	210	469
12	166	177	343	181	182	363
13	89	108	198	99	100	199
14	74	86	160	62	71	133
15	73	82	155	69	79	148
16	58	72	130	56	68	124
17	52	70	122	47	62	109
18	42	50	92	33	47	80
19	19	25	44	19	32	51

* Values represent mean (standard deviation)

Table 3.2. Mean (μ), variance (σ), skewness (ν), τ (kurtosis) and centile values for body fat percent (BF%) for all girls aged 9-19 years.

Age	Model parameters				BF% distance centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th
9	26.193	0.280	0.365	4.148	15.27	17.52	20.80	26.19	32.40	37.19	41.10
10	25.670	0.284	0.335	3.739	14.82	17.13	20.40	25.67	31.78	36.66	40.82
11	25.305	0.283	0.307	3.403	14.64	16.98	20.22	25.31	31.21	36.10	40.42
12	25.150	0.273	0.282	3.124	14.82	17.18	20.33	25.15	30.73	35.48	39.84
13	25.254	0.256	0.259	2.887	15.41	17.74	20.78	25.25	30.41	34.90	39.13
14	25.631	0.236	0.238	2.683	16.27	18.58	21.49	25.63	30.35	34.55	38.62
15	26.203	0.218	0.218	2.507	17.22	19.53	22.34	26.20	30.57	34.54	38.48
16	26.838	0.206	0.200	2.352	18.07	20.39	23.15	26.84	30.98	34.82	38.73
17	27.479	0.199	0.182	2.216	18.72	21.11	23.88	27.48	31.51	35.35	39.33
18	28.118	0.197	0.166	2.094	19.21	21.69	24.53	28.12	32.13	36.06	40.24
19	28.752	0.198	0.150	1.985	19.59	22.20	25.13	28.75	32.81	36.88	41.32

Table 3.3. Mean (μ), variance (σ), skewness (ν), τ (kurtosis) and centile values for body fat percent (BF%) for all boys aged 9-19 years.

Age	Model parameters				BF% distance centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th

9	22.720	0.316	0.181	6.064	12.91	14.57	17.40	22.72	29.30	34.28	37.94
10	22.996	0.339	0.180	5.812	12.49	14.27	17.29	23.00	30.17	35.70	39.86
11	22.856	0.360	0.149	5.573	11.97	13.80	16.91	22.86	30.50	36.54	41.22
12	21.572	0.380	0.040	5.345	11.14	12.86	15.80	21.57	29.34	35.81	41.06
13	19.383	0.396	-0.153	5.128	10.14	11.61	14.17	19.38	26.94	33.79	39.79
14	17.186	0.401	-0.357	4.921	9.26	10.50	12.65	17.19	24.24	31.27	38.05
15	15.561	0.395	-0.501	4.723	8.64	9.72	11.59	15.56	21.99	28.84	35.98
16	14.728	0.384	-0.567	4.535	8.36	9.37	11.10	14.73	20.64	27.08	34.05
17	14.417	0.373	-0.547	4.355	8.27	9.27	10.95	14.42	19.93	25.83	32.18
18	14.496	0.365	-0.458	4.183	8.28	9.33	11.05	14.50	19.77	25.20	30.86
19	14.984	0.362	-0.344	4.018	8.43	9.58	11.42	14.98	20.23	25.44	30.70

Table 3.4. Mean (μ), variance (σ), skewness (ν), τ (kurtosis) and centile values for body fat percent (BF%) for Asian girls aged 9-19 years.

Age	Model parameters				BF% distance centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th
9	25.974	0.280	0.217	6.128	15.73	17.51	20.50	25.97	32.53	37.35	40.83
10	25.278	0.273	0.233	4.687	15.31	17.23	20.18	25.28	31.31	35.94	39.60
11	24.790	0.264	0.245	3.668	15.11	17.17	20.10	24.79	30.27	34.71	38.56
12	24.738	0.247	0.251	2.999	15.43	17.61	20.48	24.74	29.63	33.83	37.73
13	25.165	0.226	0.244	2.566	16.25	18.51	21.29	25.17	29.55	33.49	37.36

14	25.873	0.208	0.219	2.286	17.28	19.59	22.30	25.87	29.87	33.63	37.48
15	26.668	0.195	0.173	2.136	18.32	20.63	23.29	26.67	30.45	34.10	37.95
16	27.429	0.187	0.107	2.118	19.20	21.48	24.10	27.43	31.16	34.80	38.68
17	28.097	0.186	0.024	2.224	19.85	22.07	24.68	28.10	31.97	35.71	39.65
18	28.672	0.189	-0.071	2.410	20.32	22.47	25.08	28.67	32.82	36.75	40.81
19	29.183	0.194	-0.172	2.611	20.68	22.76	25.39	29.18	33.66	37.84	42.09

Table 3.5. Mean (μ), variance (σ), skewness (ν), τ (kurtosis) and centile values for body fat percent (BF%) for Asian boys aged 9-19 years.

Age	Model parameters				BF% distance centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th
9	23.636	0.319	0.547	8.422	12.57	14.38	17.67	23.63	30.37	34.91	37.76
10	24.379	0.337	0.435	7.697	12.72	14.62	18.03	24.38	31.83	37.04	40.46
11	24.159	0.356	0.318	7.033	12.40	14.30	17.69	24.16	32.08	37.87	41.87
12	22.095	0.378	0.156	6.423	11.24	12.96	16.03	22.09	30.00	36.16	40.71
13	19.084	0.399	-0.085	5.865	9.85	11.27	13.81	19.08	26.61	33.12	38.44
14	16.712	0.408	-0.335	5.354	8.91	10.08	12.19	16.71	23.78	30.70	37.13
15	15.416	0.406	-0.509	4.886	8.47	9.53	11.39	15.42	22.06	29.21	36.70
16	15.003	0.395	-0.579	4.458	8.41	9.46	11.23	15.00	21.25	28.23	36.02
17	14.883	0.380	-0.522	4.066	8.41	9.49	11.27	14.89	20.62	26.85	33.75
18	15.040	0.364	-0.343	3.708	8.42	9.61	11.49	15.04	20.25	25.54	31.07

19	15.849	0.347	-0.079	3.381	8.66	10.08	12.18	15.85	20.73	25.32	29.87
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Table 3.6. Mean (μ), variance (σ), skewness (ν), τ (kurtosis) and centile values for body fat percent (BF%) for Reference girls aged 9-19 years.

Age	Model parameters				BF% distance centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th
9	25.512	0.302	-0.022	8.178	15.43	16.95	19.80	25.51	32.91	38.55	42.42
10	25.266	0.306	0.040	6.633	14.98	16.64	19.58	25.27	32.52	38.09	42.15
11	25.098	0.305	0.097	5.488	14.68	16.50	19.50	25.10	32.10	37.56	41.78
12	25.019	0.297	0.149	4.616	14.63	16.58	19.63	25.02	31.62	36.86	41.13
13	25.037	0.281	0.196	3.935	14.88	16.95	19.98	25.04	31.07	35.97	40.14
14	25.219	0.259	0.240	3.393	15.45	17.61	20.57	25.22	30.62	35.10	39.09
15	25.578	0.238	0.281	2.955	16.19	18.43	21.33	25.58	30.41	34.53	38.35
16	26.055	0.219	0.320	2.597	16.97	19.29	22.14	26.05	30.42	34.27	37.99
17	26.604	0.205	0.356	2.299	17.70	20.13	22.95	26.60	30.61	34.29	37.98
18	27.203	0.194	0.390	2.050	18.37	20.93	23.76	27.20	30.94	34.51	38.24
19	27.821	0.186	0.422	1.839	18.99	21.69	24.55	27.82	31.33	34.84	38.65

Table 3.7. Mean (μ), variance (σ), skewness (ν), τ (kurtosis) and centile values for body fat percent (BF%) for Reference boys aged 9-19 years.

Age	Model parameters				BF% distance centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th
9	22.074	0.298	0.030	3.830	12.99	14.79	17.47	22.07	27.85	32.78	37.19
10	21.563	0.329	-0.063	3.985	12.24	13.99	16.69	21.56	27.98	33.65	38.81
11	21.143	0.354	-0.148	4.132	11.68	13.38	16.07	21.14	28.14	34.55	40.52
12	20.503	0.373	-0.225	4.270	11.18	12.78	15.40	20.50	27.84	34.79	41.41
13	19.288	0.383	-0.296	4.401	10.49	11.96	14.40	19.29	26.57	33.67	40.58
14	17.614	0.387	-0.362	4.526	9.65	10.95	13.14	17.61	24.46	31.30	38.07
15	15.983	0.385	-0.423	4.645	8.88	10.02	11.96	15.98	22.25	28.62	35.01
16	14.813	0.379	-0.480	4.760	8.37	9.39	11.14	14.81	20.60	26.56	32.57
17	14.194	0.372	-0.534	4.870	8.17	9.11	10.74	14.19	19.69	25.39	31.19
18	14.020	0.366	-0.584	4.976	8.20	9.10	10.67	14.02	19.39	25.03	30.78
19	14.134	0.360	-0.632	5.079	8.38	9.27	10.82	14.13	19.50	25.18	31.01

Table 3.8. Mean (μ), variance (σ), skewness (ν), τ (kurtosis) and centile values for body fat percent (BF%) velocity for girls aged 10-19 years.

Age	Model parameters				BF% velocity centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th
10	1.535	0.049	-2.557	11.171	-7.34	-4.56	-1.75	1.54	5.25	9.29	14.43
11	1.320	0.042	-1.653	9.778	-6.76	-4.10	-1.54	1.32	4.41	7.64	11.57
12	1.096	0.035	-0.707	8.552	-6.14	-3.65	-1.36	1.10	3.66	6.25	9.34

13	0.895	0.029	0.280	7.596	-5.41	-3.14	-1.16	0.90	2.98	5.06	7.50
14	0.770	0.024	1.305	6.890	-4.69	-2.66	-0.95	0.77	2.48	4.16	6.14
15	0.722	0.021	2.367	6.265	-4.19	-2.31	-0.78	0.72	2.19	3.63	5.32
16	0.743	0.019	3.466	5.637	-3.99	-2.12	-0.65	0.74	2.09	3.42	4.98
17	0.819	0.018	4.599	5.176	-4.01	-2.04	-0.55	0.82	2.13	3.41	4.94
18	0.902	0.018	5.766	5.142	-4.10	-2.01	-0.48	0.90	2.20	3.46	4.94
19	0.913	0.019	6.967	5.607	-4.29	-2.11	-0.52	0.91	2.23	3.47	4.89

Table 3.9. Mean (μ), variance (σ), skewness (ν), τ (kurtosis) and centile values for body fat percent (BF%) velocity for boys aged 10-19 years.

Age	Model parameters				BF% velocity centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th
10	4.532	0.052	0.475	36.031	-5.72	-2.42	0.87	4.52	8.24	11.71	15.31
11	2.543	0.046	1.673	27.680	-6.97	-3.76	-0.70	2.54	5.72	8.58	11.49
12	0.486	0.040	2.888	21.022	-8.17	-5.10	-2.34	0.49	3.17	5.55	7.92
13	-1.148	0.034	3.994	15.782	-8.80	-5.99	-3.56	-1.15	1.10	3.07	5.06
14	-1.714	0.029	4.741	11.694	-8.37	-5.85	-3.75	-1.71	0.18	1.86	3.59
15	-1.274	0.024	4.859	8.582	-7.14	-4.87	-3.04	-1.28	0.37	1.88	3.49
16	-0.471	0.022	4.310	6.351	-5.87	-3.73	-2.06	-0.47	1.03	2.47	4.10
17	-0.069	0.020	3.258	4.865	-5.23	-3.13	-1.55	-0.07	1.36	2.79	4.55

18	0.358	0.019	1.780	3.984	-4.64	-2.56	-1.04	0.36	1.75	3.22	5.18
19	0.856	0.018	-0.143	3.530	-3.86	-1.89	-0.47	0.85	2.20	3.69	5.84

Table 3.10. Mean (μ), variance (σ), skewness (v), τ (kurtosis) and centile values for body fat percent (BF%) velocity for Asian girls aged 10-19 years.

Age	Model parameters				BF% velocity centiles						
	μ	σ	v	τ	3rd	10th	25th	50th	75th	90th	97th
10	0.694	0.041	-6.218	1.466	-5.61	-3.64	-1.59	0.69	3.42	6.99	12.31
11	0.700	0.037	-5.026	1.468	-5.23	-3.32	-1.38	0.70	3.08	6.00	9.95
12	0.706	0.033	-3.834	1.471	-4.85	-3.00	-1.19	0.71	2.79	5.22	8.29
13	0.712	0.029	-2.643	1.473	-4.45	-2.69	-1.00	0.71	2.54	4.59	7.06
14	0.717	0.026	-1.451	1.475	-4.07	-2.40	-0.83	0.72	2.33	4.09	6.14
15	0.723	0.024	-0.259	1.477	-3.76	-2.16	-0.70	0.72	2.17	3.71	5.47
16	0.729	0.022	0.933	1.479	-3.54	-1.99	-0.60	0.73	2.06	3.45	5.01
17	0.734	0.021	2.125	1.481	-3.42	-1.89	-0.54	0.73	1.99	3.29	4.71
18	0.740	0.020	3.316	1.483	-3.39	-1.85	-0.51	0.74	1.95	3.18	4.51
19	0.746	0.020	4.508	1.485	-3.41	-1.83	-0.49	0.75	1.93	3.11	4.37

Table 3.11. Mean (μ), variance (σ), skewness (v), τ (kurtosis) and centile values for body fat percent (BF%) velocity for Asian boys aged 10-19 years.

Age	Model parameters				BF% velocity centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th
10	6.533	0.043	0.234	9.386	-2.99	0.31	3.33	6.52	9.79	13.02	16.72
11	3.243	0.039	0.706	8.862	-5.32	-2.29	0.42	3.24	6.09	8.86	12.03
12	-0.444	0.035	1.199	8.349	-8.05	-5.30	-2.90	-0.44	2.00	4.37	7.06
13	-2.870	0.031	1.713	7.854	-9.65	-7.15	-5.01	-2.87	-0.76	1.28	3.58
14	-2.547	0.027	2.246	7.385	-8.73	-6.41	-4.47	-2.55	-0.67	1.14	3.19
15	-0.989	0.025	2.797	6.942	-6.79	-4.58	-2.76	-0.99	0.73	2.38	4.26
16	-0.028	0.023	3.367	6.537	-5.60	-3.43	-1.70	-0.03	1.58	3.12	4.89
17	0.078	0.022	3.953	6.186	-5.33	-3.19	-1.52	0.08	1.60	3.06	4.74
18	0.226	0.021	4.557	5.896	-5.06	-2.93	-1.30	0.23	1.68	3.08	4.69
19	0.986	0.020	5.178	5.659	-4.20	-2.09	-0.49	0.98	2.37	3.71	5.25

Table 3.12. Mean (μ), variance (σ), skewness (ν), τ (kurtosis) and centile values for body fat percent (BF%) velocity for Reference girls aged 10-19 years.

Age	Model parameters				BF% velocity centiles						
	μ	σ	ν	τ	3rd	10th	25th	50th	75th	90th	97th
10	1.684	0.047	-1.040	1.092	-6.95	-3.58	-0.73	1.67	4.19	7.54	12.09
11	1.397	0.041	-0.041	1.153	-6.44	-3.36	-0.78	1.40	3.64	6.41	9.94
12	0.942	0.036	0.871	1.211	-6.20	-3.38	-1.05	0.95	2.95	5.30	8.15
13	0.520	0.032	1.710	1.268	-6.00	-3.44	-1.32	0.51	2.32	4.36	6.74

14	0.485	0.029	2.486	1.323	-5.55	-3.19	-1.22	0.49	2.15	3.97	6.02
15	0.543	0.027	3.209	1.376	-5.20	-2.96	-1.10	0.54	2.13	3.80	5.64
16	0.640	0.027	3.886	1.427	-5.00	-2.82	-0.99	0.63	2.19	3.77	5.48
17	0.828	0.026	4.521	1.477	-4.81	-2.63	-0.81	0.83	2.37	3.91	5.54
18	0.983	0.026	5.120	1.526	-4.69	-2.50	-0.66	0.99	2.54	4.04	5.59
19	0.960	0.026	5.687	1.574	-4.77	-2.56	-0.71	0.97	2.53	4.00	5.50

Table 3.13. Mean (μ), variance (σ), skewness (v), τ (kurtosis) and centile values for body fat percent (BF%) velocity for Reference boys aged 10-19 years.

Age	Model parameters				BF% velocity centiles						
	μ	σ	v	τ	3rd	10th	25th	50th	75th	90th	97th
10	3.732	0.059	-2.337	38.558	-6.29	-3.37	-0.19	3.73	8.21	12.93	18.51
11	2.428	0.051	-0.464	29.405	-7.14	-4.14	-1.07	2.43	6.11	9.67	13.51
12	0.960	0.044	2.071	22.144	-8.34	-5.13	-2.15	0.96	3.97	6.68	9.43
13	-0.479	0.038	5.015	16.476	-9.59	-6.10	-3.22	-0.48	1.99	4.09	6.16
14	-1.422	0.032	7.342	12.118	-9.91	-6.41	-3.78	-1.42	0.63	2.35	4.04
15	-1.562	0.027	8.112	8.813	-8.93	-5.82	-3.56	-1.56	0.19	1.69	3.23
16	-0.952	0.023	7.180	6.341	-7.20	-4.57	-2.66	-0.95	0.59	2.00	3.54
17	-0.167	0.020	4.801	4.514	-5.60	-3.30	-1.65	-0.17	1.24	2.63	4.34
18	0.449	0.017	0.375	3.182	-4.41	-2.31	-0.85	0.45	1.76	3.26	5.47
19	0.746	0.015	-6.314	2.221	-3.83	-1.76	-0.43	0.74	2.00	3.74	7.20

Chapter 4 : Classification of obesity varies between BMI and direct measures of body fat in boys and girls of Asian and European ancestry

4. 1. Abstract⁵

BMI is a common proxy measure of body composition that may not classify youth equally across ages and ethnicities. I used sex- and ethnic-specific receiver operating characteristic (ROC) curves to determine how obesity classifications compared between BMI- and DXA-based BF%. Male (M) and female (F) participants aged 9-18 years (n=944; 487 F) were measured 1-13 times (1999 – 2012; 4,411 observations). BMI identified <50% of those classified as obese from BF%. Specificity was 99.7%, and sensitivity was 35.8%. Using area under the curve and standard error values, BMI performed significantly better for: M vs F at 10 years (yrs), Asian vs European F except at 13, 15, and 16yrs, Asian F vs M except at 10 and 15yrs, and for European M vs F, 9-11yrs ($p<.05$). My findings provide evidence that users of BMI should use caution when comparing BMI across age, sex, and ethnicity.

Keywords: obesity, measurement, ethnicity, BMI, body fat

⁵ A version of this material was submitted to Measurement in Physical Education and Exercise Science: McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., Hofer, S.M., and McKay, H. Classification of obesity varies between BMI and direct measures of body fat in boys and girls of Asian and European ancestry. Measurement in Physical Education and Exercise Science. (Submitted on March 12, 2017, Under review). Also, a preliminary version of this work was peer-reviewed for conference presentation: McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., and McKay, H. (2016). Classification of obesity varies between measures of BMI and direct measures of body fat in Asian and White boys and girls. Presented to the XIII International Congress on Obesity. Vancouver, B.C., Canada.

4.2. Introduction

Childhood obesity is a serious public health issue in Canada, and globally (Bancej et al., 2015; World Health Organization, 2015). In 2012-2013, 14.3% of Canadian children and adolescents 6-17 years old were classified as having obesity using World Health Organization (WHO) body mass index (BMI) cut-offs (Bancej et al., 2015). During childhood and adolescence, obesity is associated with adverse psychological, cardiovascular, metabolic, and orthopedic health outcomes (Daniels et al., 2005; Reilly et al., 2003). Obesity tracks strongly across the lifespan (Whitaker et al., 1997) and as excess bodyweight persists into adulthood, it can affect not only health outcomes (Maffeis & Tatò, 2001; Reilly et al., 2003) but also economic earnings, educational attainment, and quality of life over time (Puhl & Heuer, 2009). Thus, we need accurate measurement tools that help identify children and adolescents at risk for and with obesity, monitor prevalence while identifying temporal trends, and evaluate public health interventions to reduce childhood and adolescent obesity (Must & Anderson, 2006).

Although critical to health, accurate measurement of body fat is challenging (Greenberg & Obin, 2006). The most common methods to measure body fat in children and adolescents require expensive equipment and are only appropriate for research (densitometry, dual energy X-ray absorptiometry (DXA), and magnetic resonance imaging (MRI)), can vary based on the equation used to estimate body fat or the rater taking the measurements (skinfold thickness), or can vary based on hydration, ethnic group, and obesity status (bioelectrical impedance analysis (BIA)) (Goran, 1997; Meyer et al., 2011). BMI is the most common proxy measure of obesity. However, unlike body fat assessed using DXA, BMI cannot discriminate between fat mass and fat-free mass (Prentice & Jebb, 2001). Further, although BMI is strongly associated with total and percent body fat in children and adolescents (Pietrobelli et al., 1998), relationships between

BMI and DXA-derived body fat measures vary with age, sex, and ethnicity (Shaw et al., 2007). For example, Asian children and youth have lower BMIs but greater percent body fat (BF%) and are at risk of adverse health effects at a lower BMI and BF% value than those of European ancestry (Freedman et al., 2008). Asian-Indian children are more insulin resistant than children of European ancestry at the same BF% (Lakshmi et al., 2012), and Asian children have adverse total cholesterol levels at the same BMI as those of European ancestry (Holmes et al., 2015). Thus, direct measures of total and BF% are preferred as estimates of total body adiposity in children and adolescents (Prentice & Jebb, 2001).

It is difficult to interpret the implications of excess BF%, as there are no agreed-upon cut-offs or thresholds related to its adverse health risks for children and youth. Reference datasets developed from BIA and skinfold thickness measurements exist specific to U.S., U.K., and Spanish populations (Chumlea et al., 2002; Laurson et al., 2011; McCarthy et al., 2006; Mueller et al., 2004). In these datasets, BF% values at the 95th percentile ranged from 31%-38% for 9-year-old girls to 35-43% for 18-year-old girls, and from 27%-40% for 9-year-old boys to 24-44% for 18-year-old boys. These data are most often used to compare populations and identify trends. Further, BF% values that ranged from 20-28% for boys and 30-34% for girls aged 5-18 years were associated with a variety of adverse health outcomes including cardiovascular disease risk factors, high blood pressure, and high cholesterol across ethnically diverse samples from Australia, the U.S. and Japan (Dwyer & Blizzard, 1996; Going et al., 2011; Mueller et al., 2004; Washino et al., 1999; Williams et al., 1992).

Thus, there is some ambiguity surrounding BF% cut-offs. Considering the popularity of BMI as a proxy measure of obesity, and that current obesity studies with Canadian children did not utilize objective DXA-derived measures of body fat (considered the gold standard) nor did

they study ethnic differences; specifically Asian-Canadian children (Kuhle et al., 2015; Malina & Katzmarzyk, 1999), our study fills a critical gap in the literature by assessing obesity in Asian and European children across age and sex. Our objectives were threefold: 1) to examine the association between BMI and BF% in children of Asian and European ancestry, 2) to identify the sensitivity and specificity of WHO BMI cut-offs for obesity, and 3) to identify the BMI cut-off that could detect obesity with the highest degree of sensitivity and specificity as compared with BF%, across these sex and ethnic groups.

4.3. Methods

I provide a detailed description of the study design and methods for data collection in Chapter 2 and a brief overview, below.

4.3.1. Study population

Participants were drawn from a cohort of girls (n=487) and boys (n=457) aged 9-18 years who comprised the Healthy Bones III Study (HBSIII). HBSIII is a mixed longitudinal study that includes four cohorts of children and adolescents from previous school-based studies (HBS, Bounce at the Bell, Action Schools! BC pilot, 2009 cohort) (Figure 4.1). Participants were measured 1-13 times with 21.5% contributing 2 measurements resulting in 4,411 total measurements (Table 4.1).

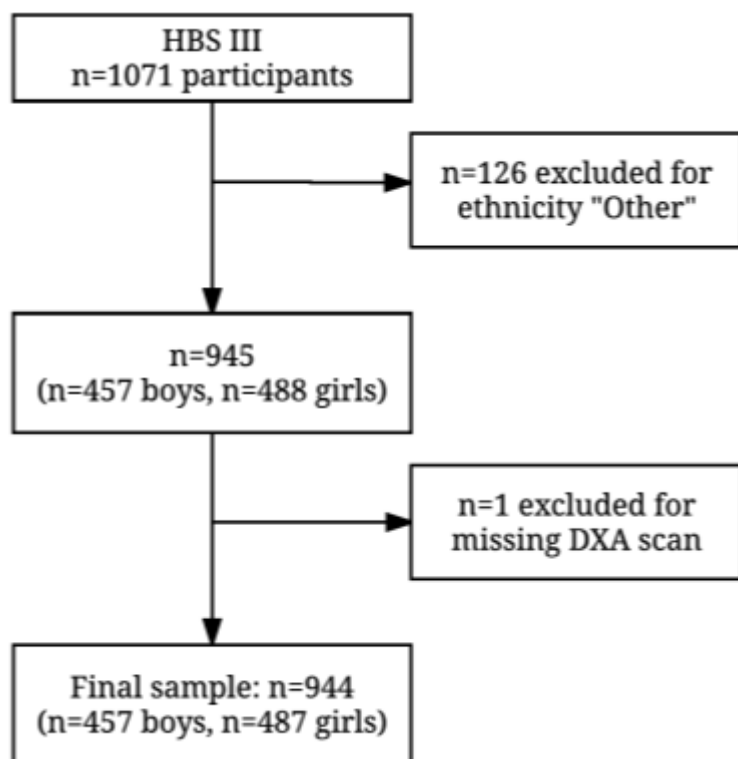


Figure 4.1. Participant inclusion diagram. HBSIII = Health Bones Study III; DXA = Dual energy x-ray absorptiometry.

4.3.2. Measures

4.3.2.1. BMI

BMI was calculated as body weight divided by height squared (kg/m^2). Height and weight were measured by trained staff. I based BMI classifications of normal weight, overweight, and obese on the WHO growth references (overweight=one standard deviation (SD) above the mean; obese=two SD above the mean) (WHO Multicentre Growth Reference Study Group). These SD-based definitions of overweight and obesity align closely with adult cut-offs for overweight and obesity of $25 \text{ kg}/\text{m}^2$ and $30 \text{ kg}/\text{m}^2$, respectively (Bancej et al., 2015; World Health Organization, 2015).

4.3.2.2. Body Fat Percent

BF% was calculated as $F\% = \frac{\text{fat mass (kg)}}{\text{body weight (kg)}}$, from values obtained by total body DXA scans (QDR 4500W; Hologic, Waltham, MA, USA).

I chose a health-related, criterion-based definition of obesity based on the established but contested relationship between BF% and health outcomes. I defined obesity as BF > 30% for girls and 25% for boys, as these thresholds have been significantly associated with cardiovascular risk factors in children and adolescents (Williams et al., 1992). This definition is conservative compared with thresholds based on 95th percentiles in current reference datasets (Laurson et al., 2011; McCarthy et al., 2006; Mueller et al., 2004; Williams et al., 1992) and widely used in studies that investigated the relationship between BMI and BF% in children and adolescents (Neovius, Linné, Barkeling, & Rossner, 2004; Wang & Hui, 2015).

4.3.2.3. Demographics

Sex, ethnicity, and age were determined using a questionnaire, completed by parents at baseline. Individuals were classified as Asian if both parents or three of four grandparents were born in Hong Kong, China, Japan, Taiwan, Philippines, Korea or India, and European, referred to as “Reference” if both parents or three of four grandparents were born in North America or Europe. Participants of mixed or other ethnicities (e.g. African, mixed-race, First Nations) were classified as “Other”. Sex was indicated as boy or girl and date of birth was used to calculate chronological age (years) as ((measurement date – date of birth / 365.25)).

4.3.3. Statistical analysis

I calculated descriptive statistics, fit multivariable regression models using the Cochrane-Orcutt method to correct for the serial autocorrelation in the data set, and developed receiver operating characteristic (ROC) curves using SPSS 23 (IBM Corp., 2015). I stratified all analyses by sex due to the different relationship between BMI and BF% in boys and girls during growth (Daniels, Khoury, & Morrison, 1997b). I included age as decimal, whole-year age groupings. I grouped by ages 9-11 years and 12-18 years to differentiate between participants who were pre- and post-puberty, respectively. Age at peak height velocity, an indicator of somatic maturity, in a subset of this cohort was 13.1 years for boys and 11.5 years for girls (Gabel et al., 2015), on average. I used a Chi-squared test to compare prevalence of obesity across age, sex, and ethnic groups.

I explored the relationship between BMI and BF% by ethnicity in sex-specific scatterplots. I selected one measurement per participant at random, and with the addition of a sub-group linear fit line for Asian and Reference children, visually inspected scatterplots (IBM Corp., 2015). I fit sex-specific multivariable regression models to determine if the relationship between BF% and BMI varied with age (decimal) and ethnic group (Asian, reference). I analyzed standardized residuals and identified 21 observations as potential outliers (girls = 10; boys = 11). I then examined the potential impact of these outliers using DfFit (model for girls DfFit min = -.77, DfFit max = .04; model for boys DfFit min = -.13, DfFit max = .06) and Cook's Distance (model for girls Cook's Distance min = .00 and Cook's Distance max = .46; model for boys Cook's Distance min = .00 and Cook's Distance max = .02), which revealed the model was robust and the outliers were not influential. The data did not meet the assumption of independent errors (model for girls Durbin-Watson value = .732; model for boys Durbin-Watson value =

.587) and thus, I used the Cochrane-Orcutt iterative procedure for adjustment. Analysis of standardized residuals, variances, collinearity, and multicollinearity revealed that the data met all other assumptions.

To evaluate accuracy of BMI cut-offs to detect obesity (BF%), I calculated sensitivity (rate of true positives; proportion of cases correctly identified with a high BMI as obese by BF%) and specificity (rate of true negatives; proportion of non-cases correctly identified with a low BMI as not obese by BF%). I then used ROC curves to assess performance of BMI to detect obesity by BF%. From ROC curves I determined the point of optimum trade-off between sensitivity and specificity of the test variable (BMI), represented by the Youden's index (J) (Fluss, Faraggi, & Reiser, 2005). Youden's index measures performance of a diagnostic test independent of the relative and absolute size of the positive and negative test groups with a value from 0 to 1 where zero indicates the test is meaningless (Youden, 1950). BMI value at the coordinate of the ROC curve with the greatest J value was chosen as the ideal BMI cut-off, giving equal weight to sensitivity and specificity (Schisterman, Perkins, Liu, & Bondell, 2005).

I then calculated area under the ROC curve (AUC) to numerically summarize the performance of BMI as an indicator of obesity. The AUC ranges from 0 to 1 (1 is a perfect score and 0.5 indicates results that are no better than chance) and reflects whether a randomly selected participant with obesity has a BMI greater than that of a randomly selected participant without obesity (Perkins & Schisterman, 2006). For this analysis AUCs with greater values indicate greater predictive ability (Fan, Upadhye, & Worster, 2006). I used AUCs and their standard errors to compare the diagnostic performance of BMI between different sexes and ethnic groups (Hanley & McNeil, 1982).

For the ROC curve, AUC, and Youden's Index analyses I included only one observation per participant. For multiyear age groups (9-11 years and 12-18 years old), I used the Select Random function in SPSS (IBM Corp., 2015) to select one observation per participant (retaining 944 total observations). For the one-year age groupings, I used the first observation for each participant in that age-year (retaining 3,932 total observations).

4.4. Results

4.4.1. Sample characteristics

Of the 944 participants in the study sample aged 9-18 years (mean = 12.3, SD = 2.5), 48% were male (n=457) and 52% were female (n=487). Most participants were of Asian ancestry (56%, n=532). Across all observations approximately 11% had obesity by BMI and 30% by BF% cut-offs. Prevalence of obesity by BMI was 7.7% greater in boys compared with girls (14.7% vs. 7.0%; ($\chi^2(1)=67.82, p<.001$)) whereas prevalence of obesity by BF% was only 3% greater in boys compared with girls (31.3% vs. 28.1%; ($\chi^2(1)=5.15, p=0.025$)). In the whole cohort, prevalence of obesity was greater among Asian participants compared with Reference participants by both BMI (11.9% vs. 9.8%; ($\chi^2(1)=5.10, p=.024$)) and BF% (31.7% vs. 27.7%; ($\chi^2(1)=8.43, p=.004$)). This was driven by the higher prevalence of obesity using both BMI and BF% in Asian boys compared with Reference boys. In girls, the prevalence of obesity using BMI and BF% was higher in the Reference sample compared with Asian girls.

4.4.2. Regression models

Visual inspection of sex-specific scatterplots of BMI and BF% with linear fit lines by ethnicity revealed a difference in the relationship between BMI and BF% between Asian and Reference boys and girls (Figures 2 and 3). Using the Cochrane-Orcutt method, the linear relationship between BF% and BMI was stronger in girls ($r^2=0.517$) than boys ($r^2=0.295$; $Z=8.9$, $p<.001$). After adjusting for age and ethnicity, the relationship was stronger in boys ($r^2=0.689$) than girls ($r^2=0.579$; $Z=6.14$, $p<.001$). In girls, BMI was a positive predictor of BF% ($\beta = 1.58$, $t(2201) = 54.62$, $p<.001$) whereas ethnicity ($\beta = -0.67$, $t(2201) = -2.97$, $p=.003$) and age ($\beta = -0.67$, $t(2201) = -17.87$, $p<.001$) were negative predictors of BF%. In boys, age ($\beta = -1.99$, $t(2198) = -52.49$, $p<.001$) and ethnicity were negative predictors of BF% ($\beta = -1.0$, $t(2198) = -3.91$, $p<.001$), and BMI was a positive predictor of BF% ($\beta = 1.80$, $t(2198) = 62.91$, $p<.001$).

4.4.3. Sensitivity and specificity

I calculated specificity and sensitivity across age, sex, and ethnic groups to determine the accuracy of WHO BMI cut-offs to identify obesity as per DXA-derived BF%. Specificity (probability that a child who is not obese by BF% is not classified as obese by BMI) was 99.7%, on average. This value ranged from 99.1% for Asian boys to 99.9% for Asian girls. Sensitivity (probability that a child who is obese by BF% is classified as obese by BMI) was 35.8%, on average. Sensitivity was greater for boys (46.2%) compared with girls (24.3%), and for Asians (36.7%) compared with Reference participants (34.8%).

4.4.4. ROC curves

Next, I assessed whether BMI correctly detected obesity by BF% and the nature of this relationship. ROC curves stratified by sex, ethnicity, and age (9-11 years and 12-18 years) are illustrated in Figure 4. I provide AUC values in Figure 5. All AUC values were significant ($p < .05$). This indicates the ability of BMI to predict obesity (defined by BF%) was greater than chance in all groups (Figure 5). AUC values ranged from 0.738 in 16-year old Asian girls to 0.985 in 16-year old Reference girls. For example, the AUC value (0.985) in 16-year-old Reference girls indicates that 98.5% of randomly selected 16-year old Reference girls with obesity had a BMI greater than that of a randomly selected 16-year old Reference girl without obesity (Perkins & Schisterman, 2006). Comparison of AUC and standard error values between sexes revealed that BMI performed significantly better in 10-year old boys compared with same-age girls ($p < 0.001$). Within ethnicities, BMI was a significantly stronger predictor of BF% in Reference boys aged 9-11 years compared with same-age Reference girls ($p = .04$), Asian girls compared with Asian boys ($p = .03$), and Asian boys aged 10 ($p = .03$) and 15 ($p = .007$) years compared with same-age Asian girls. Between ethnicities, BMI was a significantly stronger predictor in Asian girls compared with Reference girls ($p = .03$) but better in Reference girls aged 13 ($p = .02$), 15 ($p = 0.04$), and 16 ($p < .001$) years compared with same-age Asian girls.

4.4.5. Youden's index

BMI cut-off values derived from Youden's Index indicate the best trade-off between sensitivity and specificity. I provide the Youden's Index (J) value and corresponding BMI cut-offs in Table 2. The difference between our recommended BMI cut-offs in this study (whole-year age groups) and the WHO BMI values (defined for each month of age) was lowest at 1.94-

2.94 for boys aged 14 years (WHO cut-offs = 25.9-26.9 and $J = 0.735$ at BMI = 23.96) and highest at 7.19-7.79 for girls aged 15 years (WHO cut-offs = 28.2-28.8 and $J = 0.605$ at BMI = 21.01).

4.5. Discussion

To our knowledge, this is the first study to examine the predictive of ability of BMI to detect obesity, as defined by DXA-derived BF%, in a large multi-ethnic cohort of Canadian children and youth. As such, these findings represent a unique contribution to the pediatric obesity literature and will be of value to researchers and clinicians who work with children. These findings provide evidence that use of BMI to determine obesity should be done with caution if comparing across age, between sexes, and between youth of Asian and European ancestry. Our analyses clearly demonstrate that relationships between BMI and BF% were heterogeneous and varied between sexes and ethnic groups and across age groups. Specifically, BMI was more strongly associated with BF% in boys as compared with girls. BMI was a stronger diagnostic marker of obesity by BF% in boys compared with girls at age 10 and Reference boys as compared with Reference girls aged 9-11 years. There was also ethnic- and sex-specific differences in that BMI was a better indicator of obesity in Asian girls compared with Reference girls and in Asian girls compared with Asian boys, at most ages in both cases.

Prevalence of obesity by BMI in our cohort (11%) is consistent with previous Canadian studies that used BMI and WHO cut-offs (Bancej et al., 2015). However, BMI correctly classified less than half of those with obesity as defined by BF%. The inability of BMI to identify children who may be at risk of obesity is of great concern. The BF% values I used to

define obesity (BF % > 30% for girls and 25% for boys) were significantly associated with cardiovascular risk factors (Williams et al., 1992) and within the range associated with a variety of other adverse health outcomes (Dwyer & Blizzard, 1996; Going et al., 2011; Mueller et al., 2004; Washino et al., 1999; Williams et al., 1992) in previous studies. Since there is not a standardized definition of BF% that represents obesity in children and adolescents, it seems important to interpret BMI values with caution as they may not adequately represent true BF% or health risks associated with excess body fat.

I observed a different association between BF% and BMI between ethnic groups for both sexes, and a stronger relationship between BF% and BMI in boys as compared with girls. BMI, ethnicity and age were all significant predictors of BF% for both boys and girls. It is difficult to directly compare our findings with those of other studies as I was unable to identify any previous studies that included Reference and Asian children. However, in Hong Kong Chinese children and youth aged 9-19 years (Wang & Hui, 2015) and in mixed race children and youth aged 3-18 years from the U. S., (Ellis et al., 1999) the relationship between BMI and BF% was stronger for girls as compared with boys. Further, in the U.S. cohort, ethnic differences in the BMI-BF% relationship revealed that at the same BMI, black girls had a lower BF% and Hispanic girls had a higher BF% as compared with white girls, but these differences were not significant for boys. Ethnic differences are also apparent in the adverse health risks associated with obesity such as insulin resistance (Lakshmi et al., 2012) and total cholesterol (Holmes et al., 2015) for children and youth. These findings highlight the need to consider age, sex and ethnicity when identifying those who are obese rather than using BMI solely, as BMI did not represent adiposity equally across groups in our study.

In our cohort, sensitivity (probability that a child with obesity by BF% is classified as obese by BMI) was higher for boys (46.2%) compared with girls (24.3%). In a recent meta-analysis, 17/37 studies reviewed reported sex differences in the sensitivity of BMI and of these, 7 similarly reported that BMI was less sensitive in girls (Javed et al., 2015). Variability across studies is likely due to factors such as age, sex, ethnicity, obesity prevalence, and maturity. For example, the association between BF% and BMI differed by sex and obesity status with a strong association between BMI and fat mass index in children > 85th percentile for age but equally associated with fat mass index and fat free mass index for children with a BMI < 50th percentile (Freedman et al., 2004). Further, sex differences in fat mass and fat free mass without corresponding sex differences in BMI were apparent in childhood (Telford et al., 2014). This is due to the fact that BMI encompasses both muscle and fat mass. It is well known that as children traverse puberty, a higher proportion of total body mass is comprised of muscle mass in boys and fat mass in girls. This explains the heightened sex difference and heterogeneity in the relationship between BMI and BF% as children age (Taylor et al., 2010). The variation in total body fat and body fat distribution between boys and girls is partially explained by genetics (Comuzzie, Higgins, Voruganti, & Cole, 2010); however the interaction between genes, the environment, and ethnic phenotypes in the development of obesity and obesity-related comorbidities in children is not fully understood (Staiano & Katzmarzyk, 2012).

The Youden's Index BMI cut-offs might be used in public health interventions to reduce the risk of misclassifying children who have obesity or are at risk of obesity (Neovius et al., 2004). However, the lower sensitivity (a more conservative classification approach) I and others (Farias, Konrad, Rabacow, Grup, & Araújo, 2009; Neovius et al., 2004) reported, may be more appropriate for use in clinical practice to avoid misclassification of children with obesity, if they

do not have it. A misclassification may negatively impact a child's self-esteem and/or overall mental health through the associated stigma (Wang, Wild, Kipp, Kuhle, & Veugelers, 2009).

In my analysis, AUC values were significantly different in specific age-sex subgroups both across and within ethnic groups. Based on previous studies, I anticipated that AUC values would significantly differ between Reference and Asian girls and boys (Deurenberg, Deurenberg-Yap, & Guricci, 2002; Freedman et al., 2008; Shaw et al., 2007). There was not an ethnic difference for boys, this may reflect a different relationship between BF% and BMI for 'normal weight' as compared with 'overweight' Asian and Reference youth as fewer Asian boys than girls were categorized as 'normal weight' in our sample. A crossover effect has been reported wherein 'normal weight' categories (as per BMI), Asian participants had greater BF% compared with their White counterparts. However, in the 'overweight' category, Asian participants had lower BF% values compared with their White peers (Freedman & Sherry, 2009). This crossover may explain why, although Asian boys in our sample had a similar mean BMI compared with Reference boys (20.3 kg/m² vs. 19.8 kg/m²), Asian boys had a 10% difference in prevalence of obesity by BF% (36.2% vs. 26.4%). For boys who were not classified as obese by BMI, mean BF for Asian boys was 0.77% greater compared with Reference boys. However, for boys who were classified as obese by BMI, BF for Asian boys was 1.39% less than Reference boys, on average.

Ethnic differences in body fat distribution may also have influenced our findings. Distribution of body fat is a factor in the relationship between BMI and adiposity in children (Daniels et al., 1997b). Asian children 5-12 years old measured by DXA have reduced lower extremity fat as compared with Caucasian children. In addition, Asian girls have lower gynoid fat in the hips and thighs compared with Caucasian girls. To add another layer of complexity,

ethnic differences in body fat distribution also vary by sex; in a cross-sectional study of 5-12 year old Chinese and Korean children measured by DXA Asian girls had greater gynoid fat in the hip and thigh areas than Asian boys (Qin et al., 2002). These reported differences might further elucidate why ethnic differences in BMI and BF% were not observed in boys.

I acknowledge several limitations of our study. First, parent and grandparent birthplace from Hong Kong, China, Japan, Taiwan, Philippines, Korea or India were collapsed in one “Asian” category. This may mask variability in the BMI-BF% relationship and associated metabolic risk among Asian ethnic sub-groups (Wulan, Westterterp, & Plasqui, 2010). Second, although the sample was large (944 participants contributing to 4,411 observations) it was a convenience sample comprised of an extant dataset, which limits external validity of our findings. Third, BF% cut offs I used to define obesity are not age-dependent. This may overestimate prevalence of obesity in younger participants and underestimate prevalence in older participants (Taylor, Jones, et al., 2002). Others used prevalence matching and defined obesity based on age- and sex-specific BF% percentile cut-offs (Flegal et al., 2010; Freedman et al., 2013). However, critics of this approach note that BF% associated with a certain percentile may vary greatly (Sardinha, Going, Teixeira, & Lohman, 1999). Although individuals that present with the highest BF% will be identified as obese, the association of this classification with health risk is unclear (Neovius et al., 2004; Sardinha et al., 1999). There are currently no widely accepted body fat-based definitions of obesity for children (McCarthy et al., 2006; Taylor, Falorni, Jones, & Goulding, 2003). Thus, I chose a criterion-based definition associated with cardiovascular health risks for this study (Williams et al., 1992). Additionally, I did not assess body fat distribution, which is a more important correlate of cardiovascular risk factors than BF% in children and adolescents (Daniels, Morrison, Sprecher, Khoury, & Kimball, 1999).

Lastly, I used BF% to represent adiposity. However, other variables (total fat mass, fat mass index, etc. (Demerath et al., 2006; Flegal et al., 2010)) may also be associated with health risk and should be explored in future.

In summary, in this ethnically diverse cohort, BMI correctly classified less than 50% of participants as obese (as per DXA-derived BF%). The association between BMI and BF% varied significantly across age groups and between sexes and ethnicities. I highlight the need for a body fat-based definition of obesity, as this measure was associated with adverse health risk in children and youth in previous studies. Thus, results of our study and the BMI cut-offs proposed provide a foundation for further investigation of the complex relationship between BF% and BMI. Body fat is associated with a host of chronic diseases such as psychosocial disorders, cardiovascular disease, and type-II diabetes (Daniels et al., 2005; Ogden, Carroll, Curtin, Lamb, & Flegal, 2010). In adults, a number of factors influence these associations including lifestyle factors (i.e., diet and fitness) as well as total fat mass, fat distribution and genetics. Links between adiposity and lifestyle and other factors are much less clear in children and youth (Dietz, 1998). Herein lies the challenge to researchers who seek to develop body fat-based classifications of obesity in children and youth, specific to age, sex, and ethnic group (Barlow, 2007; Freedman & Sherry, 2009). Despite this challenge, there is a genuine need to better understand how BMI classification systems relate to body fat. More importantly, it seems imperative to identify body fat levels associated with adverse health outcomes by age, sex, and ethnic group. Long term prospective studies with objective measures of body fat that can be linked to health indicators are needed to achieve this.

Table 4.1. Characteristics of sample observations. Values are mean (standard deviation) unless otherwise indicated.

	Girls			Boys		
	Asian	Reference	All Girls	Asian	Reference	All Boys
n	1141	1066	2207	1098	1106	2204
Age (years)	12.5 (2.3)	13.0 (2.5)	12.7 (2.4)	12.7 (2.4)	13.0 (2.5)	12.9 (2.5)
BMI (kg/m²)	19.1 (3.4)	20.1 (3.7)	19.6 (3.6)	20.3 (4.4)	19.8 (3.7)	20.2 (4.1)
Obese by BMI	5.3%	8.8%	7.0%	18.8%	10.8%	14.7%
BF%	26.0 (6.3)	26.1 (7.2)	26.1 (6.8)	22.1 (9.1)	20.3 (8.4)	21.2 (8.8)
Obese by BF%	27.3%	29.0%	28.1%	36.2%	26.4%	31.3%

BMI=body mass index; BF%=body fat percent. Obesity was defined as BF% \geq 30% for girls and \geq 25% for boys (Staiano & Katzmarzyk, 2012) and by BMI \geq 2 S.D. above the mean on the WHO age-specific BMI charts (Neovius et al., 2004) .

Table 4.2. Youden's Index (J), associated body mass index (BMI) cut-offs, and World Health Organization recommended BMI cut-offs across age, sex, and ethnic groups.

	Age (years)	Girls			Boys		
		J	BMI cut-off (kg/m ²)	WHO BMI range (kg/m ²)	J	BMI cut-off (kg/m ²)	WHO BMI range (kg/m ²)
<i>Full Sample</i>	9	0.725	17.20	21.5 - 22.5	0.846	17.34	20.5 - 21.3
	10	0.719	18.57	22.6 - 23.6	0.825	18.50	21.4 - 22.4
	11	0.727	20.14	23.7 - 24.9	0.78	18.41	22.5 - 23.5
	12	0.718	21.26	25.0 - 26.1	0.749	19.82	23.6 - 24.7
	13	0.632	20.93	26.2 - 27.2	0.679	21.10	24.8 - 25.8
	14	0.755	21.45	27.3 - 28.2	0.753	23.96	25.9 - 26.9
	15	0.605	21.01	28.2 - 28.8	0.749	22.51	27.0 - 27.8
	16	0.584	22.41	28.9 - 29.3	0.778	24.85	27.9 - 28.6
	17	0.662	22.21	29.4 - 29.5	0.628	25.92	28.6 - 29.2
	18	0.703	22.24	29.6 - 29.7	0.726	26.32	29.2 - 29.7
<i>Reference</i>	9	0.718	18.71		0.837	18.34	
	10	0.722	18.57		0.790	18.73	
	11	0.708	19.26		0.819	18.38	
	12	0.762	21.14		0.789	19.57	
	13	0.786	20.93		0.699	20.53	
	14	0.880	21.45		0.750	24.39	
	15	0.781	23.98		0.787	22.28	
	16	0.914	23.92		0.810	24.63	
	17	0.826	22.29		0.781	23.27	
	18	0.646	22.66		0.751	25.93	
<i>Asian</i>	9	0.767	17.20		0.924	17.27	
	10	0.731	18.87		0.846	18.49	
	11	0.746	19.75		0.769	19.18	
	12	0.750	19.87		0.804	21.21	
	13	0.600	19.26		0.73	21.45	
	14	0.665	22.49		0.778	23.72	
	15	0.583	21.02		0.875	23.43	
	16	0.378	19.56		0.779	25.71	
	17	0.689	21.99		0.689	25.92	
	18	0.846	22.06		0.723	26.83	

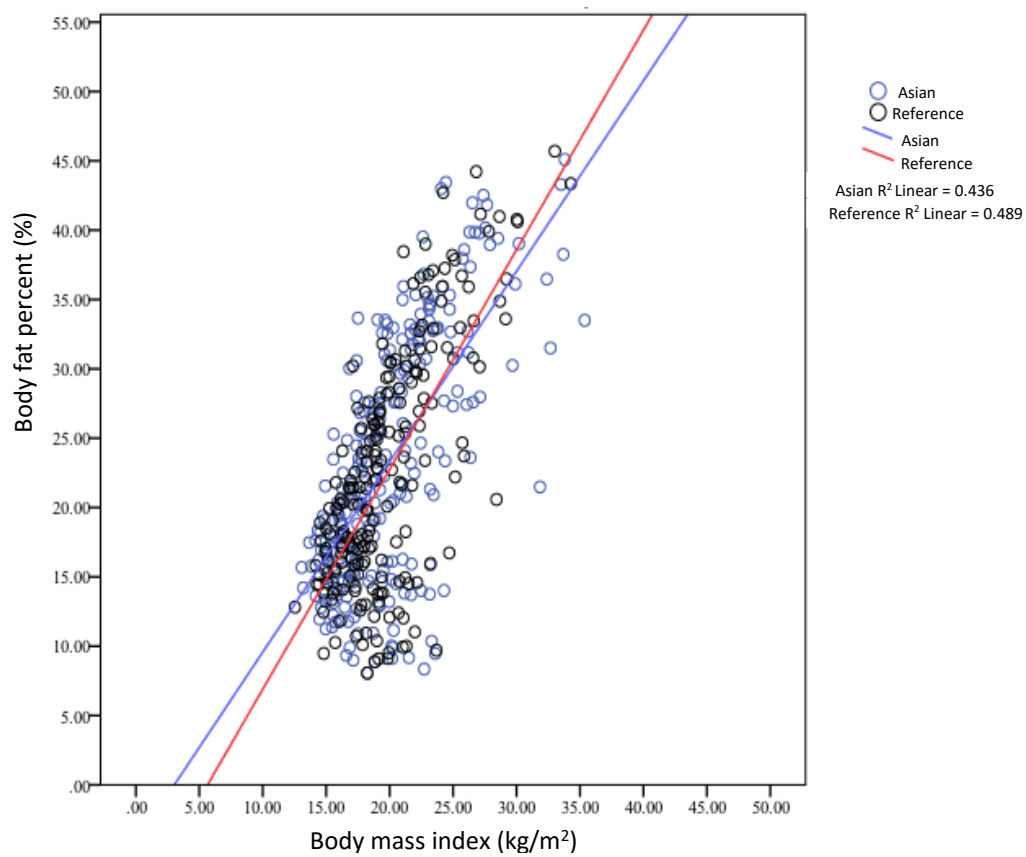


Figure 4.2. Scatterplot of body mass index and body fat percent values with linear fit lines for Asian (blue circles, blue line) and Reference boys (black circles, red line) (n=457)

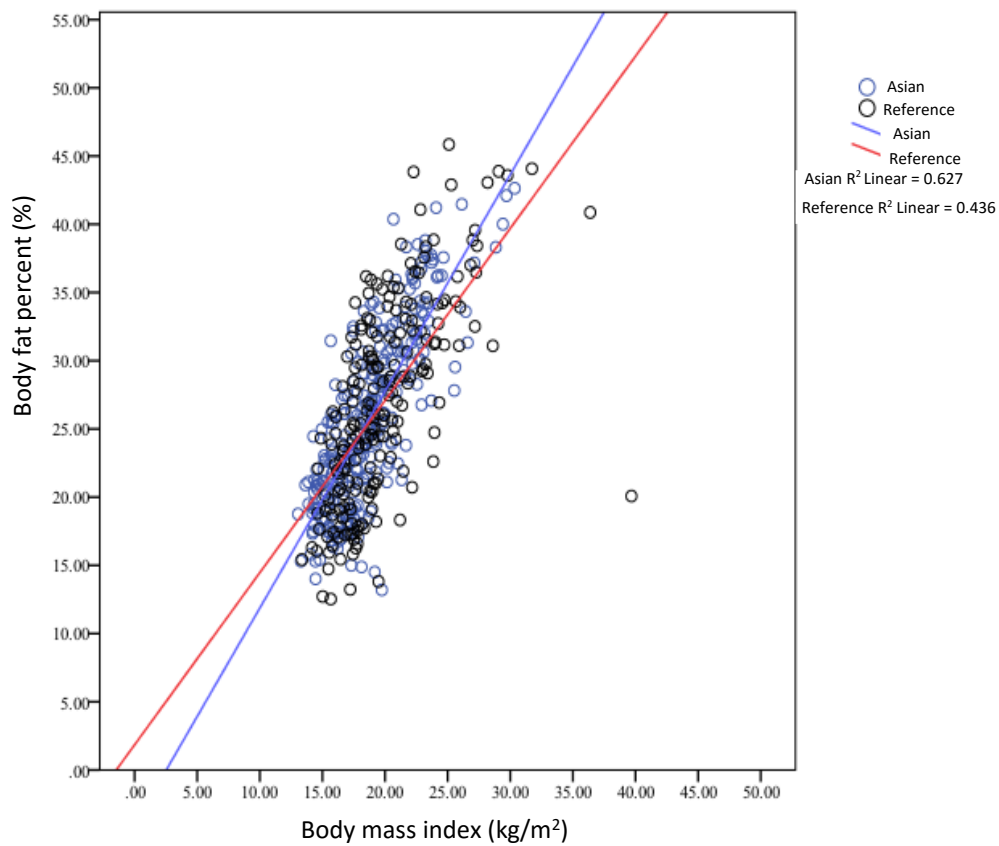


Figure 4.3. Scatterplot of body mass index and body fat percent values with linear fit lines for Asian (blue circles, blue line) and Reference girls (black circles, red line) (n=487)

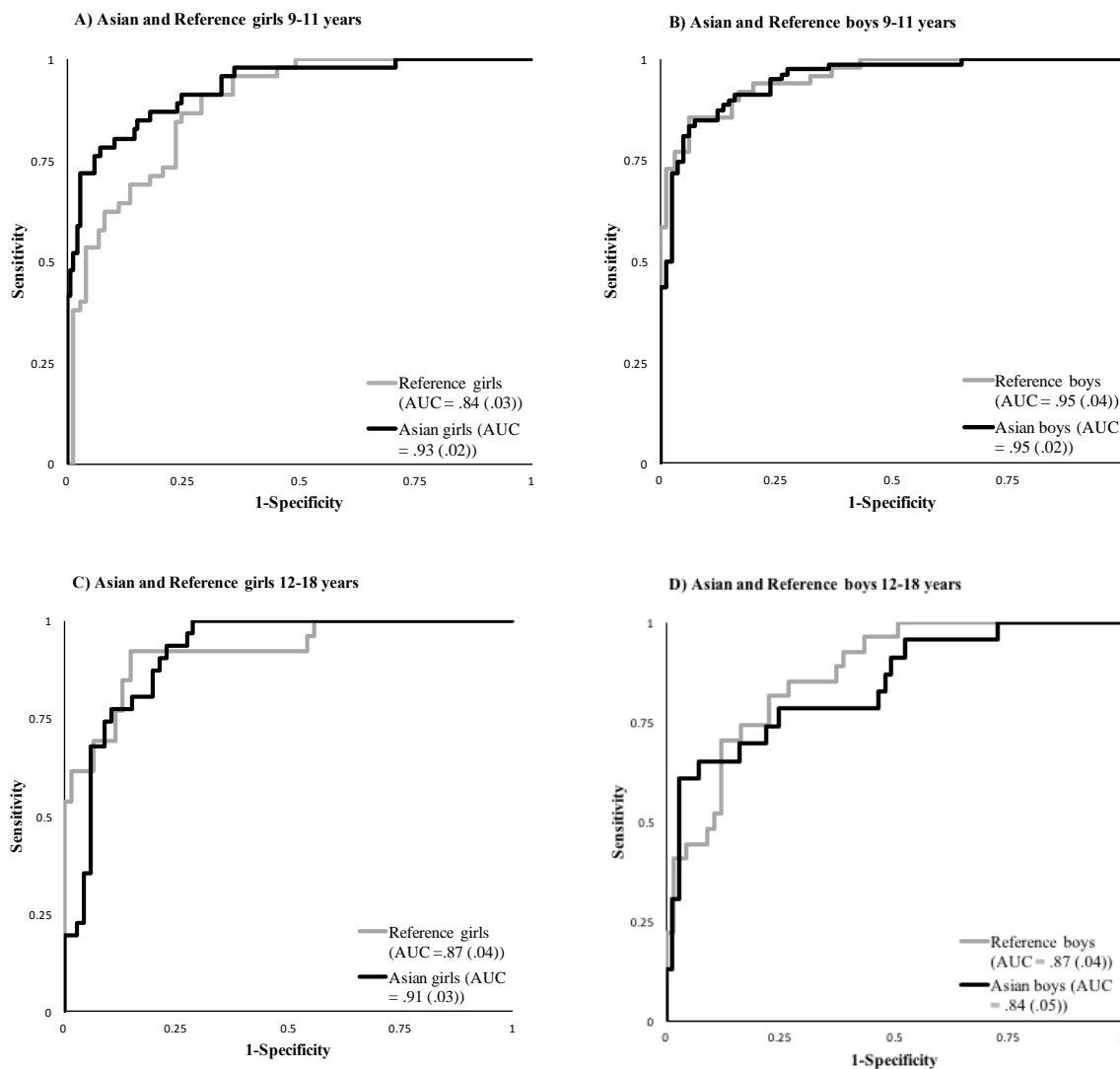


Figure 4.4 Receiver operating characteristic (ROC) curves for body mass index (BMI) predicting obesity, as defined by body fat percent (BF%) for A) Asian and Reference girls 9-11 years, B) Asian and Reference boys 9-11 years, C) Asian and Reference girls 12-18 years, and D) Asian and Reference boys 12-18 years. Obesity was defined as BF% $\geq 30\%$ for girls and $\geq 25\%$ for boys (Williams et al., 1992) and by WHO age-specific BMI cut-points (de Onis et al., 2007). AUC stands for area under the curve.

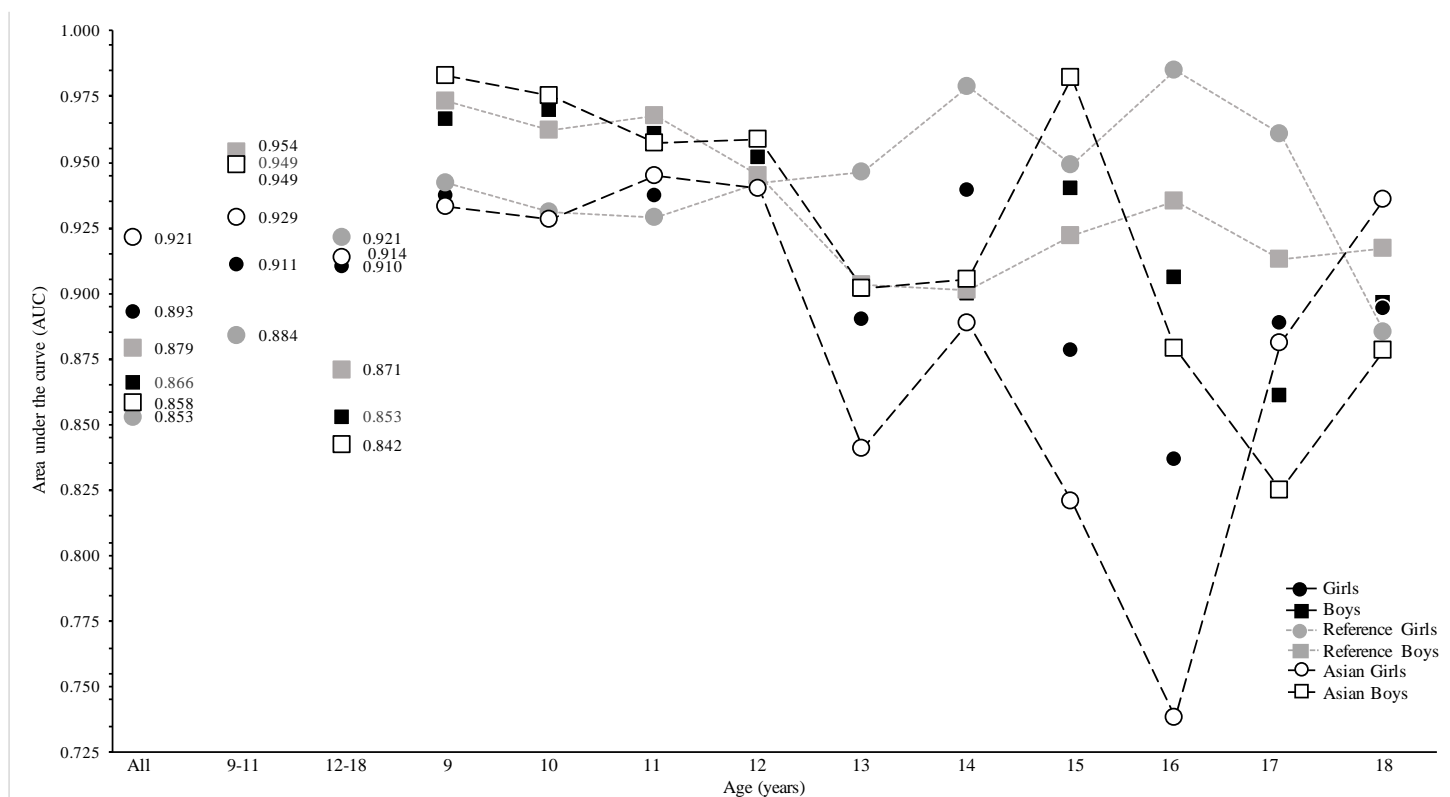


Figure 4.5. Area under the receiver operating characteristic curve (AUC) values indicating strength of agreement between body mass index- and body fat percent-based definitions of obesity by age, sex, and ethnic group.

Chapter 5 : Is adiposity predicted by physical activity, sedentary time, or caloric intake as boys and girls mature?: A 4-year mixed-longitudinal DXA-based study

5.1 Abstract⁶

Approximately 14% of Canada's children and youth have obesity. This places these young people at increased risk for a host of health problems that may track into adulthood. Physical activity, sedentary behaviour, and caloric intake are known to be associated with obesity in children and youth. However, previous studies relied primarily on cross-sectional designs and proxy measures of adiposity such as BMI to classify children as overweight or obese. Thus, a gold standard tool (DXA) was used to assess body fat (BF) % and its determinants were measured longitudinally in an ethnically diverse cohort of Canadian children and youth. The objective was to determine whether sedentary behaviour, physical activity, and daily caloric intake predicted BF% over time.

This longitudinal analysis included data obtained from 312 participants (138 boys) aged 9-21 years (mean = 14.6, SD = 3.2 years) of Asian (n=147) and European Ancestry (n=138) enrolled in the University of British Columbia's Healthy Bones III Study. Participants were measured between 1 and 4 times resulting in 748 total measurements. Age at peak height velocity (APHV) was used to generate a continuous

⁶ A version of this material is in preparation for publication: McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., Hofer, S.M., and McKay, H. Is adiposity predicted by physical activity, sedentary time, or caloric intake as boys and girls mature?: A 4-year mixed-longitudinal DXA-based study. (In preparation). Also, a preliminary, cross-sectional version of this work was peer-reviewed for conference presentation: McConnell-Nzunga, J., Naylor, P.J., Macdonald, H., Rhodes, R.E., and McKay, H. Diet and physical activity predictors of body fat percent vary by sex in a sample of Canadian children, youth, and young adults. (2017). Presented to International Society of Behavioral Nutrition and Physical Activity. Victoria, BC, Canada.

measure of MO where MO=0 at APHV. Sex and ethnicity were gathered from self-report questionnaires. Dietary recall (24-hr recall) measured daily caloric intake (kcal) and ActiGraph accelerometers (GT1M) measured time spent in moderate-to-vigorous PA (MVPA, minutes/day) and sedentary time (minutes/day) adjusted for wear time. Polynomial multilevel models were fit to examine the associations between these predictors and BF% with MO as the time variable centered at 0.

Sex was a significant predictor of nonlinear change in BF%; predicted annual rate of change in BF% was 2.1% less in boys compared with girls and this decline decelerated by 0.2% over time. In both sexes, a 10% increase in MVPA above the cohort average predicted an 11.6% decrease in BF% at MO=0, and a 1.9% linear increase in BF% annually. In both sexes, a 10% increase in sedentary time above the cohort average predicted a 4.1% decrease in BF% at MO=0, and a 0.7% linear increase in BF% annually. Lastly, in both sexes, an increase of 100 calories above the average for the cohort predicted a decrease in BF% by 0.3% at MO=0.

The rate of change in BF% over time was different between boys and girls and differences in MVPA, sedentary time, and caloric intake between individuals influenced BF% at age at peak height velocity as well as the rate of change in BF% over time.

5.2. Introduction

Excess adiposity in childhood and adolescence increases the risk of adverse health outcomes (Cook et al., 2003; Weiss et al., 2004) and is likely to track into adulthood (Roberts et al., 2012). Nearly 1 in 7 Canadian children have obesity (Rao, Kropac, Do, Roberts, & Jayaraman, 2016) as measured by BMI. However, anthropometric indices such as BMI do not discriminate between fat mass and fat-free mass (Prentice & Jebb, 2001). This is problematic because it is excess fat specifically that is associated with adverse health outcomes that are concerning for public health agencies across Canada (Greenberg & Obin, 2006; Public Health Agency of Canada, 2012). Although rates of overweight and obesity have remained stable over the past decade, many obesity prevention and treatment interventions have mixed results (Lytle, 2009; Waters et al.), indicating that gaps remain in our understanding of how body fat develops and what predicts development of body fat throughout childhood and adolescence.

Physical activity may be protective against obesity as it burns calories, directly influencing energy balance (Saunders, 2011). Unfortunately, most Canadian children and youth do not meet the 60 minutes/day of MVPA recommended for health benefits (Colley et al., 2011). As such, physical activity has been the focus of many childhood obesity interventions but, once again, with mixed results (Reilly & McDowell, 2003; Wang et al., 2013). Although there is an association between physical inactivity and obesity in children and youth (Janssen, Katzmarzyk, Boyce, King, & Pickett, 2004; Trost, Kerr, Ward, & Pate, 2001) the relationship is complex, as high rates of obesity can be both a contributing factor to and a consequence of low total physical activity (Bauman et al., 2012).

Low levels of physical activity may be accompanied by high levels of time spent in sedentary activities (Epstein et al., 2002; Robinson, 1998), each of which pose an independent risk for obesity and adverse health outcomes (Tremblay et al., 2011). High levels of sedentary time are associated with greater body weight in children and youth (Carson et al., 2016; Tremblay et al., 2011). Unfortunately, Canadian children and youth are spending many of their waking hours in sedentary activities; boys accumulate 8.5 hours of sedentary time per day, on average, and girls accumulate 8.7 hours of sedentary time per day, on average, (Colley et al., 2013), which puts youth at an increased risk for obesity.

Caloric intake above energy expenditure will result in storage of energy as fat and will eventually lead to obesity (Davison & Birch, 2001). Caloric intake has been associated with an increase in BMI cross-sectionally in some studies in children and adults (Bouchard et al., 1990; Huang et al., 2004; Levine, Eberhardt, & Jensen, 1999) but not in others (Davis et al., 2007; Moreno & Rodríguez, 2007). Research on the association between obesity and dietary caloric intake in Canadian children and youth is limited and findings are similarly heterogeneous (Garriguet, 2004; Gillis et al., 2002).

In addition to varying associations between MVPA, sedentary time, caloric intake, and obesity, occurring in tandem with these behaviours are important sex and ethnic differences in development of BF% during maturation. During adolescence, the quantity and location of body fat changes (Must, Dallal, & Dietz, 1991; Must et al., 1992; Strauss, 2000). Specifically, puberty initiates changes to hormones that influence body composition during puberty (cortisol, insulin, growth hormone, and the sex steroids (Roemmich & Rogol, 1999)) whereby boys gain muscle mass and lose fat mass and girls

gain more body fat (Malina et al., 2004; Rogol et al., 2002). For boys, BF% increases before puberty then declines and for girls, BF% is stable pre puberty then increases (Cheek, 1968). The development of obesity over time also differs between sexes, as approximately 30% of adult obesity may begin in adolescence for females and 10% for males (Braddon et al., 1986).

In Canada, prevalence of overweight and obesity varies by ethnicity, as 28% of white, 29% of black, 18% of Southeast and East Asian, 41% of off-reserve aboriginal, and 27% of 'other' youth had overweight or obesity in 2004 (Shields, 2006). This is concerning because there is variation in the deposition of body fat and associated health risks among ethnic groups. For example, Indian and Asian children have a lower BMI but greater BF% and black children have greater BMI but lower BF% compared with Caucasian children (Freedman et al., 2008; Lakshmi et al., 2012). Asian-Indian children are also more insulin resistant than Caucasian children at the same BF% (Lakshmi et al., 2012), and Asian children have adverse total cholesterol levels at the same BMI as compared with Caucasian children (Holmes et al., 2015).

Heterogeneity of study findings examining the association between MVPA, sedentary time, caloric intake and obesity, coupled with the variability related to gender and ethnicity highlights the issues limiting our current understanding of the development of BF%. Overweight and obesity develop over time, and as such longitudinal studies are the most appropriate method to capture obesity-related changes in body composition and discern the sequence of events as well as within- and between-person differences (Pettigrew, 1990). Most longitudinal studies of obesity in Canadian children and adolescents were based on national survey data with proxy measures rather than direct

measures of obesity (Carter et al., 2012; Oliver & Hayes, 2008; Tremblay & Willms, 2000; Tremblay & Willms, 2003). I aim to address these limitations and expand upon the current body of research by controlling for maturity which is associated with BF% for boys and girls (Daniels et al., 1997a) using APHV, something that has not yet been done in obesity research on Canadian children and youth.

Thus, my primary objective is to evaluate the longitudinal associations between MVPA, sedentary time, dietary calories, and BF% in an ethnically diverse cohort of boys and girls. I hypothesize that MVPA will negatively predict development of BF% in boys and girls, and sedentary time and caloric intake will positively predict BF% in boys and girls.

5. 3. Methods

I provided a detailed description of study design and methods for data collection in Chapter 2 and a brief summary below.

5. 3. 1. Study design and participants

Participants were drawn from the HBSIII Study cohort. HBSIII is a mixed longitudinal study that includes four cohorts of children and adolescents from previous school-based studies (HBS, Bounce at the Bell, Action Schools! BC pilot, 2009 cohort). Participants were measured yearly beginning in 1999. My analysis sample included 312 participants (Figure 5.1) measured between 1 and 4 times from 2008-2011 when participants had both accelerometry and DXA scans resulting in 748 total observations.

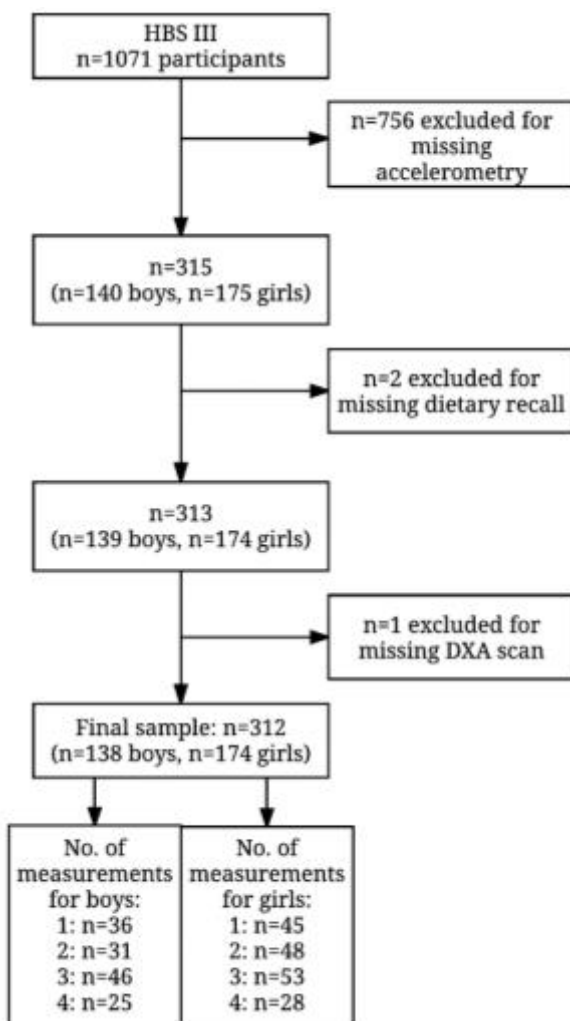


Figure 5.1. Participant inclusion diagram. HBSIII = Health Bones Study III; DXA = Dual energy x-ray absorptiometry.

5. 3. 2. Measurements

5.3.2.1 Demographics

Sex and ethnicity were determined using a questionnaire, completed by parents at baseline. Individuals were classified as Asian if both parents or three of four grandparents were born in Hong Kong, China, Japan, Taiwan, Philippines, Korea or India, and European, referred to as “Reference” if both parents or three of four grandparents were born in North America or Europe. Participants of mixed or other ethnicities (e.g. African, mixed-race, First Nations) were classified as “Other”.

5.3.2.2. Anthropometry and age at peak height velocity

Standing (cm) and sitting height (cm), and body mass (kg) were assessed using standard methods. Years from APHV represented biological maturity which was either determined directly using the cubic spline method or estimated using ethnic-specific predictions equations (Moore et al., 2015). The cubic spline method was only possible in 157 participants in this sample due to missing and mistimed anthropometric measurements. Therefore, I used the Moore equation to estimate APHV for the remaining Caucasian and Other participants, as well as ethnic-specific equations (unpublished) for Asian participants based on anthropometric data from the measurement occasion closest to the expected APHV (approximately 11.6 years in girls and 13.5 years in boys). Once all participants had an APHV, I subtracted APHV from chronological age at time of measurement to generate a continuous measure of biological age called MO in years (e.g., -1 year equals 1 year prior to attainment of APHV; +1 to one year after APHV).

5.3.2.3. Caloric intake

All participants completed a validated 24-Hour Food Recall questionnaire (Lytle et al., 1998) that was used to estimate total dietary calories (kcal/day) (Food Processor SQL, 2008). Visual inspection of the data through histograms and scatterplots revealed several outliers. I therefore performed a winsorization imputation technique to replace any data points under the 1st and over the 99th percentiles with the value of the 1st (747.1 kcal) and 99th percentiles (5703.5 kcal) respectively. Affecting 6 girls and 7 boys, a total of 14 data points were imputed this way (7 below the 1st percentile and 7 above the 99th percentile). This is a valid method to treat outliers (Dixon & Tukey, 1968; Guttman & Smith, 1969) and is commonly used in nutrition research (Au et al., 2012; D. S. Kim et al., 2013).

5.3.2.4. Body fat percent

BF% was calculated as $F\% = \frac{\text{fat mass (kg)}}{\text{body weight (kg)}}$, using values obtained from total body DXA scans (QDR 4500W; Hologic, Waltham, MA, USA).

5.3.2.5. Physical activity and sedentary time

Minutes per day of MVPA and sedentary time were estimated using accelerometry (ActiGraph GT1M) with 15-sec epochs and the Evenson cutpoints (a cut

point of <100 cpm was used to classify sedentary time and a cut point of >2296 cpm to classify MVPA) (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Trost et al., 2011). Non-wear time was defined as 60-min of consecutive zero counts. Participants with ≥ 10 hours/day on ≥ 3 days were included in this analysis. I present MVPA and sedentary time as a percent of wear time.

5. 4. Statistical analysis

I considered $p < .05$ statistically significant. Before modelling, I examined scatter plots for BF% and its determinants against MO for each participant. I used a biological age-as-time model to estimate annual change in BF%, with biological age, or MO at MO=0. I considered polynomial multilevel models with effects up to cubic and estimated the models using MPlus Version 8 (Muthén & Muthén, 2017). I centered the time-invariant (level 1) predictors of sex at female and ethnicity at Asian, and I developed models to predict change in BF% across maturity, for each level-1 predictor. Time-varying predictors include both inter-individual variation (i.e., differences between people) and intra-individual variation (i.e., differences over time within the same person) (Hoffman, 2015). I modelled MVPA, sedentary time (SED), and daily caloric intake (referred to in the model as Calorie) to represent the between-person and within-person effects on BF% separately. In my analysis, \overline{MVPA}_i , \overline{SED}_i , and $\overline{Calorie}_i$ contain the individual's mean value across years and represent the level-2 between person differences, while $MVPA_{ti} - \overline{MVPA}_i$, $SED_{ti} - \overline{SED}_i$, and $Calorie_{ti} - \overline{Calorie}_i$ represent the level-1 within-person differences from the person-mean centered variable at

each occasion (where subscript ti is a covariate observation on measurement occasion t in the i th individual and i is the covariate mean for that individual across years (Curran & Bauer, 2011)). I included the random effects to allow each individual to have their own effect of each predictor (Hoffman, 2015).

I began the analysis with an empty between-person model and built up to a final conditional model containing all time-invariant and time-varying predictors. The first model I fit was an empty means random intercept model and I used it to determine the amount of variance in BF% at the between- and within-person levels. I used the intraclass correlation coefficient to determine what percent of the variation in BF% was due to differences between people and how much was due to within person fluctuation. Next, with MO as the time variable, I fit a fixed linear time random intercept model and a random linear time model (allowing each participant his or her own slope for the effect of maturity). I proceeded to investigate models with fixed and random quadratic and fixed cubic time parameters (Hoffman (2015) showed that random cubic parameters cannot be estimated with only 4 measurement occasions). I used Wald test p-values to determine significance of individual fixed effects and relative reduction in the deviance test ($-2\Delta LL$) and χ^2 test of significance of random effects variances and covariances between nested models.

I determined that a random quadratic functional form was the best unconditional growth model to represent development of BF% over MO, referred to as Model 1a. Next, I added sex and two ethnicity dummy variables (to represent the three ethnicity categories) to the random quadratic model on the intercept, linear and quadratic terms,

referred to as Model 1b, and tested the corresponding significance using the Wald test. I retained sex and ethnicity on all parameters.

Next, I developed a series of models to address my objective to investigate the longitudinal associations between MVPA, SED, Calorie and BF% in boys and girls. I tested MVPA, SED, and Calorie starting with an empty means random intercept model through a random quadratic model to determine the amount of variance attributed to between- and within-person differences and how much individual change each covariate exhibited over MO. I tested the significance of the model improvement using the relative reduction in the deviance test ($-2\Delta LL$) and χ^2 test of significance. All models were additionally controlled for the individual's within-person and between-person effects of height to adjust for body size.

The best fitting model, referred to as Model 3, included both within- and between-persons effects of MVPA, SED, Calorie, sex, both ethnicity dummy variables, and height on the intercept, linear and quadratic parameters. I added interaction terms to examine potential moderation of the effects of MVPA, sedentary time, and calories at each level by sex and the effects of MVPA, sedentary time, and calories by maturity. Additionally, I tested the interaction effects of calories by MVPA and sedentary time, as well as the interaction of MVPA and sedentary time. However, as the interaction terms did not significantly improve model fit (based on $-2\Delta LL$ and AIC and BIC values) I removed them from the model. I visually inspected the models using residual plots (Verbeke, 1997); diagnostics revealed adequate model fit.

Model 3 is specified as follows:

Level 1

$$Y_{ti} = \beta_{0i} + \beta_{1i}(MO_{ti}) + \beta_{2i}(MO_{ti})^2 + \beta_{3i}(MVPA_{ti} - \overline{MVPA}_i) \\ + \beta_{4i}(SED_{ti} - \overline{SED}_i) + \beta_{5i}(Calorie_{ti} - \overline{Calorie}_i) + \beta_{6i}(Height_{ti} - \overline{Height}_i) + e_{ti}$$

Level 2

$$\text{Intercept: } \beta_{0i} = \gamma_{00} + \gamma_{01}(Sex_i) + \gamma_{02}(EthnicityC_i) \\ + \gamma_{03}(EthnicityO_i) + \gamma_{04}(\overline{MVPA}_i) + \gamma_{05}(\overline{SED}_i) + \gamma_{06}(\overline{Calorie}_i) \\ + \gamma_{07}(\overline{Height}_i) + U_{0i}$$

$$\text{Linear time: } \beta_{1i} = \gamma_{10} + \gamma_{11}(Sex_i) + \gamma_{12}(EthnicityC_i) + \gamma_{13}(EthnicityO_i) \\ + \gamma_{14}(\overline{MVPA}_i) + \gamma_{15}(\overline{SED}_i) + \gamma_{16}(\overline{Calorie}_i) + \gamma_{17}(\overline{Height}_i) + U_{1i}$$

$$\text{Quadratic time: } \beta_{2i} = \gamma_{20} + \gamma_{21}(Sex_i) + \gamma_{22}(EthnicityC_i) \\ + \gamma_{23}(EthnicityO_i) + \gamma_{24}(\overline{MVPA}_i) + \gamma_{25}(\overline{SED}_i) + \gamma_{26}(\overline{Calorie}_i) \\ + \gamma_{27}(\overline{Height}_i) + U_{2i}$$

$$\text{Within-person MVPA: } \beta_{3i} = \gamma_{30} + U_{3i}$$

$$\text{Within-person SED: } \beta_{4i} = \gamma_{40} + U_{4i}$$

$$\text{Within-person Calorie: } \beta_{5i} = \gamma_{50} + U_{5i}$$

$$\text{Within-person Height: } \beta_{6i} = \gamma_{60} + U_{6i}$$

MO is maturity offset (centered at 0, APHV); Boys = 1, Girls =0; EthnicityC (Caucasian) =1, EthnicityO (Other) =1, Asian as the reference group.

Where y_{it} is body fat percent on measurement occasion t in the i^{th} individual

To achieve convergence, I scaled particular covariates. I multiplied SED and MVPA by 10 at both the within-person and between-person levels and divided Calorie by 10. As such, the reported coefficients represent the change in BF% for a 10% difference in MVPA or SED as a percent of wear time and the change in BF% for a 10 Calorie difference.

5. 5. Results

The sample included 312 participants (girls =174; 56%) between 9 and 21 years of age (mean=14.6, SD = 3.2 years) at first measurement. Overall, participants contributed 748 measurements (see Table 5.1 for the number of DXA measurements for boys and girls by MO). Participants were ethnically diverse with 47% identifying as Asian, 44% as Reference, and 9% as other. I provide participant characteristics for all demographics and covariates at first measurement in Table 5.2.

Table 5.1. Number of DXA measurements of BF% by sex and maturity offset.

Maturity Offset	Girls	Boys
-4	-	1
-3	3	18
-2	18	26
-1	44	28
0	54	14
1	37	17
2	15	27
3	9	39
4	29	50
5	41	41
6	37	31
7	38	24
8	40	12
9	18	5
10	16	3
11	12	-
12	1	-
Total	412	336

Table 5.2. Characteristics of boys and girls at first accelerometry measurement occasion.

	Girls (n=174)			Boys (n=138)		
	Mean (SD)	Min	Max	Mean (SD)	Min	Max
Age (years)	14.4 (3.5)	9.5	21.3	14.9 (2.9)	9.5	21.6
No. Asian / Reference / Other	84 / 75 / 15	-	-	63 / 63 / 12	-	-
Maturity offset (years)	2.92 (3.56)	-2.65	10.62	1.73 (3.0)	-4.06	9.31
APHV (years)	11.5 (0.7)	9.4	14.1	13.1 (0.9)	10.9	15.9
Height (cm)	154.9 (11.4)	130.0	181.6	165.3 (14.5)	129.7	192.2
Body fat percent	26.8 (6.3)	12.5	46.5	18.8 (8.1)	7.1	40.2
Accelerometer wear time (min/day)	834.6 (74.6)	655.9	1073.0	840.5 (69.7)	662.0	999.5
SED (min/day)	592.4 (101.7)	324.6	868.1	584.1 (105.3)	347.4	804.0
MVPA (min/day)	40.6 (17.5)	4.8	104.1	59.6 (26.7)	14.7	142.8
Daily calories (kcal)	2130.9 (883.0)	747.1	5703.1	2891.5 (1196.5)	757.2	5703.5

Maturity offset is years from age at peak height velocity (APHV). SED, sedentary activity; MVPA, moderate to vigorous physical activity.

The intraclass correlation was 0.922 indicating that 92.2% of the variation in BF% was due to differences between people and 7.8% of the variation was due to within person fluctuation.

Just over a quarter of the sample (26%) met the minimum recommended daily requirements of 60 minutes/day of MVPA, on average. Participants accumulated nearly 9 hours/day of sedentary time, on average (mean=539.9 minutes; SD=100.3 minutes). Boys consumed more calories, on average, than is recommended by Health Canada, which ranges from 1750 to 2700 kcal/day for boys aged 9 to 19 years, respectively. Girls caloric intake was at the upper end of the recommended range for girls aged 9-19 years (1600 to 2100 kcal/day) (Katamay et al., 2007).

5.5.1. Influence of MVPA, sedentary time, and daily caloric intake on BF%

I provide results of multilevel mixed models to examine the influence of MVPA, sedentary time, and caloric intake on BF% in

Table 5.3. Results from Model 1a indicate significant individual variation in BF% at MO=0 (intercept), as well as in the linear, and quadratic change in BF% across maturity. According to this model, BF% is expected to be 22.8% (SD = 0.52%) at MO=0 decreasing linearly by -0.291% annually and accelerating by an additional 0.08% per year as indicated by the significant quadratic parameter.

In model 1b, I examined the time invariant effects of sex (0=girls) and ethnicity (0=Asian; represented by 2 dummy variables) on the intercept, and linear, and quadratic slopes annually. Sex had a significant effect on the intercept linear, and quadratic parameters, indicating that boys were predicted to have 1.1% less BF% at MO=0 compared with girls. The negative linear slope and positive quadratic slope signify that BF% was predicted to decline for boys but this decline decelerated over time. BF% was different only with ethnicity “other” predicted to significantly accelerate over time by 0.1% per year. Residual variances remained significant for the intercept, linear, and quadratic terms indicating individual variation in the level of BF% at MO=0 as well as the rate of change over time.

Table 5.3. Body fat percent model building results. Results from an unconditional growth model (1a), a conditional growth model (1b), a fully adjusted growth model (3) for body fat percent. Model 3 shows the longitudinal effects of MVPA, sedentary time (SED), and caloric intake (Calorie) as predictors of body fat percent. Numbers in brackets indicate the standard error of the parameter and values are bolded where $p < .05$.

Model effects		Model 1a		Model 1b		Model 3	
		Estimate	<i>p</i>	Estimate	<i>p</i>	Estimate	<i>p</i>
<u>Intercept</u>							
γ_{00}	Body fat percent	22.830 (0.52)	0.000	25.043 (0.837)	0.000	29.293 (1.629)	0.000
γ_{01}	Sex			- 4.936 (0.991)	0.000	- 0.860 (1.236)	0.486
γ_{02}	MVPA					- 11.621 (2.598)	0.000
γ_{03}	SED					- 4.122 (0.951)	0.000
γ_{04}	Calorie					- 0.030 (0.006)	0.000
γ_{05}	EthnicC			- 0.302 (1.015)	0.765	0.230 (1.017)	0.821
γ_{06}	EthnicO			- 0.232 (1.860)	0.901	0.855 (1.702)	0.616
<u>Linear</u>							
γ_{10}	Intercept	- 0.291 (0.165)	0.078	0.522 (0.271)	0.042	0.498 (0.606)	0.411
γ_{11}	Sex			- 1.854 (0.312)	0.000	- 2.129 (0.386)	0.000
γ_{12}	MVPA					1.944 (0.847)	0.022
γ_{13}	SED					0.657 (0.327)	0.045
γ_{14}	Calorie					0.003 (0.002)	0.097
γ_{15}	EthnicC			0.038 (0.316)	0.905	0.050 (0.342)	0.883
γ_{16}	EthnicO			- 0.482 (0.558)	0.388	- 0.040 (0.526)	0.939
<u>Quadratic</u>							
γ_{20}	Intercept	0.076 (0.017)	0.000	0.011 (0.020)	0.704	0.024 (0.064)	0.704
γ_{21}	Sex			0.125 (0.035)	0.000	0.159 (0.041)	0.000
γ_{22}	MVPA					- 0.164 (0.092)	0.073
γ_{23}	SED					- 0.048 (0.038)	0.209
γ_{24}	Calorie					0.000 (0.000)	0.177
γ_{25}	EthnicC			- 0.013 (0.035)	0.717	- 0.015 (0.037)	0.685
γ_{26}	EthnicO			0.120 (0.059)	0.042	0.041 (0.052)	0.426
<u>Within-person</u>							
γ_{30}	MVPA					- 1.257 (0.664)	0.058
γ_{40}	SED					0.361 (0.286)	0.206
γ_{50}							

					Calorie		
					- 0.001 (0.001)	0.255	
<u>Variiances</u>							
u_{0i}	Intercept	54.504 (5.907)	0.000	45.526 (4.966)	0.000	36.061 (4.252)	0.000
u_{1i}	Linear	3.024 (0.556)	0.000	2.063 (0.436)	0.000	0.302 (0.831)	0.716
u_{2i}	Quadratic	0.016 (0.006)	0.003	0.017 (0.006)	0.008	0.001 (0.009)	0.890
u_{3i}	MVPA					1.070 (4.445)	0.810
u_{4i}	SED					1.171 (0.912)	0.199
u_{5i}	Calorie					0.000 (0.000)	0.878
ε_{ti}	Residual	2.618 (0.256)	0.000	2.754 (0.279)	0.000	2.091 (0.252)	0.000

ML Model fit

Number of parameters	10	19	39
-2 LL	4281.588	4142.362	3991.198
AIC	4301.587	4180.362	4069.198
BIC	4347.761	4207.76	4249.276

Notes: Model 1a estimates a random quadratic model for body fat percent by maturity offset as time, where the intercept is MO=0 years. Model 1b includes model 1a plus the time-invariant covariates of sex and ethnicity. Model 3 includes model 1b plus the time-varying covariates of MVPA, SED, and Calories. Model 3 is additionally controlled for height. MVPA is moderate to vigorous physical activity; SED is sedentary time; EthnicC indicates individual's ethnicity is Reference; EthnicO indicates individuals' ethnicity is other. Asian Ethnicity is the reference group. MVPA and SED are expressed as a percent of wear time and multiplied by 10. Calorie (kcal) is divided by 10.

In model 3, I added time-varying covariates both within- and between-persons to predict BF% across maturity. Sex remained a significant predictor of nonlinear change in BF%; rate of change in BF% was 2.1% less per year from APHV in boys compared with girls but this decline decelerated by 0.2% over maturity.

In model 3, MVPA was a significant predictor of BF% on the intercept and linear slope parameters indicating that at MO=0 10% more MVPA than the cohort average predicts 11.6% lower BF%. However, for each year past MO=0 a 10% increase in MVPA was associated with a 1.9% increase in BF%. Similarly, 10% more sedentary time above the cohort average at MO=0 predicted 4.1% less BF%, but for each year past MO=0 a

10% increase in sedentary time was associated with a 0.7% increase in BF%.

Unexpectedly, an increase in 100 calories (kcal per day) above the average for the cohort predicted 0.3% less BF% at MO=0. Figure 5.2 provides a visual depiction of model 3.

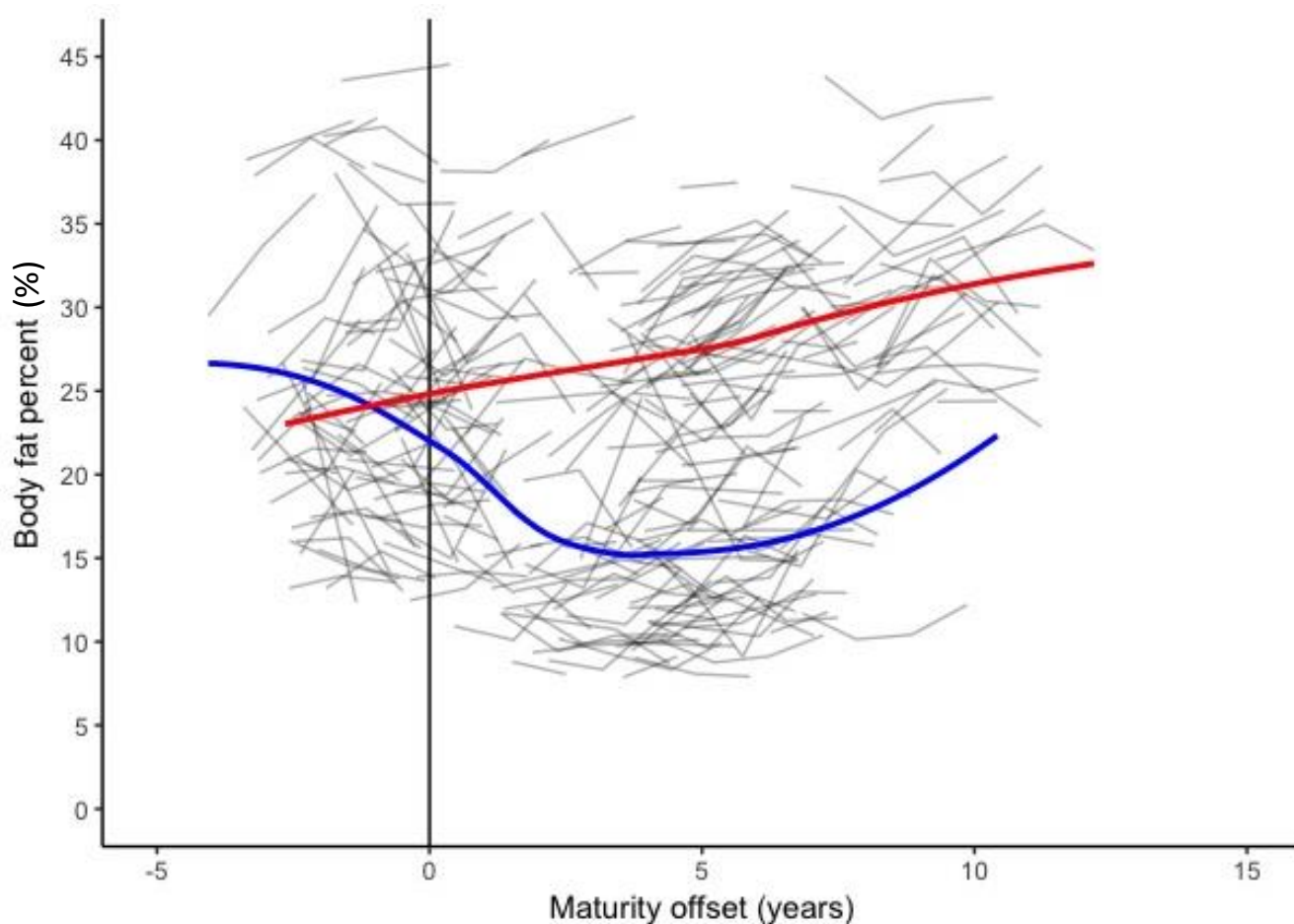


Figure 5.2. Body fat percent individual growth curves for all participants (thin grey lines) and the fully adjusted polynomial mixed model (model 3) growth curves for boys (blue line) and girls (red line) for body fat percent. The vertical line indicates maturity offset (years from age at peak height velocity) of 0.

I did not find any significant within-person effects for MVPA, sedentary time, or caloric intake on BF%. This indicates that an individual's deviation from their own usual level of MVPA, sedentary time, or caloric intake did not predict BF% accrual.

5.6. Discussion

In this study, I used longitudinal multilevel mixed models to investigate BF% accrual and its determinants in children and youth across maturity. My study is the first to longitudinally assess body fat using objective measures and biological age in an ethnically diverse sample of Canadian children and youth. I provide unique insight into development of BF% across maturity and unravel the within- and between-person differences (if an individual varies around their own average or “usual” behaviour, and if the individual's usual behaviour differs around the usual for the cohort) in MVPA, sedentary time, and caloric intake. My results suggest that rate of change in BF% across maturity differs between boys and girls and that differences in MVPA, sedentary time, and caloric intake between individuals influences BF% at APHV as well as the accrual of BF% across maturity.

Results of my multilevel mixed models highlight significant between-person differences in the predictors of BF% accrual, but no significant within-person variation. This means that individuals getting more or less MVPA, sedentary time, or caloric intake than what is “usual” for them was not significantly associated with BF%. This may be due to the tracking effect observed in physical activity, caloric intake (Craigie, Lake, Kelly, Adamson, & Mathers, 2011; Janz, Burns, & Levy, 2005; Telama, 2009; Telama et al., 2005) and sedentary behaviour (Biddle, Pearson, Ross, & Braithwaite, 2010) across

childhood and adolescence. Tracking of these behaviours across age is complex, as an example, MVPA declines in some groups (Farooq et al., 2017; Kimm et al., 2002) but tracks across others, often tracking more strongly in boys than girls (Janz et al., 2005; Telama, 2009; Telama et al., 2005). In the current study, assessing youth aged 9 years or older at baseline may have been too late to observe the impact of within-individual variation in MVPA, sedentary time, or calories as these behaviours could already be well established and stable. If this is the case, public health interventions may need to focus efforts on the earlier years before physical activity, sedentary time, and eating behaviours are set.

5.6.1 MVPA

MVPA burns calories and directly influences energy balance (Saunders, 2011) but despite this biological process, findings from previous studies that examined the association between MVPA and BF% are equivocal. Similarly, I found that MVPA was negatively associated with BF% at APHV (as expected based on the biological mechanism) and positively associated with the rate of change per year from APHV (which was unexpected). I identified four other longitudinal studies that examined DXA-derived BF% accrual and accelerometry-measured physical activity (Janz et al., 2005; Janz et al., 2009; Riddoch et al., 2009; Stevens et al., 2004). The age of participants in these 4 studies varied from 5 to 12 years old at baseline, and after 2 to 6 years of follow up, participants were between 9 and 14 years old at study end. The results were also not

conclusive, including favourable, and null associations between BF% accrual and physical activity across different intensities.

The study most similar to mine included 4150 boys and girls whose fat mass (by DXA) and physical activity (by accelerometry) were measured across two years (at age 12 and again at age 14 years) (Riddoch et al., 2009). Total physical activity and daily MVPA at age 12 were associated with fat mass at age 14 in boys and girls. An extra 15 minutes/day (approximately) of MVPA at age 12 was associated with 11.9% lower fat mass at age 14 for boys and a 9.8% lower fat mass for girls. In my study, 5 minutes/day (approximately) of MVPA above the cohort average (about 50 minutes/day) predicted 11.6% lower BF% at APHV (approximately 11.6 years old for girls and 13.5 years old for boys). However, per year from APHV, a 10% increase in MVPA was associated with 1.9% more BF% indicating that although the association between MVPA and BF% was negative at APHV, the association became less negative over time. I investigated the within- and between-person effects separately and only found a significant association with BF% at the between-person level. As Riddoch and colleagues (2009) did not disaggregate the within- and between-person effects it is difficult to compare results between studies.

Physical activity interventions are able to increase MVPA up to 11.8 minutes per day in children and adolescents (van Sluijs, McMinn, & Griffin, 2007). Based on my prediction equations, an increase in MVPA of that magnitude could have a large impact on BF% at APHV, particularly if the individual's baseline MVPA level is at or near 50 minutes/day. This has public health implications as it provides some evidence that a small change in MVPA may have a large effect on BF%.

5.6.2. Sedentary time

I found that increased sedentary time was associated with a lower BF% at APHV (unexpected), but for each year past APHV an increase in sedentary time was associated with an increase in BF% (expected). These findings contribute to an existing literature base that is not definitive about the relationship between sedentary time and obesity; a recent systematic review of sedentary behaviour and a range of body composition outcomes (BMI, waist circumference, BF%) in children and youth found mostly null associations for longitudinal studies using accelerometer-derived sedentary time (Carson et al., 2016). Three of nine studies reported unfavorable body composition outcomes with increased sedentary time, one study found a favourable association with increased sedentary time and waist circumference outcomes and the remaining 5 studies found no association. One of the studies that demonstrated a null finding used DXA-derived fat mass and log-transformed BF% as outcomes and controlled for maturity using estimated APHV (Kwon, Burns, Levy, & Janz, 2013; Mirwald et al., 2002), providing a sound comparator for my results. Kwon and colleagues (2013) studied 554 white boys and girls measured at ages 8, 11, 13 and 15 years and found that sedentary time and frequency of breaks in sedentary time were not associated with FM. I included time points well beyond 15 years of age in my analysis and this may be why a positive association was shown after APHV (which was around 13 years when averaged across boys and girls).

A second systematic review of longitudinal studies found little evidence that changes in sedentary time were associated with changes in adiposity (many studies used BMI as an outcome) in children and youth (Tanaka, Reilly, & Huang, 2014). However, the authors reported consistent evidence that sedentary behaviour increased by

approximately 30 minutes/day per year in school-aged boys and girls (Tanaka et al., 2014). As I found a negative relationship between sedentary time and BF%, where more sedentary time was associated with less BF%, the reported trend of increasing sedentary time across age (Tanaka et al., 2014), may be masking any underlying associations with BF% in my sample.

5.6.3. Caloric intake

The finding that an increase of 100 calories above the average for the cohort was related to a decrease in BF% by .3% is contrary to my hypothesis but is not out of line with the literature. The relationship between caloric intake and BMI was positive in some studies of children and adults (Bouchard et al., 1990; Huang et al., 2004; Levine et al., 1999), but null (Davis et al., 2007; Moreno & Rodríguez, 2007) and negative in others (Gazzaniga & Burns, 1993; Nielsen, Siega-Riz, et al., 2002; Ortega et al., 2007). Findings from the limited research on Canadian children are similarly heterogeneous. For example, in a cross-sectional study of 181 Canadian children aged 4-16 years, girls and boys with obesity had significantly greater total EI (approximately 400 calories per day) than their peers without obesity suggesting a clear association (Gillis et al., 2002). While results from the 1970-1972 Nutrition Canada Survey (National Health and Welfare, 1977) and the 2004 Canadian Community Health Survey (Statistics Canada, 2004) show that caloric intake decreased between the two survey cycles for males 12-64 years old and remained the same for females (Garriguet, 2004).

I hypothesized that increased caloric intake would be associated with an increase in BF% due to the biological mechanism: caloric intake above energy expenditure results

in storage of energy as fat and eventually in excessive levels of body fat (Davison & Birch, 2001). Although there is biological plausibility for the association between caloric intake and adiposity, there are many potential reasons why the relationship did not consistently appear as expected in my analysis. Although the HBSIII used a valid 24-hour dietary recall tool (Lytle et al., 1998; Mullenbach et al., 1992), dietary data are notoriously difficult to collect from children (Huang & McCrory, 2005). For instance, during data cleaning, I noted values as low as 78 kcal per day and as high as 22,000 kcal per day. Moreover, there is also evidence supporting the association between obesity and specific nutrients such as dietary fat (Davis et al., 2007) and calcium intake (da Cunha, 2015).

My study is not without limitations. First, I chose BF% to represent adiposity which includes fat mass in the numerator and denominator. This can pose a statistical problem as individuals with obesity could experience large changes in fat mass with only small changes in BF% (Wells, 2000). Additionally, other measures of adiposity such as total fat mass and fat mass index (Demerath et al., 2006; Flegal et al., 2010) may also be associated with health risks in children and youth and should be explored in future studies. Second, I did not account for regional distribution of body fat, which is strongly associated with health outcomes for children and youth (Daniels et al., 1999). Third, the HBSIII cohort was a convenience sample, which limits external validity of my findings. Fourth, I did not assess individual components of dietary analyses, and finally, uniaxial accelerometers were not worn during water-based activities such as swimming, they can't accurately capture certain activities (i.e., bicycling or carrying loads), and they do not distinguish between sedentary postures such as sitting, standing and lying down.

Therefore, some physical activities were likely not included in my measure of MVPA, and standing time may have been included in estimates of sedentary time.

5.7. Conclusions

My study was uniquely positioned to examine predictors of BF% development during maturation in children and adolescents. To the best of my knowledge, this is the first longitudinal study to examine determinants of body fat accrual during child and adolescent growth while aligning Canadian girls and boys on a common maturational time point and using an objective measure of MVPA and sedentary behaviour. My study adds unique findings to the field of body fat development and its determinants across maturity highlighting the potential need for early intervention, the strength of the association between BF% and MVPA and the smaller effect of sedentary time and caloric intake in this select sample.

The strong association I observed between MVPA and BF% was apparent only between individuals, which highlights the potential tracking effect of MVPA across maturity in this cohort. Of particular interest is that the influence of MVPA on BF% slowly became less negative per years post-APHV indicating that adolescents may need to increase their activity levels as they age to protect against increased BF%. The association between sedentary time and BF% similarly changed direction; sedentary time was negatively associated with BF% at APHV but positively association per year from APHV. Caloric intake was negatively, albeit weakly, associated with BF% at APHV and this association did not change across maturity. The unexpected relationships I found

between increased sedentary time and increased calories and lower BF% may be artifacts of trends of increasing sedentary time during later adolescence or the relative importance of diet composition over total caloric intake. Future studies should use newer accelerometers or ActivPALs (Godfrey, Culhane, & Lyons, 2007) capable of capturing a wider range of physical activities and sedentary behaviours. In addition, investigation of specific dietary components such as fat or calcium intake could elucidate a stronger relationship between diet and BF%. Lastly, investigating different components of body fat distributions could yield outcomes more closely tied to risk of adverse health outcomes.

Chapter 6 : Integrated Discussion

Chapter 6 is the culminating chapter of my dissertation. The overall aim of my dissertation was to investigate BF%, specifically, its measurement and its development and determinants over time in a diverse group of Canadian children and adolescents. I conducted three studies to achieve this aim. In this chapter, I first briefly summarize and integrate key findings from the three studies (Chapters 3-5), and then discuss the unique contributions and implications of my findings to the field of childhood obesity research. I follow this with a discussion of the overall limitations, and outline opportunities for future research.

6.1. Overview of findings

6.1.1. Body fat accrual trajectories for Asian and Caucasian-Canadian children and youth: A longitudinal DXA-based study

Summary (Primary objective – develop BF% distance and velocity centile curves)

- A) Distance centile curves reflected the change in body composition as boys and girls matured; boys gained more fat-free mass and girls gained more fat mass. Curves for Asian and reference participants were of similar shape for girls but not boys.
- B) BF% velocity curves showed the change in body composition for boys and girls as they matured; differences in velocity centile curves between ethnicities were apparent for boys only.

6.1.2. Classification of obesity varies between BMI and direct measures of body fat in boys and girls of Asian and European ancestry

Summary (Primary objective - examine how BMI classifications categorized children and youth compared with BF%)

- A) BMI identified <50% of those classified as obese from BF%; specificity was 99.7%, and sensitivity was 35.8%.

Summary (Secondary objective - investigate how age, sex, and ethnicity influence classification of obesity by BMI and BF%)

- A) BMI performed significantly better for: males vs females at 10 years old, Asian vs Reference females except at 13, 15, and 16 years old, Asian females vs males except at 10 and 15 years old, and for Reference males vs females, 9-11 yrs.

6.1.3. Is adiposity predicted by physical activity, sedentary time, or caloric intake as boys and girls mature?: A 4-year mixed-longitudinal study

Summary (Primary objective - To evaluate associations between MVPA, sedentary time, dietary calories and BF% across maturity)

- A) Rate of change in BF% over time differed between boys and girls; in girls, BF% increased across maturity whereas in boys, BF% decreased.

- B) Differences in MVPA, sedentary time, and caloric intake between individuals influenced BF% at APHV and rate of change in BF% across maturity.

6.2. Implications

Taken together, findings from my three studies address gaps in the literature whereby the previous literature frequently relied on proxy measures, cross-sectional designs and included little ethnic diversity. In Chapter 3, I showed how patterning of BF% and BF% velocity through distance centiles and velocity centiles changes as boys and girls age. I draw attention to the fact that at age 18 Asian girls reached a BF% of 35% which is associated with adverse cardio-metabolic health outcomes (De Lorenzo et al., 2003; Organization, 1995; Romero-Corral et al., 2008), nearly 7 BMI percentile points lower than Reference girls at a similar age threshold. This finding highlights the need for future studies to consider ethnic-specific cut-offs for BF% percentiles. Although ethnic-specific cut-offs based on risk do not currently exist, my findings suggest that a lower BF% cut-off for Asian girls than for Caucasian girls would be preferred.

I provide BF% and BF% velocity values at common percentiles (3rd, 10th, 25th, 50th, 75th, 90th, and 97th) in tabular format by sex and ethnic group for the first time for Canadian children and youth. Future research can draw on these values to investigate differences across geographical regions in Canada and attract attention to the need for collection and analysis of BF% that is nationally representative of diverse Canadian youth.

In Chapter 4, I compared obesity classifications between BMI- and DXA-based BF% cut-offs in Asian and Caucasian boys and girls and discovered that BMI identified <50% of those with obesity by BF% and that the BMI-BF% relationship varied by sex and ethnicity. I also provided the first set of BMI cut-offs for Asian- and Reference-Canadian children and youth based on the highest level of sensitivity and specificity to detect obesity by BF%. These findings provide actionable evidence that clinicians and researchers should not compare individuals from different ethnic groups using currently available BMI charts (e.g., WHO charts). The BMI cut-offs I derived reflect a unique geographical sample in Canada and should now be studied in children with measured health outcomes to examine their predictive validity. In generating these cut-offs, I emphasized sensitivity over specificity, which reduces the risk of misclassifying children who do not have obesity. This is particularly important in research with vulnerable populations where misclassification could be especially damaging.

In chapter 5, I demonstrated the strength of the association between BF% and MVPA, the smaller influence of sedentary time and caloric intake on BF%, and the absence of significant individual fluctuation in health behaviours as children mature. These findings can be utilized by public health officials in obesity prevention efforts, highlighting the need to promote MVPA and potentially intervene earlier in childhood before lifestyle behaviours are established. Although my findings and the literature suggest these behaviours may track throughout the lifespan and earlier intervention may have a stronger influence on BF% more research is needed to confirm this.

Taken together, these three studies highlight heterogeneity in BF% development, measurement, and determinants and the absence of a one-size-fits-all answer in obesity

research. I presented evidence of variation in BF% patterning and BF% velocity centiles, obesity definitions, and predictors of adiposity among different age, sex, and ethnic comparisons. It is tempting to evaluate individuals against the same criteria and to anticipate equivalent response to an intervention but that appears to be inappropriate in a multicultural society such as Canada. It is imperative that we adapt our interventions, our measurement of obesity and our expectations of BF% development to reflect individual characteristics such as ethnicity or maturational timing. BMI growth charts have been sex-specific since inception and some nations are moving to ethnic-specific BMI charts as well (Mansourian et al., 2012; Rosario, Kurth, Stolzenberg, Ellert, & Neuhauser, 2010). I would recommend that BF% growth charts be ethnic specific when developed, and accordingly obesity intervention and prevention efforts should be tailored as well.

6.3. Challenges and future directions

In Chapter 1, I highlighted challenges in measurement of adiposity in children and youth, and in Chapters 3-5 I discussed the limitations of each study and analysis specifically. To avoid repetition, in this section I discuss some additional challenges to studying obesity in children and youth and challenges related to longitudinal studies. I conclude this section by discussing the extension of this work for future research.

6.3.1. Studying obesity in children and youth

A major challenge in the obesity research field, which I highlighted in all three of my studies, is the lack of agreed-upon cut-offs and reference data for body fat in children and youth. It is imperative that we reach a consensus on reference data for normative development of body composition and fat distribution throughout maturation and across ethnic groups. The key to developing valid reference data is a clear understanding of risks for adverse health outcomes based on different variations in body fat accrual and body fat distribution and the differential risks among population groups and at different points in growth (Goran, 1997; McCarthy et al., 2006).

Obesity is the result of genetic, environmental, historical, social, and behavioural factors and although robust evidence exists for many single risk factors, there remains a lack of comprehensive understanding of the aetiology of childhood obesity (Karnik & Kanekar, 2012). Obesity researchers point to the need to move from bivariate, cross-sectional studies towards development of a more comprehensive model of factors, potential predictors, and consequences of childhood obesity across the lifespan (Must & Tybor, 2005). This approach should include robust data on dietary, activity, and sleep habits, parenting practices, the environment including household and neighbourhood characteristics, characteristics of the child, such as sex and maturity, parent characteristics including weight status, and social factors such as SES and ethnicity (Davison & Birch, 2001). In reality, the complexity required to gather these data in a valid, reliable, and robust way is a real challenge that is present in my own studies and across the field as a whole.

Obesity develops over time, and thus we should acknowledge the cohort effect of people growing up in different generations with different exposures and experiences

(Atingdui, 2011). Much of the literature on obesity and its development across the lifespan is based on cohorts raised in previous generations when the prevalence of obesity was lower. This highlights an urgent need to re-assess the long-term risks of obesity in modern cohorts with a much higher prevalence of obesity and development of obesity at a younger age than in previous generations (Han, Lawlor, & Kimm, 2010; Reilly et al., 2003).

6.3.2. Challenges inherent to longitudinal studies

Although longitudinal analysis is the preferred analytic design to study childhood obesity, longitudinal studies have disadvantages as well. One of which is assessment intervals; because longitudinal or cross-sectional studies can only gather data at discrete time points no matter how close together or far apart the measurement occasions are. For a nondiscrete process such as development of obesity it would be beneficial to have enough discrete measurements to be able to discern precise transition points and changes in weight trajectories (Ruspini, 2002).

Also, assessment intervals should be theoretically based to capture the outcome of interest at essential points between cause and effect (Ruspini, 2002). However, the time between cause and effect in childhood obesity is not well understood and likely varies across predictors. Most studies that investigated obesity trajectories throughout childhood and adolescence measured children annually (Carter et al., 2012; Danner, 2008; Mustillo et al., 2003; Pryor, Tremblay, & Boivin, 2011) or every two years (Huang et al., 2011; Li, Goran, Kaur, Nollen, & Ahluwalia, 2007; Moss & Yeaton, 2012; Parsons, 2005; Ventura, Loken, & Birch, 2009). Many of these studies were designed to evaluate overall population health (Huang et al., 2011; Li et al., 2007), or childhood growth (Pryor et al.,

2011). Thus, the rationale or theoretical frameworks for assessment intervals may not be ideal for studying obesity. School-based studies are common for children and youth and in these studies, assessment intervals are based on the school calendar. Measurement intervals based on birthdate or more frequent intervals would be preferred, but costly, and logistically challenging (Wake, Hardy, Canterford, Sawyer, & Carlin, 2007).

Lastly, longitudinal studies are also particularly susceptible to attrition bias due to study duration. Participants may move out of the area or country, choose not to participate, or become otherwise ineligible for participation over time and this may bias the remaining sample or the conclusions drawn from it (Young, Powers, & Bell, 2006).

6.3.5. Future directions

In this section I discuss the extension of my work for future research. My three studies fill gaps in the obesity research literature wherein BF% distance and velocity curves did not previously exist for Canadian children and youth, the relationship between BMI- and BF%-based definitions of obesity was not well understood between Asian and Caucasian children, and longitudinal studies with objective measurements were minimal.

In Chapter 3, I developed BF% distance and velocity centile curves for Canadian children and youth. This study sets the groundwork for future research that should include health outcomes, a longer assessment of individuals, and expand to include other ethnicities than just Asian and Caucasian. Inclusion of health outcomes such as hyperlipidemia, glucose intolerance, and hypertension (Dietz, 1998) would give context to the results and help the field work towards agreed-upon reference values and cut-offs

for BF%. Concordantly, longer assessment of individuals is necessary to not only expand the potential future BF% curves to younger children and adults but also, when combined with health measures, to capture effects of a chronic disease such as obesity that can take decades to manifest (Dietz, 1998). Potential future research questions include:

- 1) How does patterning and velocity of BF% as children and youth age relate to health outcomes such as type-II diabetes or metabolic syndrome?
- 2) Which values of BF% and BF% velocity should be recommended for cut-offs related to adverse health outcomes?
- 3) Are there critical periods during childhood and adolescence for future risk related to BF% and BF% velocity values?
- 4) Are the associations or critical periods for health risks different between boys and girls or across ethnic groups?

In Chapter 4, I assessed the relationship between BMI- and BF%-based definitions of obesity across Asian and Reference boys and girls. The ideal BMI cut-offs I derived based on the maximum sensitivity and specificity of BMI to detect obesity by BF% should be evaluated in conjunction with health measurements in future research. Assessment of health outcomes such as hyperlipidemia, glucose intolerance, and hypertension (Dietz, 1998) could validate these BMI cut-offs for use in similar populations across Canada. Additionally, future research could replicate this study in a sample with additional ethnic groups more representative of the Canadian population.

- 1) How are the BMI cut-offs defined in Chapter 4 related to health outcomes in children and adolescents?

- 2) Does the relationship between BMI- and BF%-based definitions of obesity differ among other ethnic groups (e.g. African-Canadians, First Nations, Arab-Canadians)?

In Chapter 5, I evaluated longitudinal determinants of BF% as boys and girls mature. Future research should build on this study and add robust measures of diet (including caloric intake, dietary fat intake, calcium intake, sugar-sweetened beverage intake, and fruit and vegetable intake), sleep habits (quality and duration), levels of intensity in physical activity (light physical activity), parental characteristics (weight status, health outcomes, employment and education characteristics), and SES, as these are all known to be related to childhood obesity (Parsons et al., 1999; Saunders, 2011). Additionally, longer follow-up and earlier baseline entry would help determine critical periods when determinants of obesity may play their most influential role.

- 1) What is the relationship between activity, diet, SES, sleep, and family characteristics and BF% as children and youth mature?
- 2) Are there critical periods for the association between activity, diet, SES, sleep, and family characteristics and BF% as children and youth mature?
- 3) How does BF% develop for individuals on different MVPA trajectories (high vs. low, or meeting guidelines vs. not meeting guidelines)?

Exploring these research questions in future will improve our understanding of childhood obesity, its determinants, and adult health outcomes. The results could have significant public health implications across the lifespan and globally.

References

- American Anthropological Association. (1998). AAA statement on race. *American Anthropologist*, 100(3), 712-713. Retrieved from <Go to ISI>://WOS:000078520000011
- American Psychological Association. (2015). Guidelines for psychological practice with transgender and gender nonconforming people. *American Psychologist*, 70(9), 832-864.
- Ang, Y. N., Wee, B. S., Poh, B. K., & Ismail, M. N. (2013). Multifactorial influences of childhood obesity. *Current Obesity Reports*, 2, 10-22. doi:10.1007/s13679-012-0042-7
- Atingdui, N. (2011). Cohort Effect. In S. Goldstein & J. Naglieri (Eds.), *Encyclopedia of child behavior and development* (pp. 389-389): Springer US.
- Au, L. E., Economos, C. D., Goodman, E., Houser, R. F., Must, A., Chomitz, V. R., Morgan, E. H., et al. (2012). Dietary intake and cardiometabolic risk in ethnically diverse urban schoolchildren. *J Acad Nutr Diet*, 112(11), 1815-1821.
- Bailey, D., Baxter-Jones, A., Mirwald, R., & Faulkner, R. (2003). Bone growth and exercise studies: The complications of maturation. *Journal of Musculoskeletal and Neuronal Interactions*, 3(4), 335-337.
- Bancej, C., Jayabalasingham, B., Wall, R., Rao, D., Do, M., de Groh, M., & Jayaraman, G. (2015). Evidence brief trends and projections of obesity among Canadians. *Health Promotion*, 35(7).
- Barker, D. J. P., Osmond, C., Forsen, T. J., Kajantie, E., & Eriksson, J. G. (2005). Trajectories of growth among children who have coronary events as adults. *New England Journal of Medicine*, 353(17), 1802-1809. doi:10.1056/NEJMoa044160
- Barlow, S. E. (2007). Expert committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: summary report. *Pediatrics*, 120 Suppl 4, S164-192. doi:10.1542/peds.2007-2329C
- Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J., Martin, B. W., & Group, L. P. A. S. W. (2012). Correlates of physical activity: why are some people physically active and others not? *The Lancet*, 380(9838), 258-271. Retrieved from [http://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(12\)60735-1/abstract](http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(12)60735-1/abstract)
- Baxter-Jones, A. D., Eisenmann, J. C., & Sherar, L. B. (2005). Controlling for maturation in pediatric exercise science. *Pediatric Exercise Science*, 17(1), 18-30.
- Baxter-Jones, A. D. G., Faulkner, R. A., Forwood, M. R., Mirwald, R. L., & Bailey, D. A. (2011). Bone mineral accrual from 8 to 30 years of age: An estimation of peak bone mass. *Journal of Bone and Mineral Research*, 26(8), 1729-1739. doi:10.1002/jbmr.412
- Berkey, C. S., Rockett, H. R. H., Field, A. E., Gillman, M. W., Frazier, A. L., Camargo, C. A., MD, J., et al. (2000). Activity, Dietary Intake, and Weight Changes in a Longitudinal Study of Preadolescent and Adolescent Boys and Girls. *Pediatrics*, 105, e56-e56. doi:10.1542/peds.105.4.e56

- Bhopal, R. (2004). Glossary of terms relating to ethnicity and race: for reflection and debate. *Journal of Epidemiology and Community Health*, 58, 441-445.
- Biddle, S. J., Pearson, N., Ross, G. M., & Braithwaite, R. (2010). Tracking of sedentary behaviours of young people: a systematic review. *Preventive Medicine*, 51(5), 345-351.
- Bishop, N., Braillon, P., Burnham, J., Cimaz, R., Davies, J., Fewtrell, M., Hogler, W., et al. (2008). Dual-energy X-ray absorptiometry assessment in children and adolescents with diseases that may affect the skeleton: the 2007 ISCD Pediatric Official Positions. *Journal of Clinical Densitometry*, 11(1), 29-42. Retrieved from [http://www.clinicaldensitometry.com/article/S1094-6950\(07\)00252-1/abstract](http://www.clinicaldensitometry.com/article/S1094-6950(07)00252-1/abstract)
- Borghini, E., de Onis, M., Garza, C., Van den Broeck, J., Frongillo, E. a., Grummer-Strawn, L., Van Buuren, S., et al. (2006). Construction of the World Health Organization child growth standards: selection of methods for attained growth curves. *Statistics in Medicine*, 25, 247-265. doi:10.1002/sim.2227
- Bouchard, C., Tremblay, A., Despres, J. P., Nadeau, A., Lupien, P. J., Theriault, G., Dussault, J., et al. (1990). The response to long-term overfeeding in identical-twins. *New England Journal of Medicine*, 322(21), 1477-1482. doi:10.1056/nejm199005243222101
- Braddon, F. E., Rodgers, B., Wadsworth, M. E., & Davies, J. M. (1986). Onset of obesity in a 36 year birth cohort study. *British Medical Journal (Clinical Research Ed.)*, 293(6542), 299-303. Retrieved from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1340984/pdf/bmjcred00245-0017.pdf>
- Bridge, P., Pocock, N. a., Nguyen, T., Munns, C., Cowell, C. T., Forwood, N., & Thompson, M. W. (2011). Validation of longitudinal DXA changes in body composition from pre- to mid-adolescence using MRI as reference. *J Clin Densitom*, 14, 340-347. doi:10.1016/j.jocd.2011.04.005
- Britz, B., Siegfried, W., Ziegler, A., Lamertz, C., Herpertz-Dahlmann, B. M., Remschmidt, H., Wittchen, H. U., et al. (2000). Rates of psychiatric disorders in a clinical study group of adolescents with extreme obesity and in obese adolescents ascertained via a population based study. *International Journal of Obesity*, 24(12), 1707-1714. doi:10.1038/sj.ijo.0801449
- Buuren, S. v., & Fredriks, M. (2001). Worm plot: a simple diagnostic device for modelling growth reference curves. *Statistics in Medicine*, 20(8), 1259-1277.
- Caine-Bish, N. L., & Scheule, B. (2009). Gender differences in food preferences of school-aged children and adolescents. *Journal of School Health*, 79(11), 532-540. doi:10.1111/j.1746-1561.2009.00445.x
- Campbell, K., Waters, E., O'Meara, S., & Summerbell, C. (2001). Interventions for preventing obesity in childhood. A systematic review. *Obesity Reviews*, 2(3), 149-157. Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/12120100>
- Canadian Institutes of Health Research. (2015). Sex, gender and health research guide: A tool for CIHR applicants. *Funding*. Retrieved from <http://www.cihr-irsc.gc.ca/e/32019.html>
- Canadian Obesity Summit. (2015). People-first language and appropriate images. *Resources*. Retrieved from <http://www.con-obesitysummit.ca/more>

- Canadian UNICEF Committee. (2009). Aboriginal children's health: leaving no child behind : Canadian supplement to the state of the world's children 2009.
- Carson, V., Hunter, S., Kuzik, N., Gray, C. E., Poitras, V. J., Chaput, J.-P., Saunders, T. J., et al. (2016). Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update. *Applied Physiology, Nutrition, and Metabolism*, 41(6 (Suppl. 3)), S240-S265. doi:10.1139/apnm-2015-0630
- Carter, M. A., Dubois, L., Tremblay, M. S., Taljaard, M., & Jones, B. L. (2012). Trajectories of childhood weight gain: the relative importance of local environment versus individual social and early life factors. *PLoS ONE*, 7, e47065. doi:10.1371/journal.pone.0047065
- Carter, P. J., Taylor, B. J., Williams, S. M., & Taylor, R. W. (2011). Longitudinal analysis of sleep in relation to BMI and body fat in children: the FLAME study. *British Medical Journal*, 342. doi:10.1136/bmj.d2712
- Casazza, K., Beasley, T. M., & Fernandez, J. R. (2011). Beyond thriftiness: Independent and interactive effects of genetic and dietary factors on variations in fat deposition and distribution across populations. *American Journal of Physical Anthropology*, 145(2), 181-191. doi:10.1002/ajpa.21483
- Centers for Disease Control and Prevention. (2012, April 27). Defining Overweight and Obesity. *Overweight and Obesity*. Retrieved from <http://www.cdc.gov/obesity/adult/defining.html>
- Chaput, J. P., Brunet, M., & Tremblay, A. (2006). Relationship between short sleeping hours and childhood overweight/obesity: results from the 'Quebec en Forme' Project. *International Journal of Obesity*, 30(7), 1080-1085. doi:10.1038/sj.ijo.0803291
- Cheek, D. B. (1968). Human growth. Body composition, cell growth, energy, and intelligence. *Human growth. Body composition, cell growth, energy, and intelligence*.
- Cheng, G., Bolzenius, K., Joslowski, G., Gunther, A. L., Kroke, A., Heinrich, J., & Buyken, A. E. (2015). Velocities of weight, height and fat mass gain during potentially critical periods of growth are decisive for adult body composition. *European Journal of Clinical Nutrition*, 69(2), 262-268. doi:10.1038/ejcn.2014.131
- Chinapaw, M., Proper, K., Brug, J., Van Mechelen, W., & Singh, A. (2011). Relationship between young peoples' sedentary behaviour and biomedical health indicators: a systematic review of prospective studies. *Obesity Reviews*, 12(7), e621-e632.
- Chiu, M., Austin, P. C., Manuel, D. G., Shah, B. R., & Tu, J. V. (2011). Deriving ethnic-specific BMI cutoff points for assessing diabetes risk. *Diabetes Care*, 34(8), 1741-1748.
- Chumlea, W. C., Guo, S. S., Kuczmarski, R. J., Flegal, K. M., Johnson, C. L., Heymsfield, S. B., Lukaski, H. C., et al. (2002). Body composition estimates from NHANES III bioelectrical impedance data. *International Journal of Obesity and Related Metabolic Disorders*, 26(12), 1596-1609. doi:10.1038/sj.ijo.0802167
- Cole, T. J. (1990). The LMS method for constructing normalized growth standards. *European Journal of Clinical Nutrition*, 44, 45-60.

- Cole, T. J. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *British Medical Journal*, *320*, 1240-1240. doi:10.1136/bmj.320.7244.1240
- Cole, T. J. (2012). The development of growth references and growth charts. *Annals of Human Biology*, *39*(5), 382-394. doi:10.3109/03014460.2012.694475
- Colley, R. C., Garriguet, D., Janssen, I., Craig, C. L., Clarke, J., & Tremblay, M. S. (2011). Physical activity of Canadian children and youth: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. *Health Reports*, *22*(1), 15-23.
- Colley, R. C., Garriguet, D., Janssen, I., Wong, S. L., Saunders, T. J., Carson, V., & Tremblay, M. S. (2013). The association between accelerometer-measured patterns of sedentary time and health risk in children and youth: results from the Canadian Health Measures Survey. *BMC Public Health*, *13*(1), 200. doi:10.1186/1471-2458-13-200
- Comuzzie, A. G., Higgins, P. B., Voruganti, S., & Cole, S. (2010). Cutting the fat: the genetic dissection of body weight. *Progress in Molecular Biology and Translational Science*, *94*, 197-212. doi:10.1016/s1877-1173(10)94007-6
10.1016/b978-0-12-375003-7.00007-8
- Cook, S., Weitzman, M., Auinger, P., Nguyen, M., & Dietz, W. H. (2003). Prevalence of a metabolic syndrome phenotype in adolescents - Findings from the Third National Health and Nutrition Examination Survey, 1988-1994. *Archives of Pediatrics and Adolescent Medicine*, *157*(8), 821-827. doi:10.1001/archpedi.157.8.821
- Craigie, A. M., Lake, A. A., Kelly, S. A., Adamson, A. J., & Mathers, J. C. (2011). Tracking of obesity-related behaviours from childhood to adulthood: A systematic review. *Maturitas*, *70*(3), 266-284. doi:<http://dx.doi.org/10.1016/j.maturitas.2011.08.00>
- Curran, P. J., & Bauer, D. J. (2011). The disaggregation of within-person and between-person effects in longitudinal models of change. *Annual Review of Psychology*, *62*, 583-619. doi:10.1146/annurev.psych.093008.100356
- da Cunha, K. A. (2015). Calcium intake, serum vitamin D and obesity in children: is there an. *33*(2), 222-229. doi:10.1016/j.rpped.2015.03.001
- Daniels, S. R., Arnett, D. K., Eckel, R. H., Gidding, S. S., Hayman, L. L., Kumanyika, S., Robinson, T. N., et al. (2005). Overweight in children and adolescents: pathophysiology, consequences, prevention, and treatment. *Circulation*, *111*(15), 1999-2012. doi:10.1161/01.CIR.0000161369.71722.10
- Daniels, S. R., Houry, P. R., & Morrison, J. A. (1997a). The utility of body mass index as a measure of body fatness in children and adolescents: Differences by race and gender. *Pediatrics*, *99*(6), 804-807. doi:10.1542/peds.99.6.804
- Daniels, S. R., Houry, P. R., & Morrison, J. A. (1997b). The utility of the body mass index as a measure of fatness in children and adolescents: differences by race and gender. *Pediatrics*, *99*, 804-807. Retrieved from <http://dx.doi.org/10.1542/peds.99.6.804>
<http://pediatrics.aappublications.org/content/99/6/804.long>
- Daniels, S. R., Houry, P. R., & Morrison, J. A. (2000). Utility of different measures of body fat distribution in children and adolescents. *American Journal of*

- Epidemiology*, 152(12), 1179-1184. Retrieved from <http://aje.oxfordjournals.org/content/152/12/1179.full.pdf>
- Daniels, S. R., Morrison, J. A., Sprecher, D. L., Houry, P., & Kimball, T. R. (1999). Association of body fat distribution and cardiovascular risk factors in children and adolescents. *Circulation*, 99(4), 541-545. doi:10.1161/01.cir.99.4.541
- Danner, F. W. (2008). A national longitudinal study of the association between hours of TV viewing and the trajectory of BMI growth among US children. *Journal of Pediatric Psychology*, 33(10), 1100-1107. doi:10.1093/jpepsy/jsn034
- Davis, M. M., Gance-Cleveland, B., Hassink, S., Johnson, R., Paradis, G., & Resnicow, K. (2007). Recommendations for prevention of childhood obesity. *Pediatrics*, 120(Supplement 4), S229-S253.
- Davison, K. K., & Birch, L. L. (2001). Childhood overweight: a contextual model and recommendations for future research. *Obesity Reviews*, 2(3), 159-171. doi:10.1046/j.1467-789x.2001.00036.x
- De Lorenzo, A., Deurenberg, P., Pietrantuono, M., Di Daniele, N., Cervelli, V., & Andreoli, A. (2003). How fat is obese? *Acta Diabetologica*, 40(1), s254-s257. doi:10.1007/s00592-003-0079-x
- De Onis, M., Garza, C., Victora, C. G., Onyango, A. W., Frongillo, E. A., & Martines, J. (2004). The WHO multicentre growth reference study: planning, study design, and methodology. *Food and nutrition bulletin*, 25(1_suppl1), S15-S26.
- de Onis, M., Onyango, A. W., Borghi, E., Siyam, A., Nishida, C., & Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bulletin of the World Health Organization*, 85, 660-667. Retrieved from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2636412/pdf/07-043497.pdf>
- Dehghan, M., Akhtar-Danesh, N., & Merchant, A. T. (2005). Childhood obesity, prevalence and prevention. *Nutr J*, 4(1), 24. doi:10.1186/1475-2891-4-24
- Demerath, E. W., Schubert, C. M., Maynard, L. M., Sun, S. S., Chumlea, W. C., Pickoff, A., Czerwinski, S. A., et al. (2006). Do changes in body mass index percentile reflect changes in body composition in children? Data from the Fels Longitudinal Study. *Pediatrics*, 117(3), E487-E495. doi:10.1542/peds.2005-0572
- Deurenberg, P., Deurenberg-Yap, M., & Guricci, S. (2002). Asians are different from Caucasians and from each other in their body mass index/body fat percent relationship. *Obesity reviews : an official journal of the International Association for the Study of Obesity*, 3(3), 141-146. doi:10.1046/j.1467-789X.2002.00065.x
- Dieticians of Canada. (2014). *A health professional's guide for using the WHO growth charts for Canada*. Retrieved from http://www.dietitians.ca/Downloads/Public/DC_HealthProGrowthGuideE.aspx
- Dietz, W. H. (1994). Critical periods in childhood for the development of obesity. *American Society for Clinical Nutrition*, 59, 955-959.
- Dietz, W. H. (1998). Health consequences of obesity in youth: childhood predictors of adult disease. *Pediatrics*, 101(Supplement 2), 518-525.
- Dixon, W. J., & Tukey, J. W. (1968). Approximate behavior of the distribution of Winsorized (Trimming/Winsorization). *Technometrics*, 10(1), 83-98.
- Dunn, L. C., & Kuper, L. (1975). *Race, science and society*. Paris: The Unesco Press.

- Dwyer, T., & Blizzard, C. L. (1996). Defining obesity in children by biological endpoint rather than population distribution. *International Journal of Obesity*, 20(5), 472-480. Retrieved from <Go to ISI>://WOS:A1996UH73600012
- Ekoó, J. M., Rewers, M., Williams, R., & Zimmet, P. (2008). *The epidemiology of diabetes mellitus*: John Wiley & Sons.
- Ellis, K. J., Abrams, S. A., & Wong, W. W. (1999). Monitoring childhood obesity: assessment of the weight/height² index. *American Journal of Epidemiology*, 150, 939-946. Retrieved from <http://aje.oxfordjournals.org/content/150/9/939.full.pdf>
- Elowsson, P., Forslund, A. H., Mallmin, H., Feuk, U., Hansson, I., & Carlsten, J. (1998). An evaluation of dual-energy X-Ray absorptiometry and underwater weighing to estimate body composition by means of carcass analysis in piglets. *Journal of Nutrition*, 128(9), 1543-1549. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/9732317>
- Epstein, L. H., Gordy, C. C., Raynor, H. A., Beddome, M., Kilanowski, C. K., & Paluch, R. (2001). Increasing fruit and vegetable intake and decreasing fat and sugar intake in families at risk for childhood obesity. *Obesity (Silver Spring)*, 9(3), 171-178.
- Epstein, L. H., Paluch, R. A., Consalvi, A., Riordan, K., & Scholl, T. (2002). Effects of manipulating sedentary behavior on physical activity and food intake. *The Journal of pediatrics*, 140(3), 334-339. Retrieved from [http://www.jpeds.com/article/S0022-3476\(02\)98040-6/abstract](http://www.jpeds.com/article/S0022-3476(02)98040-6/abstract)
- Erickson, S. J., Robinson, T. N., Haydel, K. F., & Killen, J. D. (2000). Are overweight children unhappy? Body mass index, depressive symptoms, and overweight concerns in elementary school children. *Archives of Pediatrics and Adolescent Medicine*, 154(9), 931-935. Retrieved from <Go to ISI>://WOS:000089222200012
- Esliger, D. W., Copeland, J. L., Barnes, J. D., & Tremblay, M. S. (2005). Standardizing and optimizing the use of accelerometer data for free-living physical activity monitoring. *Journal of Physical Activity and health*, 3, 366-383.
- Evenson, K. R., Catellier, D. J., Gill, K., Ondrak, K. S., & McMurray, R. G. (2008). Calibration of two objective measures of physical activity for children. *Journal of Sports Sciences*, 26(14), 1557-1565. doi:10.1080/02640410802334196
- Fan, B., Shepherd, J. A., Levine, M. A., Steinberg, D., Wacker, W., Barden, H. S., Ergun, D., et al. (2014). National Health and Nutrition Examination Survey whole-body dual-energy X-ray absorptiometry reference data for GE lunar systems. *Journal of Clinical Densitometry*, 17(3), 344-377. Retrieved from [http://www.clinicaldensitometry.com/article/S1094-6950\(13\)00160-1/abstract](http://www.clinicaldensitometry.com/article/S1094-6950(13)00160-1/abstract)
- Fan, J., Upadhye, S., & Worster, A. (2006). Understanding receiver operating characteristic (ROC) curves. *Canadian Journal of Emergency Medical Care*, 8(01), 19-20.
- Farias, J. C., Konrad, L. M., Rabacow, F. M., Grup, S., & Araújo, V. C. (2009). Sensitivity and specificity of criteria for classifying body mass index in adolescents. *Revista de Saúde Pública*, 43(1), 53-59.
- Farooq, M. A., Parkinson, K. N., Adamson, A. J., Pearce, M. S., Reilly, J. K., Hughes, A. R., Janssen, X., et al. (2017). Timing of the decline in physical activity in

- childhood and adolescence: Gateshead Millennium Cohort Study. *British Journal of Sports Medicine*. doi:10.1136/bjsports-2016-096933
- Farrington, D. P. (1991). Longitudinal research strategies: Advantages, problems, and prospects. *Journal of the American Academy of Child and Adolescent Psychiatry*, 30(3), 369-374.
- Faulkner, R. A., Bailey, D. A., Drinkwater, D. T., Wilkinson, A. A., Houston, C. S., & McKay, H. A. (1993). Regional and total body bone mineral content, bone mineral density, and total body tissue composition in children 8–16 years of age. *Calcified Tissue International*, 53(1), 7-12. doi:10.1007/BF01352007
- Flegal, K. M., Ogden, C. L., Yanovski, J. A., Freedman, D. S., Shepherd, J. A., Graubard, B. I., & Borrud, L. G. (2010). High adiposity and high body mass index-for-age in US children and adolescents overall and by race-ethnic group. *American Journal of Clinical Nutrition*, 91(4), 1020-1026. doi:10.3945/ajcn.2009.28589
- Flegal, K. M., Shepherd, J. A., Looker, A. C., Graubard, B. I., Borrud, L. G., Ogden, C. L., Harris, T. B., et al. (2009). Comparisons of percentage body fat, body mass index, waist circumference, and waist-stature ratio in adults. *The American Journal of Clinical Nutrition*, 89(2), 500-508. doi:10.3945/ajcn.2008.26847
- Flores, G., Fuentes-Afflick, E., Carter-Pokras, O., Claudio, L., Lamberty, G., Lara, M., Pachter, L., et al. (2001). Why ethnicity and race are so important in child health services research today. *Archives of Pediatrics and Adolescent Medicine*, 155(10), 1178-1179. Retrieved from <Go to ISI>://WOS:000171320800022
- Fluss, R., Faraggi, D., & Reiser, B. (2005). Estimation of the Youden Index and its associated cutoff point. *Biometrical Journal*, 47(4), 458-472.
- Food Processor SQL. (2008). Food Processor nutrition and fitness software. *Food Processor SQL Inc., Salem, OR, USA*.
- Fraza, E. (1999). America's eating habits: changes and consequences. *Agriculture Information Bulletin-United States Department of Agriculture*(750).
- Freedman, D. S., Dietz, W. H., Srinivasan, S. R., & Berenson, G. S. (1999). The relation of overweight to cardiovascular risk factors among children and adolescents: The Bogalusa Heart Study. *Pediatrics*, 103(6), 1175-1182.
- Freedman, D. S., Ogden, C. L., Berenson, G. S., & Horlick, M. (2005). Body mass index and body fatness in childhood. *Current Opinion in Clinical Nutrition and Metabolic Care*, 8(6), 618-623.
- Freedman, D. S., Ogden, C. L., Blanck, H. M., Borrud, L. G., & Dietz, W. H. (2013). The abilities of body mass index and skinfold thicknesses to identify children with low or elevated levels of dual-energy X-Ray absorptiometry– determined body fatness. *The Journal of pediatrics*, 163(1), 160-166. e161.
- Freedman, D. S., & Sherry, B. (2009). The validity of bmi as an indicator of body fatness and risk among children. *Pediatrics*, 124, S23-S34. doi:10.1542/peds.2008-3586E
- Freedman, D. S., Srinivasan, S. R., Burke, G. L., Shear, C. L., Smoak, C. G., Harsha, D. W., Webber, L. S., et al. (1987). Relation of body fat distribution to hyperinsulinemia in children and adolescents: the Bogalusa Heart Study. *The American Journal of Clinical Nutrition*, 46(3), 403-410.
- Freedman, D. S., Wang, J., Maynard, L. M., Thornton, J. C., Mei, Z., Pierson, R. N., Jr., Dietz, W. H., et al. (2004). Relation of BMI to fat and fat-free mass among

- children and adolescents. *International Journal of Obesity and Related Metabolic Disorders*, 29(1), 1-8. Retrieved from <http://dx.doi.org/10.1038/sj.ijo.0802735>
- Freedman, D. S., Wang, J., Thornton, J. C., Mei, Z., Pierson, R. N., Dietz, W. H., & Horlick, M. (2008). Racial/ethnic differences in body fatness among children and adolescents. *Obesity (Silver Spring)*, 16(5), 1105-1111.
- Freedman, D. S., Wang, J., Thornton, J. C., Mei, Z., Sopher, A. B., Pierson, R. N., Jr., Dietz, W. H., et al. (2009). Classification of body fatness by body mass index-for-age categories among children. *Archives of Pediatrics and Adolescent Medicine*, 163(9), 805-811.
- Gabel, L., Nettlefold, L., Brasher, P. M., Moore, S. A., Ahamed, Y., Macdonald, H. M., & McKay, H. A. (2015). Reexamining the surfaces of bone in boys and girls during adolescent growth: A 12-year mixed longitudinal PQCT study. *Journal of Bone and Mineral Research*.
- Gabel, L. E. C. (2017). *Bone strength accrual across adolescent growth and the influences of physical activity and sedentary time*. (Text). Retrieved from <https://open.library.ubc.ca/collections/24/items/1.0343985>
- Galloway, T. (2007). Gender differences in growth and nutrition in a sample of rural Ontario schoolchildren. *American Journal of Human Biology*, 19(6), 774-788. doi:10.1002/ajhb.20637
- Garriguet, D. (2004). Overview of Canadians' eating habits. *Health Reports*, 2, 82-620. Retrieved from <http://weldenscott.ca/pdf/82-620-m2006002-eng.pdf>
- Gazzaniga, J. M., & Burns, T. L. (1993). Relationship between diet composition and body fatness, with adjustment for resting energy expenditure and physical activity, in preadolescent children. *American Journal of Clinical Nutrition*, 58(1), 21-28.
- Geronimus, A. T. (1992). The weathering hypothesis and the health of African-American women and infants: evidence and speculations. *Ethnicity and Disease*, 2(3), 207-221.
- Gillis, L., Kennedy, L., Gillis, A., & Bar-Or, O. (2002). Relationship between juvenile obesity, dietary energy and fat intake and physical activity. *International journal of obesity and related metabolic disorders: journal of the International Association for the Study of Obesity*, 26(4), 458-463.
- Godfrey, A., Culhane, K., & Lyons, G. (2007). Comparison of the performance of the activPAL™ Professional physical activity logger to a discrete accelerometer-based activity monitor. *Medical Engineering and Physics*, 29(8), 930-934.
- Going, S. B., Lohman, T. G., Cussler, E. C., Williams, D. P., Morrison, J. A., & Horn, P. S. (2011). Percent body fat and chronic disease risk factors in U.S. Children and youth. *American Journal of Preventive Medicine*, 41(4, Supplement 2), S77-S86. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0749379711004922>
[http://www.ajpmonline.org/article/S0749-3797\(11\)00492-2/abstract](http://www.ajpmonline.org/article/S0749-3797(11)00492-2/abstract)
- González-Muniesa, P., Martínez-González, M.-A., Hu, F. B., Després, J.-P., Matsuzawa, Y., Loos, R. J. F., Moreno, L. A., et al. (2017). Obesity. 3, 17034. doi:10.1038/nrdp.2017.34

- Goran, M. I. (1997). Measurement issues related to studies of childhood obesity- assessment of body composition, body fat distribution, physical activity, and food intake. *Pediatrics*, 505-518.
- Goran, M. I., Kaskoun, M., Johnson, R., Martinez, C., Kelly, B., & Hood, V. (1995). Energy expenditure and body fat distribution in Mohawk children. *Pediatrics*, 95(1), 89-95.
- Greenberg, A. S., & Obin, M. S. (2006). Obesity and the role of adipose tissue in inflammation and metabolism. *The American Journal of Clinical Nutrition*, 83(2), 461S-465S.
- Gutin, B., Litaker, M., Islam, S., Manos, T., Smith, C., & Treiber, F. (1996). Body-composition measurement in 9-11-y-old children by dual-energy X-ray absorptiometry, skinfold-thickness measurements, and bioimpedance analysis. *American Journal of Clinical Nutrition*, 63(3), 287-292.
- Guttman, I., & Smith, D. E. (1969). Investigation of rules for dealing with outliers in small samples from the normal distribution: I: Estimation of the mean. *Technometrics*, 11(3), 527-550.
- Han, J. C., Lawlor, D. A., & Kimm, S. Y. S. (2010). Childhood obesity. *Lancet*, 375(9727), 1737-1748. doi:10.1016/s0140-6736(10)60171-7
- Hanley, J. A., & McNeil, B. J. (1982). The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology*, 143, 29-36.
- Hauspie, R., Das, S., Preece, M., & Tanner, J. M. (1980). A longitudinal study of the growth in height of boys and girls of West Bengal (India) aged six months to 20 years. *Annals of Human Biology*, 7(5), 429-440.
- Healy, M., Yang, M., Tanner, J., & Zumrawi, F. (1988). *Use of short-term increments in length to monitor growth in infancy*. Paper presented at the Nestle nutrition workshop series.
- Helba, M., & Binkovitz, L. A. (2009). Pediatric body composition analysis with dual-energy X-ray absorptiometry. *Pediatric Radiology*, 39(7), 647-656. doi:10.1007/s00247-009-1247-0
- Hill, J. O., & Trowbridge, F. L. (1998). Childhood obesity: future directions and research priorities. *Pediatrics*, 101(3), 570-574.
- Hoffman, L. (2015). *Longitudinal analysis: Modeling within-person fluctuation and change*. New York, NY: Routledge.
- Holmes, L., LaHurd, A., Wasson, E., McClarin, L., & Dabney, K. (2015). Racial and ethnic heterogeneity in the association between total cholesterol and pediatric obesity. *International Journal of Environmental Research and Public Health*, 13(1), 19. Retrieved from <https://www.ncbi-nlm-nih-gov.ezproxy.library.uvic.ca/pmc/articles/PMC4730410/pdf/ijerph-13-00019.pdf>
- Hologic Inc. (2002). QDR 4500 Fan Beam X-Ray Bone Densitometer User's Guide. Waltham MA: Hologic Inc.
- Hoy, C. L. (2010). *The Influence of Adiposity on Bone Quality in Children, Adolescents and Young Adults*. (Master of Science), University of British Columbia, Vancouver, BC.
- Huang, R.-C., de Klerk, N. H., Smith, A., Kendall, G. E., Landau, L. I., Mori, T. A., Newnham, J. P., et al. (2011). Lifecourse childhood adiposity trajectories

- associated with adolescent insulin resistance. *Diabetes Care*, 34(4), 1019-1025. doi:10.2337/dc10-1809
- Huang, T. T. K., Howarth, N. Y. C., Lin, B. H., Roberts, S. B., & McCrory, M. A. (2004). Energy intake and meal portions: Associations with BMI percentile in US children. *Obesity Research*, 12(11), 1875-1885. doi:10.1038/oby.2004.233
- Huang, T. T. K., & McCrory, M. A. (2005). Dairy intake, obesity, and metabolic health in children and adolescents: Knowledge and gaps. *Nutrition Reviews*, 63(3), 71-80. doi:10.1111/j.1753-4887.2005.tb00124.x
- IBM Corp. (2013). IBM SPSS Statistics for Windows, Version 22.0. (Vol. 22.0). Armonk, NY: IBM Corp.
- IBM Corp. (2015). IBM SPSS Statistics for Macintosh, Version 23.0. Armonk, NY: IBM Corp.
- Janssen, I., Katzmarzyk, P. T., Boyce, W. F., King, M. A., & Pickett, W. (2004). Overweight and obesity in Canadian adolescents and their associations with dietary habits and physical activity patterns. *Journal of Adolescent Health*, 35, 360-367. doi:<http://dx.doi.org/10.1016/j.jadohealth.2003.11.095>
- Janz, K. F., Burns, T. L., & Levy, S. M. (2005). Tracking of activity and sedentary behaviors in childhood - The Iowa Bone Development Study. *American Journal of Preventive Medicine*, 29(3), 171-178. doi:10.1016/j.amepre.2005.06.001
- Janz, K. F., Kwon, S., Letuchy, E. M., Eichenberger Gilmore, J. M., Burns, T. L., Torner, J. C., Willing, M. C., et al. (2009). Sustained effect of early physical activity on body fat mass in older children. *American Journal of Preventive Medicine*, 37(1), 35-40. doi:10.1016/j.amepre.2009.03.012
- Javed, A., Jumean, M., Murad, M. H., Okorodudu, D., Kumar, S., Somers, V. K., Sochor, O., et al. (2015). Diagnostic performance of body mass index to identify obesity as defined by body adiposity in children and adolescents: a systematic review and meta-analysis. *Pediatric Obesity*, 10(3), 234-244. doi:10.1111/ijpo.242
- Jebb, S. A., Goldberg, G. R., & Elia, M. (1992). DXA measurements of fat and bone mineral density in relation to depth and adiposity. *Basic Life Sciences*, 60, 115-119.
- Kamath, C. C., Vickers, K. S., Ehrlich, A., McGovern, L., Johnson, J., Singhal, V., Paulo, R., et al. (2008). Clinical review: behavioral interventions to prevent childhood obesity: a systematic review and metaanalyses of randomized trials. *Journal of Clinical Endocrinology and Metabolism*, 93(12), 4606-4615. doi:10.1210/jc.2006-2411
- Kaplan, J. B., & Bennett, T. (2003). Use of race and ethnicity in biomedical publication. *Journal of the American Medical Association*, 289(20), 2709-2716. doi:10.1001/jama.289.20.2709
- Karnik, S., & Kanekar, A. (2012). Childhood obesity: a global public health crisis. *International Journal of Preventive Medicine*, 3(1), 1.
- Katamay, S. W., Esslinger, K. A., Vigneault, M., Johnston, J. L., Junkins, B. A., Robbins, L. G., Sirois, I. V., et al. (2007). Eating well with Canada's Food Guide (2007): development of the food intake pattern. *Nutrition Reviews*, 65(4), 155-166.
- Katzmarzyk, P. T. (2004). Waist circumference percentiles for Canadian youth 11-18[thinsp]y of age. *European Journal of Clinical Nutrition*, 58(7), 1011-1015. Retrieved from <http://dx.doi.org/10.1038/sj.ejcn.1601924>

- Kelly, T. L., Wilson, K. E., & Heymsfield, S. B. (2009). Dual energy X-ray absorptiometry body composition reference values from NHANES. *PLoS ONE*, 4(9). doi:10.1371/journal.pone.0007038
- Kim, D. S., Maden, S. K., Burt, A. A., Ranchalis, J. E., Furlong, C. E., & Jarvik, G. P. (2013). Dietary fatty acid intake is associated with paraoxonase 1 activity in a cohort-based analysis of 1,548 subjects. *Lipids in Health and Disease*, 12(1), 183.
- Kim, K., Yun, S. H., Jang, M. J., & Oh, K. W. (2013). Body fat percentile curves for Korean children and adolescents: a data from the Korea National Health and Nutrition Examination Survey 2009-2010. *Journal of Korean Medical Science*, 28(3), 443-449.
- Kimbrow, R. T., Brooks-Gunn, J., & McLanahan, S. (2007). Racial and ethnic differentials in overweight and obesity among 3-year-old children. *American Journal of Public Health*, 97(2), 298-305. doi:10.2105/ajph.2005.080812
- Kimm, S. Y. S., Glynn, N. W., Kriska, A. M., Barton, B. A., Kronsberg, S. S., Daniels, S. R., Crawford, P. B., et al. (2002). Decline in Physical Activity in Black Girls and White Girls during Adolescence. *New England Journal of Medicine*, 347(10), 709-715. doi:10.1056/NEJMoa003277
- Kinugasa, A., Tsunamoto, K., Furukawa, N., Sawada, T., Kusunoki, T., & Shimada, N. (1984). Fatty liver and its fibrous changes found in simple obesity of children. *Journal of Pediatric Gastroenterology and Nutrition*, 3(3), 408-414.
- Krieger, N., Williams, D., & Zierler, S. (1999). "Whiting out" white privilege will not advance the study of how racism harms health. *American Journal of Public Health*, 89(5), 782-783. doi:10.2105/ajph.89.5.782
- Kuczarski, R. J., Ogden, C., & Guo, S. (2001). 2000 CDC growth charts for the United States: Methods and development. National Center for Health Statistics. *Vital Health Statistics*, 246, 1-190.
- Kuczarski, R. J., Ogden, C. L., Guo, S. S., Grummer-Strawn, L. M., Flegal, K. M., Mei, Z., Wei, R., et al. (2002). 2000 CDC growth charts for the United States: methods and development. *Vital and health statistics. Series 11, Data from the national health survey*(246), 1-190.
- Kuhle, S., Ashley-Martin, J., Maguire, B., & Hamilton, D. C. (2016). Percentile curves for skinfold thickness for Canadian children and youth. *PeerJ*, 4, e2247.
- Kuhle, S., Maguire, B., Ata, N., & Hamilton, D. C. (2015). Percentile curves for anthropometric measures for Canadian children and youth. *PLoS ONE*, 10(7), e0132891. doi:10.1371/journal.pone.0132891
- Kwon, S., Burns, T. L., Levy, S. M., & Janz, K. F. (2013). Which Contributes More to Childhood Adiposity? High Levels of Sedentarism Versus Low Levels of Moderate-through-Vigorous Physical Activity: The Iowa Bone Development Study. *The Journal of pediatrics*, 162(6), 1169-1174. doi:10.1016/j.jpeds.2012.11.071
- Kyle, T. K., & Puhl, R. M. (2014). Putting people first in obesity. *Obesity (Silver Spring)*, 22(5), 1211. doi:10.1002/oby.20727
- Lakshman, R., Elks, C. E., & Ong, K. K. (2012). Childhood obesity. *Circulation*, 126(14), 1770-1779.
- Lakshmi, S., Metcalf, B., Joglekar, C., Yajnik, C. S., Fall, C. H., & Wilkin, T. J. (2012). Differences in body composition and metabolic status between white UK and

- Asian Indian children (EarlyBird 24 and the Pune Maternal Nutrition Study). *Pediatric Obesity*, 7(5), 347-354. doi:10.1111/j.2047-6310.2012.00063.x
- Landgraf, K., Rockstroh, D., Wagner, I. V., Weise, S., Tauscher, R., Schwartze, J. T., Loffler, D., et al. (2015). Evidence of early alterations in adipose tissue biology and function and its association with obesity-related inflammation and insulin resistance in children. *Diabetes*, 64(4), 1249-1261. doi:10.2337/db14-0744
- Largo, R., Gasser, T., Prader, A., Stuetzle, W., & Huber, P. (1978). Analysis of the adolescent growth spurt using smoothing spline functions. *Annals of Human Biology*, 5(5), 421-434.
- Laskey, M., Lyttle, K., Flaxman, M., & Barber, R. (1992). The influence of tissue depth and composition on the performance of the Lunar dual-energy X-ray absorptiometer whole-body scanning mode. *European Journal of Clinical Nutrition*, 46(1), 39-45.
- Laskey, M. A. (1996). Dual-energy X-ray absorptiometry and body composition. *Nutrition*, 12(1), 45-51.
- Laurson, K. R., Eisenmann, J. C., & Welk, G. J. (2011). Body fat percentile curves for US children and adolescents. *American Journal of Preventive Medicine*, 41(4), S87-S92. doi:10.1016/j.amepre.2011.06.044
- Laveist, T. A. (1996). Why we should continue to study race But do a better job: An essay on race, racism and health. *Ethnicity and Disease*, 6(1-2), 21-29. Retrieved from <Go to ISI>://BCI:BCI199698799006
- Lerner, R. M., & Steinberg, L. (2004). The scientific study of adolescent development *Handbook of adolescent psychology* (pp. 12).
- Levine, J. A., Eberhardt, N. L., & Jensen, M. D. (1999). Role of nonexercise activity thermogenesis in resistance to fat gain in humans. *Science*, 283(5399), 212-214.
- Li, C., Goran, M. I., Kaur, H., Nollen, N., & Ahluwalia, J. S. (2007). Developmental trajectories of overweight during childhood: role of early life factors. *Obesity (Silver Spring)*, 15(3), 760-771.
- Lloyd, T., Chinchilli, V. M., Eggli, D. F., Rollings, N., & Kulin, H. E. (1998). Body composition development of adolescent white females: The penn state young women's health study. *Archives of Pediatrics and Adolescent Medicine*, 152(10), 998-1002. doi:10.1001/archpedi.152.10.998
- Luder, E., Melnik, T. A., & DiMaio, M. (1998). Association of being overweight with greater asthma symptoms in inner city black and Hispanic children. *Journal of Pediatrics*, 132(4), 699-703. doi:10.1016/s0022-3476(98)70363-4
- Ludwig, D. S., Peterson, K. E., & Gortmaker, S. L. (2001). Relation between consumption of sugar-sweetened drinks and childhood obesity: a prospective, observational analysis. *Lancet*, 357. doi:10.1016/s0140-6736(00)04041-1
- Lytle, L. A. (2009). Examining the etiology of childhood obesity: The IDEA study. *American Journal of Community Psychology*, 44(3-4), 338-349. doi:10.1007/s10464-009-9269-1
- Lytle, L. A., Murray, D. M., Perry, C. L., & Eldridge, A. L. (1998). Validating fourth-grade students' self-report of dietary intake: results from the 5 A Day Power Plus program. *Journal of the American Dietetic Association*, 98(5), 570-572. Retrieved from [http://www.andjrnل.org/article/S0002-8223\(98\)00127-8/abstract](http://www.andjrnل.org/article/S0002-8223(98)00127-8/abstract)

- Macdonald, H. M., Kontulainen, S. A., Khan, K. M., & McKay, H. A. (2007). Is a school-based physical activity intervention effective for increasing tibial bone strength in boys and girls? *Journal of Bone and Mineral Research*, 22(3), 434-446.
- MacDougall, J. D., Wenger, H. A., & Green, H. J. (1991). *Physiological testing of the high-performance athlete*: Champaign, Ill.: Human Kinetics Books.
- MacKelvie, K. J., McKay, H. A., Khan, K. M., & Crocker, P. R. E. (2001). A school-based exercise intervention augments bone mineral accrual in early pubertal girls. *Journal of Pediatrics*, 139(4), 501-508. doi:10.1067/mpd.2001.118190
- MacKelvie, K. J., McKay, H. A., Petit, M. A., Moran, O., & Khan, K. M. (2002). Bone mineral response to a 7-month randomized controlled, school-based jumping intervention in 121 prepubertal boys: Associations with ethnicity and body mass index. *Journal of Bone and Mineral Research*, 17(5), 834-844. doi:10.1359/jbmr.2002.17.5.834
- MacKelvie, K. J., Petit, M. A., Khan, K. M., Beck, T. J., & McKay, H. A. (2004). Bone mass and structure are enhanced following a 2-year randomized controlled trial of exercise in prepubertal boys. *Bone*, 34(4), 755-764. doi:10.1016/j.bone.2003.12.017
- Maffeis, C., & Tatò, L. (2001). Long-term effects of childhood obesity on morbidity and mortality. *Hormone Research in Paediatrics*, 55(suppl 1)(Suppl. 1), 42-45.
- Malik, V. S., Schulze, M. B., & Hu, F. B. (2006). Intake of sugar-sweetened beverages and weight gain: a systematic review. *The American Journal of Clinical Nutrition*, 84(2), 274-288.
- Malina, R. (1989). Growth and maturation: normal variation and effect of training. *Perspectives in exercise science and sports medicine*, 2, 223-265.
- Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, Maturation, and Physical Activity* (2 ed.). Champaign, IL: Human Kinetics.
- Malina, R. M., Bouchard, C., & Beunen, G. (1988). Human growth: Selected aspects of current research on well-nourished children. *Annual Review of Anthropology*, 17(1), 187-219.
- Malina, R. M., & Katzmarzyk, P. T. (1999). Validity of the body mass index as an indicator of the risk and presence of overweight in adolescents. *American Journal of Clinical Nutrition*, 70(1), 131S-136S.
- Manna, I. (2014). Growth Development and Maturity in Children and Adolescent: Relation to Sports and Physical Activity. *American Journal of Sports Science and Medicine*, 2(5A), 48-50. Retrieved from <http://pubs.sciepub.com/ajssm/2/5A/11>
- Mansourian, M., Marateb, H. R., Kelishadi, R., Motlagh, M. E., Aminae, T., Taslimi, M., Majdzadeh, R., et al. (2012). First growth curves based on the World Health Organization reference in a Nationally-Representative Sample of Pediatric Population in the Middle East and North Africa (MENA): the CASPIAN-III study. *BMC Pediatrics*, 12, 149. doi:10.1186/1471-2431-12-149
- Margulies, L., Horlick, M., Thornton, J. C., Wang, J., Ioannidou, E., & Heymsfield, S. B. (2005). Reproducibility of pediatric whole body bone and body composition measures by dual-energy X-ray absorptiometry using the GE Lunar Prodigy. *Journal of Clinical Densitometry*, 8(3), 298-304.

- Martins, C., Truby, H., & Morgan, L. M. (2007). Short-term appetite control in response to a 6-week exercise programme in sedentary volunteers. *British Journal of Nutrition*, 98(4), 834-842. doi:10.1017/S000711450774922X
- Mattocks, C., Ness, A., Leary, S., Tilling, K., Blair, S. N., Shield, J., Deere, K., et al. (2008). Use of accelerometers in a large field-based study of children: protocols, design issues, and effects on precision. *J Phys Act Health*, 5 Suppl 1, S98-111.
- Mayer, J., Roy, P., & Mitra, K. P. (1956). Relation between caloric intake, body weight, and physical work studies in an industrial male population in West Bengal. *The American Journal of Clinical Nutrition*, 4(2), 169-175.
- Mazess, R. B., Barden, H. S., Bisek, J. P., & Hanson, J. (1990). Dual-energy x-ray absorptiometry for total-body and regional bone-mineral and soft-tissue composition. *The American Journal of Clinical Nutrition*, 51(6), 1106-1112.
- McCarthy, H. D., Cole, T. J., Fry, T., Jebb, S. A., & Prentice, A. M. (2006). Body fat reference curves for children. *International Journal of Obesity*, 30(4), 598-602. doi:10.1038/sj.ijo.0803232
- McKay, H. A., Macdonald, H. M., Nettlefold, L., Masse, L. C., Day, M., & Naylor, P. (2014). Action Schools! BC implementation: from efficacy to effectiveness to scale-up. *British Journal of Sports Medicine*, bjsports-2013-093361.
- McKay, H. A., MacLean, L. B., Petit, M. A., MacKelvie-O'Brien, K., Janssen, P., Beck, T. J., & Khan, K. M. (2005). "Bounce at the Bell": a novel program of short bouts of exercise improves proximal femur bone mass in early pubertal children. *British Journal of Sports Medicine*, 39(8), 521-526.
- Mei, Z., Grummer-Strawn, L. M., Pietrobelli, A., Goulding, A., Goran, M. I., & Dietz, W. H. (2002). Validity of body mass index compared with other body-composition screening indexes for the assessment of body fatness in children and adolescents. *The American Journal of Clinical Nutrition*, 75(6), 978-985.
- Metcalf, B. S., Hosking, J., Jeffery, A. N., Voss, L. D., Henley, W., & Wilkin, T. J. (2011). Fatness leads to inactivity, but inactivity does not lead to fatness: a longitudinal study in children (EarlyBird 45). *Archives of Disease in Childhood*, 96(10), 942-U947. doi:10.1136/adc.2009.175927
- Meyer, K. A., Friend, S., Hannan, P. J., Himes, J. H., Demerath, E. W., & Neumark-Sztainer, D. (2011). Ethnic variation in body composition assessment in a sample of adolescent girls. *Int J Pediatr Obes*, 6(5-6), 481-490. doi:10.3109/17477166.2011.596841
- Microsoft Corp. (2016). Microsoft Excel for Mac.
- Mirwald, R. L., & Bailey, D. A. (1986). Maximal aerobic power. London, Ontario: Sports Dynamics.
- Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise*, 34(4), 689-694.
- Misra, A., & Khurana, L. (2011). Obesity-related non-communicable diseases: South Asians vs White Caucasians. *International Journal of Obesity*, 35(2), 167-187.
- Moore, F. D., & Boyden, C. M. (1963). Body cell mass and limits of hydration of the fat-free body: Their relation to estimated skeletal weight. *Annals of the New York Academy of Sciences*, 110(1), 62-71.

- Moore, S. A., McKay, H. A., Macdonald, H., Nettlefold, L., Baxter-Jones, A. D., Cameron, N., & Brasher, P. M. (2015). Enhancing a somatic maturity prediction model. *Medicine and Science in Sports and Exercise*, 47(8), 1755-1764.
- Moreno, L. A., Mesana, M. I., Gonzalez-Gross, M., Gil, C. M., Fleta, J., Warnberg, J., Ruiz, J. R., et al. (2005). Anthropometric body fat composition reference values in Spanish adolescents. The AVENA Study. *European Journal of Clinical Nutrition*, 60(2), 191-196.
- Moreno, L. A., & Rodríguez, G. (2007). Dietary risk factors for development of childhood obesity. *Current Opinion in Clinical Nutrition and Metabolic Care*, 10(3), 336-341.
- Moss, B. G., & Yeaton, W. H. (2012). U.S. children's preschool weight status trajectories: patterns from 9-month, 2-year, and 4-year Early Childhood Longitudinal Study-Birth cohort data. *American Journal of Health Promotion*, 26(3), 172-175. doi:10.4278/ajhp.100304-ARB-73
- Mueller, W. H. (1982). The changes with age of the anatomical distribution of fat. *Social Science and Medicine*, 16(2), 191-196.
- Mueller, W. H., Harrist, R. B., Doyle, S. R., & Labarthe, D. R. (2004). Percentiles of body composition from bioelectrical impedance and body measurements in U.S. adolescents 8-17 years old: Project HeartBeat! *American Journal of Human Biology*, 16(2), 135-150. doi:10.1002/ajhb.20002
- Mullenbach, V., Kushi, L., Jacobson, C., Prineas, R., & Sinaiko, A. (1992). Comparison of 3-day food record and 24-hour recall by telephone for dietary evaluation in adolescents. *Journal of the American Dietetic Association*.
- Murray, L., Johnston, B., Lane, A., Harvey, I., Donovan, J., Nair, P., & Harvey, R. (2003). Relationship between body mass and gastro-oesophageal reflux symptoms: The Bristol Helicobacter Project. *International Journal of Epidemiology*, 32(4), 645-650. doi:10.1093/ije/dyg108
- Must, A., & Anderson, S. E. (2006). Body mass index in children and adolescents: considerations for population-based applications. *International Journal of Obesity*, 30(4), 590-594. Retrieved from <http://dx.doi.org/10.1038/sj.ijo.0803300>
- Must, A., Dallal, G. E., & Dietz, W. H. (1991). Reference data for obesity - 85th and 95th percentiles of body-mass index (wt/ht²) and triceps skinfold thickness. *American Journal of Clinical Nutrition*, 53(4), 839-846.
- Must, A., Jacques, P. F., Dallal, G. E., Bajema, C. J., & Dietz, W. H. (1992). Long-term morbidity and mortality of overweight adolescents. A follow-up of the Harvard Growth Study of 1922 to 1935. *New England Journal of Medicine*, 327(19), 1350-1355. doi:10.1056/NEJM199211053271904
- Must, A., & Tybor, D. (2005). Physical activity and sedentary behavior: a review of longitudinal studies of weight and adiposity in youth. *International Journal of Obesity*, 29, S84-S96.
- Mustillo, S., Worthman, C., Erkanli, A., Keeler, G., Angold, A., & Costello, E. J. (2003). Obesity and psychiatric disorder: Developmental trajectories. *Pediatrics*, 111(4), 851-859. doi:10.1542/peds.111.4.851
- Muthén, L. K., & Muthén, B. O. (2017). Mplus User's Guide. Eighth Edition. Los Angeles, CA: Muthén & Muthén.

- Nadeau, C., Asakawa, K., Flanagan, W., Wall, R., Bancej, C. M., & Morrison, H. (2013). Projection of body mass index (BMI), chronic conditions and healthcare costs in Canada: An application of microsimulation. *Canadian journal of diabetes*(37), S243-S244.
- National Health and Welfare. (1977). *Food Consumption Patterns Report*. Retrieved from Ottawa, ON:
- National Institutes of Health. (1985). *Health implications of obesity*. Retrieved from <https://consensus.nih.gov/1985/1985Obesity049html.htm>
- Naylor, P. J., Macdonald, H. M., Reed, K. E., & McKay, H. A. (2006). Action Schools! BC: A socioecological approach to modifying chronic disease risk factors in elementary school children. *Preventing Chronic Disease*, 3, A60.
- Neovius, M. G., Linné, Y. M., Barkeling, B. S., & Rossner, S. O. (2004). Sensitivity and specificity of classification systems for fatness in adolescents. *The American Journal of Clinical Nutrition*, 80(3), 597-603.
- Newman III, W. P., Freedman, D. S., Voors, A. W., Gard, P. D., Srinivasan, S. R., Cresanta, J. L., Williamson, G. D., et al. (1986). Relation of serum lipoprotein levels and systolic blood pressure to early atherosclerosis. *New England Journal of Medicine*, 314(3), 138-144.
- Nicklas, T. A., Elkasabany, A., Srinivasan, S. R., & Berenson, G. (2001). Trends in nutrient intake of 10-year-old children over two decades (1973–1994) The Bogalusa Heart Study. *American Journal of Epidemiology*, 153(10), 969-977.
- Nielsen, S. J., Siega-Riz, A. M., & Popkin, B. M. (2002). Trends in Energy Intake in U.S. between 1977 and 1996: Similar Shifts Seen across Age Groups. *Obesity Research*, 10(5), 370-378. doi:10.1038/oby.2002.51
- Nielsen, S. J., Siega-Riz, A. M., & Popkin, B. M. (2002). Trends in energy intake in US between 1977 and 1996: similar shifts seen across age groups. *Obesity Research*, 10(5), 370-378.
- Njeh, C., Samat, S., Nightingale, A., McNeil, E., & Boivin, C. (1997). Radiation dose and in vitro precision in paediatric bone mineral density measurement using dual X-ray absorptiometry. *The British journal of radiology*, 70(835), 719-727.
- Norman, G. J., Schmid, B. A., Sallis, J. F., Calfas, K. J., & Patrick, K. (2005). Psychosocial and environmental correlates of adolescent sedentary behaviors. *Pediatrics*, 116(4), 908-916.
- Obesity Action Coalition. (2015). People-First Language for Obesity. Retrieved from <http://www.obesityaction.org/weight-bias-and-stigma/people-first-language-for-obesity>.
- Ogden, C., Carroll, M. D., Curtin, L. R., Lamb, M. M., & Flegal, K. M. (2010). About childhood obesity. *Journal of the American Medical Association*, 303(3), 242-249.
- Ogden, C. L., Carroll, M. D., & Flegal, K. M. (2008). High body mass index for age among US children and adolescents, 2003-2006. *Journal of the American Medical Association*, 299(20), 2401-2405. doi:10.1001/jama.299.20.2401
- Ogden, C. L., & Flegal, K. M. (2010). Changes in terminology for childhood overweight and obesity. *Journal of the American Aging Association*, 12, 12.

- Oliver, L., & Hayes, M. (2008). Effects of neighbourhood income on reported body mass index: an eight year longitudinal study of Canadian children. *BMC Public Health*, 8(1), 16.
- Organization, W. H. (1995). Physical status: The use of and interpretation of anthropometry, Report of a WHO Expert Committee.
- Ortega, R. M., Requejo, A. M., Andrés, P., López-Sobaler, A. M., Redondo, R., & González-Fernández, M. (2007). Relationship between diet composition and body mass index in a group of Spanish adolescents. *British Journal of Nutrition*, 74(6), 765-773. doi:10.1079/BJN19950004
- Pan, H., & Cole, T. J. (2004). A comparison of goodness of fit tests for age-related reference ranges. *Statistics in Medicine*, 23(11), 1749-1765. doi:10.1002/sim.1692
- Parikh, R., Mathai, A., Parikh, S., Sekhar, G. C., & Thomas, R. (2008). Understanding and using sensitivity, specificity and predictive values. *Indian Journal of Ophthalmology*, 56(1), 45.
- Parsons, T. (2005). Childhood predictors of BMI trajectories *Child Obes* (pp. 165-187): CRC Press.
- Parsons, T. J., Power, C., Logan, S., & Summerbell, C. D. (1999). Childhood predictors of adult obesity: a systematic review. *International Journal of Obesity*, 23, S1-S107.
- Patton, I. T., & McPherson, A. C. (2013). Anthropometric measurements in Canadian children: A scoping review. *Canadian Journal of Public Health. Revue Canadienne de Santé Publique*, 104(5), 369-374.
- PDAY Research Group. (1990). Relationship of atherosclerosis in young men to serum lipoprotein cholesterol concentrations and smoking. *Journal of the American Medical Association*, 264, 3018-3024.
- Pearson, N., Braithwaite, R. E., Biddle, S. J. H., van Sluijs, E. M. F., & Atkin, A. J. (2014). Associations between sedentary behaviour and physical activity in children and adolescents: a meta-analysis. *Obesity Reviews*, 15(8), 666-675. doi:10.1111/obr.12188
- Perkins, N. J., & Schisterman, E. F. (2006). The inconsistency of “optimal” cutpoints obtained using two criteria based on the receiver operating characteristic curve. *American Journal of Epidemiology*, 163(7), 670-675.
- Pettigrew, A. M. (1990). Longitudinal field research on change: Theory and practice. *Organization Science*, 1(3), 267-292. doi:10.2307/2635006
- Phillips, C. M., Tierney, A. C., Perez-Martinez, P., Defoort, C., Blaak, E. E., Gjelstad, I. M., Lopez-Miranda, J., et al. (2013). Obesity and body fat classification in the metabolic syndrome: impact on cardiometabolic risk metabotype. *Obesity (Silver Spring)*, 21(1), E154-E161.
- Pietrobelli, A., Faith, M. S., Allison, D. B., Gallagher, D., Chiumello, G., & Heymsfield, S. B. (1998). Body mass index as a measure of adiposity among children and adolescents: A validation study. *Journal of Pediatrics*, 132(2), 204-210. doi:10.1016/s0022-3476(98)70433-0
- Poitras, V. J., Gray, C. E., Borghese, M. M., Carson, V., Chaput, J.-P., Janssen, I., Katzmarzyk, P. T., et al. (2016). Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged

- children and youth. *Applied Physiology, Nutrition, and Metabolism*, 41(6 (Suppl. 3)), S197-S239. doi:10.1139/apnm-2015-0663
- Pramanik, P., Chowdhury, R., & Das, A. (2014). Reference values of body fat indices for semi urban children and adolescent of bengalee ethnicity. *Global Journal of Biology, Agriculture & Health Sciences*, 3(4), 19-29.
- Prentice, A. M., & Jebb, S. A. (2001). Beyond body mass index. *Obesity reviews : an official journal of the International Association for the Study of Obesity*, 2(3), 141-147. doi:10.1046/j.1467-789x.2001.00031.x
- Prospective Studies Collaboration. (2008). Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies. *The Lancet*, 373(9669), 1083-1096.
- Pryor, L., Tremblay, R. E., & Boivin, M. (2011). Developmental trajectories of body mass index in early childhood and their risk factors- an 8-year longitudinal study. *Archives of Pediatrics and Adolescent Medicine*, 165(10), 906-912.
- Public Health Agency of Canada. (2012). *Curbing childhood obesity: A Federal, Provincial and Territorial framework for action to promote healthy weights*. Ottawa, ON Retrieved from <http://www.phac-aspc.gc.ca/hp-ps/hl-mvs/framework-cadre/index-eng.php>.
- Public Health Agency of Canada. (2015). Social Determinants of Health. Retrieved from <http://cbpp-pcpe.phac-aspc.gc.ca/public-health-topics/social-determinants-of-health/>
- Puhl, R., Peterson, J. L., & Luedicke, J. (2013). Motivating or stigmatizing? Public perceptions of weight-related language used by health providers. *International Journal of Obesity*, 37(4), 612-619. doi:10.1038/ijo.2012.110
- Puhl, R. M., & Heuer, C. A. (2009). The stigma of obesity: a review and update. *Obesity (Silver Spring)*, 17(5), 941-964. doi:10.1038/oby.2008.636
- Qin, H., Horlick, M., Thornton, J., Wang, J., Pierson, R. N. J., Heshka, S., & Gallagher, D. (2002). Sex and race differences in fat distribution among Asian, African-American, and Caucasian prepubertal children. *The Journal of Clinical Endocrinology & Metabolism*, 87(5), 2164-2170. doi:doi:10.1210/jcem.87.5.8452
- Rahman, M., & Berenson, A. B. (2010). Accuracy of current body mass index obesity classification for white, black and Hispanic reproductive-age women. *Obstetrics and Gynecology*, 115(5), 982.
- Rao, D. P., Kropac, E., Do, M. T., Roberts, K. C., & Jayaraman, G. C. (2016). Childhood overweight and obesity trends in Canada. *Health Promotion and Chronic Disease Prevention in Canada : Research, Policy and Practice*, 36(9), 194-198.
- Reilly, J., Wilson, J., & Durnin, J. (1995). Determination of body composition from skinfold thickness: a validation study. *Archives of Disease in Childhood*, 73(4), 305-310.
- Reilly, J. J., Armstrong, J., Dorosty, A. R., Emmett, P. M., Ness, A., Rogers, I., Steer, C., et al. (2005). Early life risk factors for obesity in childhood: cohort study. *British Medical Journal*, 330(7504), 1357.
- Reilly, J. J., & McDowell, Z. C. (2003). Physical activity interventions in the prevention and treatment of paediatric obesity: systematic review and critical appraisal. *Proceedings of the Nutrition Society*, 62(3), 611-619.

- Reilly, J. J., Methven, E., McDowell, Z. C., Hacking, B., Alexander, D., Stewart, L., & Kelnar, C. J. (2003). Health consequences of obesity. *Archives of Disease in Childhood*, 88(9), 748-752.
- Rennie, K. L., Johnson, L., & Jebb, S. A. (2005). Behavioural determinants of obesity. *Best Practice & Research Clinical Endocrinology & Metabolism*, 19(3), 343-358.
- Rich, P. (2015). CMA recognizes obesity as a disease. Retrieved from https://www.cma.ca/En/Pages/cma-recognizes-obesity-as-a-disease.aspx?utm_content=bufferb35ae&utm_medium=social&utm_source=facebook.com&utm_campaign=buffer
- Riddoch, C. J., Leary, S. D., Ness, A. R., Blair, S. N., Deere, K., Mattocks, C., Griffiths, A., et al. (2009). Prospective associations between objective measures of physical activity and fat mass in 12-14 year old children: the Avon Longitudinal Study of Parents and Children (ALSPAC). *British Medical Journal*, 339. doi:10.1136/bmj.b4544
- Rigby, R. A., & Stasinopoulos, D. M. (2005). Generalized additive models for location, scale and shape. *Journal of the Royal Statistical Society: Series C (Applied Statistics)*, 54(3), 507-554.
- Rigby, R. A., & Stasinopoulos, D. M. (2005). Generalized additive models for location, scale and shape,(with discussion). *Applied Statistics*, 54(3), 507-554.
- Rigby, R. A., & Stasinopoulos, D. M. (2006). Using the Box-Cox t distribution in GAMLSS to model skewness and kurtosis. *Statistical Modelling*, 6(3), 209-229.
- Rigby, R. A., & Stasinopoulos, D. M. (2014). Automatic smoothing parameter selection in GAMLSS with an application to centile estimation. *Statistical Methods in Medical Research*, 23(4), 318-332.
- Rigby, R. A., & Stasinopoulos, M. D. (2004). Smooth centile curves for skew and kurtotic data modelled using the Box-Cox power exponential distribution. *Statistics in Medicine*, 23(19), 3053-3076.
- Roberts, K. C., Shields, M., De Groh, M., Aziz, A., & Gilbert, J. A. (2012). Overweight and obesity in children and adolescents: Results from the 2009 to 2011 Canadian Health Measures Survey. *Health Reports*, 23, 3-7.
- Robinson, T. N. (1998). Does television cause childhood obesity? *Journal of the American Medical Association*, 279(12), 959-960.
- Rodriguez, G., Moreno, L., Blay, M., Blay, V., Fleta, J., Sarria, A., & Bueno, M. (2005). Body fat measurement in adolescents: comparison of skinfold thickness equations with dual-energy X-ray absorptiometry. *European Journal of Clinical Nutrition*, 59(10), 1158-1166.
- Rodriguez, M. A., Winkleby, M. A., Ahn, D., Sundquist, J., & Kraemer, H. C. (2002). Identification of population subgroups of children and adolescents with high asthma prevalence - Findings from the Third National Health and Nutrition Examination Survey. *Archives of Pediatrics and Adolescent Medicine*, 156(3), 269-275.
- Roemmich, J. N., & Rogol, A. D. (1999). Hormonal changes during puberty and their relationship to fat distribution. *American Journal of Human Biology*, 11(2), 209-224. doi:10.1002/(SICI)1520-6300(1999)11:2<209::AID-AJHB9>3.0.CO;2-G

- Rogol, A. D., Roemmich, J. N., & Clark, P. A. (2002). Growth at puberty. *Journal of Adolescent Health, 31*(6, Supplement), 192-200. Retrieved from <http://www.sciencedirect.com/science/article/pii/S1054139X02004858>
- Romero-Corral, A., Somers, V. K., Sierra-Johnson, J., Thomas, R. J., Collazo-Clavell, M. L., Korinek, J., Allison, T. G., et al. (2008). Accuracy of body mass index in diagnosing obesity in the adult general population. *International Journal of Obesity, 32*(6), 959-966. doi:10.1038/ijo.2008.11
- Rosario, A. S., Kurth, B., Stolzenberg, H., Ellert, U., & Neuhauser, H. (2010). Body mass index percentiles for children and adolescents in Germany based on a nationally representative sample (KiGGS 2003-2006). *European Journal of Clinical Nutrition, 64*(4), 341.
- Roy, M., Sempe, M., Orssaud, E., & Pedron, G. (1972). Evolution Clinique de la puberté de la fille. *Arch Franç Pédiatr, 29*, 155-168.
- Roy, M. P. (1971). Evolution Clinique de la puberté du garçon. In C. I. d. l'Enfance (Ed.), *Compte Rendu de la XIe. Reunion des Equipes Chargees des Etudes sur la Croissance et al Developpement de l'Engant Normal*. (pp. 185-190). Paris, France.
- RStudio Team. (2015). RStudio: Integrated Development for R. Boston, MA: RStudio Inc.,
- Ruspini, E. (2002). *Introduction To longitudinal research*. London ; New York: Routledge.
- Sala, A., Webber, C. E., Morrison, J., Beaumont, L. F., & Barr, R. D. (2007). Whole-body bone mineral content, lean body mass, and fat mass measured by dual-energy X-ray absorptiometry in a population of normal canadian children and adolescents. *Canadian Association of Radiologists Journal, 58*(1), 46-52.
- Sallis, J. F., Prochaska, J. J., & Taylor, W. C. (2000). A review of correlates of physical activity of children and adolescents. *Medicine and Science in Sports and Exercise, 32*, 963-975.
- Sardinha, L. B., Going, S. B., Teixeira, P. J., & Lohman, T. G. (1999). Receiver operating characteristic analysis of body mass index, triceps skinfold thickness, and arm girth for obesity screening in children and adolescents. *American Journal of Clinical Nutrition, 70*, 1090-1095.
- Saunders, T. (2011). Potential contributors to the Canadian pediatric obesity epidemic. *ISRN Pediatr, 2011*, 917684. doi:10.5402/2011/917684
- Schisterman, E. F., Perkins, N. J., Liu, A., & Bondell, H. (2005). Optimal cut-point and its corresponding Youden Index to discriminate individuals using pooled blood samples. *Epidemiology, 73*-81.
- Shaw, N. J., Crabtree, N. J., Kibirige, M. S., & Fordham, J. N. (2007). Ethnic and gender differences in body fat in British schoolchildren as measured by DXA. *Archives of Disease in Childhood, 92*(10), 872-875. doi:10.1136/adc.2007.117911
- Shields, M. (2006). Overweight and obesity among children and youth. *Health Reports, 17*, 27-42.
- Shields, M., & Tremblay, M. S. (2010). Canadian childhood obesity estimates based on WHO, IOTF and CDC cut-points. *International Journal of Pediatric Obesity, 5*(3), 265-273. doi:10.3109/17477160903268282

- Siervo M., & Jebb S.A. (2010). Body composition assessment - theory into practice - introduction of multicompartement models. *IEEE Engineering in Medicine and Biology Magazine*, 48-59. doi:10.1109/MEMB.2009.935471
- Simen-Kapeu, A., & Veugeliers, P. (2010). Should public health interventions aimed at reducing childhood overweight and obesity be gender-focused? *BMC Public Health*, 10(1), 340.
- Singer, K. (2017). The initiation of metabolic inflammation in childhood obesity. *The Journal of clinical investigation*, 127(1), 65-73. doi:10.1172/JCI88882
- Skinner, J. D., Bounds, W., Carruth, B. R., & Ziegler, P. (2003). Longitudinal calcium intake is negatively related to children's body fat indexes. *Journal of the American Dietetic Association*, 103(12), 1626-1631. doi:10.1016/s0002-8223(03)01361-0
- Sopher, A. B., Thornton, J. C., Wang, J., Pierson, R. N., Heymsfield, S. B., & Horlick, M. (2004). Measurement of percentage of body fat in 411 children and adolescents: a comparison of dual-energy X-ray absorptiometry with a four-compartment model. *Pediatrics*, 113, 1285-1290. doi:10.1542/peds.113.5.1285
- Staiano, A., & Katzmarzyk, P. (2012). Ethnic and sex differences in body fat and visceral and subcutaneous adiposity in children and adolescents. *International Journal of Obesity*, 36(10), 1261-1269.
- Stamatakis, E., Primatesta, P., Chinn, S., Rona, R., & Falaschetti, E. (2005). Overweight and obesity trends from 1974 to 2003 in English children: what is the role of socioeconomic factors? *Archives of Disease in Childhood*, 90(10), 999-1004. doi:10.1136/adc.2004.068932
- Statistics Canada. (2004). Canadian Community Health Survey, Cycle 2.2: Nutrition: General Health Component 2010.
- Statistics Canada. (2009). Population by selected ethnic origins, by province and territory (2006 Census) (British Columbia).
- Stevens, J., Suchindran, C., Ring, K., Baggett, C. D., Jobe, J. B., Story, M., Thompson, J., et al. (2004). Physical activity as a predictor of body composition in American Indian children. *Obesity Research*, 12(12), 1974-1980. doi:10.1038/oby.2004.248
- Strauss, R. S. (2000). Childhood obesity and self-esteem. *Pediatrics*, 105(1), e15.
- Strauss, R. S., & Pollack, H. A. (2003). Social marginalization of overweight children. *Archives of Pediatrics and Adolescent Medicine*, 157(8), 746-752. doi:10.1001/archpedi.157.8.746
- Sung, R. Y., So, H. K., Choi, K. C., Li, A. M., Yin, J., & Nelson, E. A. (2009). Body fat measured by bioelectrical impedance in Hong Kong Chinese children. *Hong Kong Medical Journal. Xianggang Yi Xue Za Zhi*, 15(2), 110-117. Retrieved from <http://www.hkmj.org/system/files/hkm0904p110.pdf>
- Tanaka, C., Reilly, J. J., & Huang, W. Y. (2014). Longitudinal changes in objectively measured sedentary behaviour and their relationship with adiposity in children and adolescents: systematic review and evidence appraisal. *Obesity Reviews*, 15(10), 791-803. doi:10.1111/obr.12195
- Tanner, J. M. (1952). The assessment of growth and development in children. *Archives of Disease in Childhood*, 27(131), 10.
- Tanner, J. M. (1963). The regulation of human growth. *Child Development*, 817-847.
- Tanner, J. M. (1990). *Foetus into man: Physical growth from conception to maturity*: Harvard University Press.

- Tanner, J. M., Whitehouse, R. H., Marubini, E., & Resele, L. F. (1976). The adolescent growth spurt of boys and girls of the Harpenden growth study. *Annals of Human Biology*, 3(2), 109-126. Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/1275435>
- Tanner, J. M., Whitehouse, R. H., & Takaishi, M. (1966). Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. I. *Archives of Disease in Childhood*, 41(219), 454.
- Taranger, J., & Hägg, U. (1980). The timing and duration of adolescent growth. *Acta Odontologica Scandinavica*, 38(1), 57-67.
- Taveras, E. M., Gillman, M. W., Kleinman, K., Rich-Edwards, J. W., & Rifas-Shiman, S. L. (2010). Racial/ethnic differences in early-life risk factors for childhood obesity. *Pediatrics*, 125(4), 686-695. doi:10.1542/peds.2009-2100
- Taylor, R. W., Falorni, A., Jones, I. E., & Goulding, A. (2002). Identifying adolescents with high percentage body fat: a comparison of BMI cutoffs using age and stage of pubertal development compared with BMI cutoffs using age alone. *European Journal of Clinical Nutrition*, 57(6), 764-769.
- Taylor, R. W., Falorni, A., Jones, I. E., & Goulding, A. (2003). Identifying adolescents with high percentage body fat: a comparison of BMI cutoffs using age and stage of pubertal development compared with BMI cutoffs using age alone. *European Journal of Clinical Nutrition*, 57(6), 764-769. doi:10.1038/sj.ejcn.1601608
- Taylor, R. W., Grant, A. M., Williams, S. M., & Goulding, A. (2010). Sex differences in regional body fat distribution from pre- to postpuberty. *Obesity (Silver Spring)*, 18(7), 1410-1416. doi:10.1038/oby.2009.399
- Taylor, R. W., Jones, I. E., Williams, S. M., & Goulding, A. (2002). Body fat percentages measured by dual-energy X-ray absorptiometry corresponding to recently recommended body mass index cutoffs for overweight and obesity in children and adolescents aged 3-18 y. *American Journal of Clinical Nutrition*, 76(6), 1416-1421.
- Telama, R. (2009). Tracking of Physical Activity from Childhood to Adulthood: A Review. *Obes Facts*, 2(3), 187-195. doi:10.1159/000222244
- Telama, R., Yang, X., Viikari, J., Välimäki, I., Wanne, O., & Raitakari, O. (2005). Physical activity from childhood to adulthood: A 21-year tracking study. *American Journal of Preventive Medicine*, 28, 267-273. doi:<http://dx.doi.org.ezproxy.library.uvic.ca/10.1016/j.amepre.2004.12.003>
- Telford, R. D., Cunningham, R. B., & Abhayaratna, W. P. (2014). Temporal divergence of percent body fat and body mass index in pre-teenage children: the LOOK longitudinal study. *Pediatric Obesity*, 9(6), 448-454. doi:10.1111/j.2047-6310.2013.00194.x
- Telford, R. D., Cunningham, R. B., Daly, R. M., Reynolds, G. J., Lafferty, A. R. A., Gravenmaker, K. J., Budge, M. M., et al. (2008). Discordance of international adiposity classifications in Australian boys and girls - The LOOK study. *Annals of Human Biology*, 35(3), 334-341. doi:10.1080/03014460802014625
- The American Psychological Association. (2015). Guidelines for Nonhandicapping Language in APA Journals. *APA Style*. Retrieved from <http://www.apastyle.org/manual/related/nonhandicapping-language.aspx>

- The Obesity Society. (2015). People-first language for obesity. *Position Statement*. Retrieved from <http://www.obesity.org/publications/position-statements.htm>
- Tremblay, A., Fontaine, E., Poehlman, E., Mitchell, D., Perron, L., & Bouchard, C. (1985). The effect of exercise-training on resting metabolic rate in lean and moderately obese individuals. *International Journal of Obesity*, 10(6), 511-517.
- Tremblay, M., & Willms, J. (2000). Secular trends in the body mass index of Canadian children. *Canadian Medical Association Journal*, 163, 1429 - 1433.
- Tremblay, M. S., LeBlanc, A. G., Kho, M. E., Saunders, T. J., Larouche, R., Colley, R. C., Goldfield, G., et al. (2011). Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *International Journal of Behavioural Nutrition and Physical Activity*, 8(1), 98.
- Tremblay, M. S., & Willms, J. D. (2003). Is the Canadian childhood obesity epidemic related to physical inactivity? *International Journal of Obesity*, 27(9), 1100-1105. doi:10.1038/sj.ijo.0802376
- Troiano, R. P., Briefel, R. R., Carroll, M. D., & Bialostosky, K. (2000). Energy and fat intakes of children and adolescents in the United States: data from the National Health and Nutrition Examination Surveys. *The American Journal of Clinical Nutrition*, 72(5), 1343s-1353s.
- Trost, S. G., Kerr, L., Ward, D. S., & Pate, R. R. (2001). Physical activity and determinants of physical activity in obese and non-obese children. *International Journal of Obesity*, 25(6), 822.
- Trost, S. G., Loprinzi, P. D., Moore, R., & Pfeiffer, K. A. (2011). Comparison of accelerometer cut points for predicting activity intensity in youth. *Medicine and Science in Sports and Exercise*, 43(7), 1360-1368. doi:10.1249/MSS.0b013e318206476e
- van Sluijs, E. M. F., McMinn, A. M., & Griffin, S. J. (2007). Effectiveness of interventions to promote physical activity in children and adolescents: Systematic review of controlled trials. *BMJ: British Medical Journal*, 335, 703-707. doi:10.1136/bmj.39320.843947.BE
- Ventura, A. K., Loken, E., & Birch, L. L. (2009). Developmental trajectories of girls' BMI across childhood and adolescence. *Obesity (Silver Spring)*, 17(11), 2067-2074. doi:10.1038/oby.2009.123
- Verbeke, G. (1997). Linear mixed models for longitudinal data *Linear mixed models in practice* (pp. 63-153): Springer.
- Wake, M., Hardy, P., Canterford, L., Sawyer, M., & Carlin, J. B. (2007). Overweight, obesity and girth of Australian preschoolers: prevalence and socio-economic correlates. *International Journal of Obesity*, 31(7), 1044-1051. doi:10.1038/sj.ijo.0803503
- Wang, F., Wild, T. C., Kipp, W., Kuhle, S., & Veugelers, P. J. (2009). The influence of childhood obesity on the development of self-esteem. *Health Reports*, 20(2), 21.
- Wang, J., Thornton, J. C., Russell, M., Burastero, S., Heymsfield, S., & Pierson, R. N. (1994). Asians have lower body mass index (BMI) but higher percent body fat than do whites: comparisons of anthropometric measurements. *The American Journal of Clinical Nutrition*, 60(1), 23-28.

- Wang, L., & Hui, S. (2015). Diagnostic accuracy of different body weight and height-based definitions of childhood obesity in identifying overfat among Chinese children and adolescents: a cross-sectional study. *BMC Public Health*, *15*(1), 1.
- Wang, Y., & Beydoun, M. A. (2007). The obesity epidemic in the United States--gender, age, socioeconomic, racial/ethnic, and geographic characteristics: a systematic review and meta-regression analysis. *Epidemiologic Reviews*, *29*, 6-28. doi:10.1093/epirev/mxm007
- Wang, Y., Wu, Y., Wilson, R. F., Bleich, S., Cheskin, L., Weston, C., Showell, N., et al. (2013). *Childhood obesity prevention programs: comparative effectiveness review and meta-analysis*.
- Wareham, N. J., & Rennie, K. L. (1998). The assessment of physical activity in individuals and populations: Why try to be more precise about how physical activity is assessed? *International Journal of Obesity*, *22*, S30-S38.
- Washino, K., Takada, H., Nagashima, M., & Iwata, H. (1999). Significance of the atherosclerogenic index and body fat in children as markers for future, potential coronary heart disease. *Pediatrics International*, *41*(3), 260-265. doi:10.1046/j.1442-200x.1999.01065.x
- Waters, E., de Silva-Sanigorski, A., Burford, B. J., Brown, T., Campbell, K. J., Gao, Y., Armstrong, R., et al. (2011). Interventions for preventing obesity in children. *The Cochrane Library*.
- Weber, D. R., Moore, R. H., Leonard, M. B., & Zemel, B. S. (2013). Fat and lean BMI reference curves in children and adolescents and their utility in identifying excess adiposity compared with BMI and percentage body fat. *American Journal of Clinical Nutrition*, *98*(1), 49-56. doi:10.3945/ajcn.112.053611
- Weiss, R., Dziura, J., Burgert, T. S., Tamborlane, W. V., Taksali, S. E., Yeckel, C. W., Allen, K., et al. (2004). Obesity and the metabolic syndrome in children and adolescents. *New England Journal of Medicine*, *350*(23), 2362-2374. doi:10.1056/NEJMoa031049
- Wells, J. C. (2014). Toward body composition reference data for infants, children, and adolescents. *Advanced Nutrition*, *5*(3), 320s-329s. doi:10.3945/an.113.005371
- Whitaker, R. C., Wright, J. A., Pepe, M. S., Seidel, K. D., & Dietz, W. H. (1997). Predicting obesity in young adulthood from childhood and parental obesity. *The New England Journal of Medicine*, *337*, 869-873. doi:10.1056/NEJM199709253371301
- WHO Multicentre Growth Reference Study Group. (2006). WHO Child Growth Standards based on length/height, weight and age. *Acta Paediatrica (Oslo, Norway: 1992)*, *450*, 76.
- Wiecha, J. L., Peterson, K. E., Ludwig, D. S., Kim, J., Sobol, A., & Gortmaker, S. L. (2006). When children eat what they watch: impact of television viewing on dietary intake in youth. *Archives of Pediatrics and Adolescent Medicine*, *160*(4), 436-442.
- Williams, D. P., Going, S. B., Lohman, T. G., Harsha, D. W., Srinivasan, S. R., Webber, L. S., & Berenson, G. S. (1992). Body fatness and risk for elevated blood-pressure, total cholesterol, and serum-lipoprotein ratios in children and adolescents. *American Journal of Public Health*, *82*(3), 358-363. doi:10.2105/ajph.82.3.358

- Wong, W. W., Hergenroeder, A. C., Stuff, J. E., Butte, N. F., O'Brian Smith, E., & Ellis, K. J. (2002). Evaluating body fat in girls and female adolescents: Advantages and disadvantages of dual-energy X-ray absorptiometry. *American Journal of Clinical Nutrition*, 76, 384-389.
- World Health Organization. (2009). *WHO child growth standards: growth velocity based on weight, length and head circumference: methods and development*: World Health Organization.
- World Health Organization. (2015). Childhood overweight and obesity. *Global Strategy on Diet, Physical Activity and Health*.
- Wulan, S. N., Westerterp, K. R., & Plasqui, G. (2010). Ethnic differences in body composition and the associated metabolic profile: A comparative study between Asians and Caucasians. *Maturitas*, 65(4), 315-319.
- Youden, W. J. (1950). Index for rating diagnostic tests. *Cancer*, 3(1), 32-35.
- Young, A. F., Powers, J. R., & Bell, S. L. (2006). Attrition in longitudinal studies: who do you lose? *Australian and New Zealand Journal of Public Health*, 30(4), 353-361.
- Zimmermann, M. B., Gubeli, C., Puntener, C., & Molinari, L. (2004). Detection of overweight and obesity in a national sample of 6-12-y-old Swiss children: accuracy and validity of reference values for body mass index from the US Centers for Disease Control and Prevention and the International Obesity Task Force. *American Journal of Clinical Nutrition*, 79(5), 838-843.

Appendix 1 - Ethical approval certificate




Office of Research Services | Human Research Ethics Board
 Administrative Services Building Rm B202 PO Box 1700 STN CSC Victoria BC V8W 2Y2 Canada
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Certificate of Renewed Approval

PRINCIPAL INVESTIGATOR: Jennifer McConnell	ETHICS PROTOCOL NUMBER 16-044 Minimal Risk Review - Delegated
UVic STATUS: Ph.D. Student	ORIGINAL APPROVAL DATE: 01-Feb-16
UVic DEPARTMENT: EPHE	RENEWED ON: 31-Jan-17
SUPERVISOR: Dr. Patti-Jean Naylor	APPROVAL EXPIRY DATE: 31-Jan-18
<p>PROJECT TITLE: An Investigation of Overweight and obesity and Potential Social and Behavioural Contributors in an Ethnically Diverse Cohort of British Columbian Children and Youth</p> <p>RESEARCH TEAM MEMBER Advisory Committee Members: Heather Macdonald (UBC), Scott Hofer (UVic), Ryan Rhodes (UVic)</p> <p>DECLARED PROJECT FUNDING: None</p>	
CONDITIONS OF APPROVAL	
<p>This Certificate of Approval is valid for the above term provided there is no change in the protocol.</p> <p>Modifications To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.</p> <p>Renewals Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.</p> <p>Project Closures When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.</p>	
Certification	
<p>This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants.</p> <p style="text-align: center;">_____ Dr. Rachael Scarth Associate Vice-President Research Operations</p>	

Certificate Issued On: 16-Feb-17

16-044
McConnell, Jennifer



Appendix 2 – Health History Questionnaire



Action Schools! BC

Health History Questionnaire - Fall 2005

Please take the time to answer the following questions about your child's health. This questionnaire is voluntary and you are free to leave any questions unanswered. Please be assured that all information will remain strictly confidential and will only be available to the researchers. If you have any questions regarding the contents of this questionnaire, please contact _____.

You can also email any questions to _____ . Please return this questionnaire to your child's teacher along with the consent form if you and your child choose to participate. Thank you for your participation in the Evaluation Component of Action Schools! BC.

Your Child's Name: _____

Age: _____ Birth Date (d/m/y): _____ Gender: Male _____ Female: _____

School: _____ Grade: _____ Division: _____
Teacher: _____

Home Address: _____
City: _____

Postal Code: _____ Phone Number: _____

Mother's Name: _____ Father's Name: _____

Do you have a computer at home: Yes _____ No _____ Do you use email: Yes _____ No _____

E-Mail Address: _____

ABOUT YOU (THE PARENTS OR GUARDIANS):

1.0 Where were you born?

Mother: _____ Father: _____

1.1 Where were **your parents** born?

Maternal Mother: _____ Maternal Father:

Paternal Mother: _____ Paternal Father:

1.2 How long have you lived in North America? Years: _____
Months: _____**1.3** Where did your family live before moving to North America?

1.4 How would you classify your family ethnically? (i.e., Caucasian-Canadian, Japanese-Canadian, etc.)

ABOUT YOUR CHILD:

Child's birth weight _____ Circle one: Grams or Lbs/Ozs

2.0 **Nutrition History:****2.1** Who prepares your child's meals (i.e. mother, father, grandmother, nanny)? _____**2.2** Does your child drink milk every day?

_____ YES: if yes:

How many cups per day? _____

Has your child always drank milk every day (after being weaned from breast or bottle)?

yes _____ no _____

if **no**, at what age did she/he start drinking milk every day? _____ years old._____ NO: if **no**:

Has your child ever drank one or more cups of milk per day (after being weaned from breast or bottle)?

_____ yes: at what age did she/he stop drinking milk every day? _____ years old.

How many cups did he/she drink until that age? _____ cups per day

_____ no : (never drank milk on a daily basis after being weaned)

2.3 Is your child on a special diet? _____ Yes _____ No

If yes: _____ vegetarian
 _____ low sodium
 _____ low cholesterol
 _____ other

Please specify:

3.0 Medical

History and Status:

3.1 Has your child ever been treated for any of the following conditions?

	Yes	No
food allergies	<input type="radio"/>	<input type="radio"/>
hypothyroidism	<input type="radio"/>	<input type="radio"/>
other allergies	<input type="radio"/>	<input type="radio"/>
hyperthyroidism	<input type="radio"/>	<input type="radio"/>
asthma	<input type="radio"/>	<input type="radio"/>

other conditions (please list) _____

3.2 Is your child currently taking any medications? _____ Yes _____ No

If yes, what medication(s) is your child taking? _____

What are these medication(s) for? _____

3.3 Has your family doctor ever said that your child has a heart condition and that he/she should only do physical activity recommended by a doctor? _____ Yes _____ No

3.4 Does your child complain of chest pain when they are doing physical activity? _____ Yes _____ No

3.5 In the past month, has your child complained of chest pain when they were not doing any physical activity? _____ Yes _____ No

3.6 Does your child have a bone or joint problem that could be made worse by a change in their physical activity? _____ Yes _____ No

3.7 Does your child lose their balance because of dizziness or do they ever lose consciousness?
_____Yes _____No

3.8 Do you know of any other reason why your child should not participate in physical activity?
_____Yes _____No

4.0 Bone History:

4.1 Has your child ever been hospitalized, confined to bed or had a limb immobilized (i.e., arm in a cast)?

_____ Yes _____ No

If **yes:** list condition, approximate date and time involved

(Example: wrist fracture summer, 1990 10 weeks)

Reason

Date

Time Involved

4.2 Is there a history of wrist, hip, or spine fractures in your family? _____ Yes _____ No

If **yes:** indicate who was affected

_____ mother _____ father
 _____ maternal grandmother _____ paternal grandmother
 _____ maternal grandfather _____ paternal grandfather

4.3 Is there a history of osteoporosis in your family? _____ Yes _____ No

If **yes:** indicate who was affected

_____ mother _____ father
 _____ maternal grandmother _____ paternal grandmother
 _____ maternal grandfather _____ paternal grandfather

4.4 Is there a history of any other bone disease in your family?

_____ Yes _____ No

If **yes:** please indicate the family member(s) affected

1. _____
 2. _____

What is the name of the condition(s) affecting this family member?

1. _____
 2. _____

5.0 Physical Activity:

5.1 How would you rate the physical activity level of your child?

Physical activity is defined as vigorous activity that makes them sweat and/or breathe hard.

_____ Inactive
 _____ Sometimes active
 _____ Moderately active
 _____ Often active
 _____ Very active

THANK YOU FOR YOUR PARTICIPATION