MEASUREMENT AND ASSESSMENT OF HEALTH OUTCOMES, BODY COMPOSITION, AND PHYSICAL ACTIVITY IN OBESITY

Arshdeep K. Randhawa

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Abstract

It is yet unknown how obesity relates with temporal changes in health outcomes and how it influences the assessment of body composition and physical activity (PA). The first study of this thesis determined that the obesity-associated health outcomes including hypertension and dyslipidemia have decreased over the last 15 years while there was an increase in general and abdominal obesity ($p<0.05$). The prevalence of type 2 diabetes has increased only in women with general or abdominal obesity (BMI*time; WC*time, $p<0.05$). There may be other temporal changes that have altered how obesity relates with health risks.

The second study of this thesis determined the importance of the commonly held BIA assumptions related to hydration level and fluid distribution in the assessment of body fat (%BF). The results showed that there were no differences in the %BF values between the control and dehydration, exercise, water and/or food intake, & non-voided bladder test conditions (-1.9 to 0.4%, $p >0.05$). Further, no differences in Δ%BF between control and test conditions were observed by weight status (overweight: -2.8 to 0.1% and normal weight: -1.7 to 0.5%; BMI*trial, $p=0.99$). The minor variations in %BF are smaller than what would be expected with weight loss interventions and are similar to reported day-to-day variations in BIA.

Lastly, the third study of this thesis explored differences in objectively measured PA after accounting for cardiorespiratory fitness (CRF) and body mass because these variables may influence the relative workload of a given PA intensity. After accounting for CRF, the individualized cut-offs were higher than the standard cut-offs, wherein men with obesity have lower counts per minute (CPM) values than men without obesity (4004 ± 497 CPM versus 5589 ± 372 CPM, $p <0.05$). Whereas, there was no difference in women by obesity status ($p > 0.05$). However, there were no differences in the PA volume by obesity status with either standard or

individualized cut-offs ($p > 0.05$). Despite using individualized CPM cut-offs, the PA durations remained similar between those with (28.8 ± 20.3 minutes/day) or without obesity (16.0 ± 16.6 minutes/day) ($p = 0.18$). Thus, PA performed by individuals with obesity may be under measured when assessed by current objective measures.

Since some of the obesity associated health outcomes have decreased over time, targeted efforts may be needed to better define obesity and its health consequences. Further, better measures of PA are also needed for individuals with obesity.

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Abbreviations	Terms
BMI	Body Mass Index
%BF	Percent Body Fat
BIA	Bioelectrical Impedance Analysis
CPM	Counts Per Minute
COM	Center of Mass
CRF	Cardiorespiratory Fitness
CVD	Cardiovascular Disease
DXA	Dual-energy X-ray Absorptiometry
FFM	Fat Free Mass
FM	Fat Mass
MET	Metabolic Equivalent of Task
MVPA	Moderate-to-Vigorous Intensity Physical Activity
PA	Physical Activity
SOS	Sum of Skinfolds
TBW	Total Body Water
VM3	Vector Magnitude in Three Planes
VO_2peak	Peak Oxygen Uptake
WC	Waist Circumference

1.0 General Introduction

Obesity is defined as abnormal or excessive fat accumulation that may impair health (1). However, within a clinical setting, obesity is typically operationalized as having a body mass index (BMI) of over 30 kg/m^2. Using this metrics, there has been a marked increase in obesity in the U.S. with the prevalence of obesity among adults rising from 15% to 36.5% between 1988 and 2011 (2). Several national surveys have shown that people living with obesity have an increased risk of several adverse health outcomes and chronic conditions, notably hypertension, diabetes, cardiovascular disease (CVD) and mortality (1,3,4). The prevalence of these chronic conditions is expected to continue to increase along with the increasing obesity and places a great financial burden on the health care system. Not only has general obesity increased, but so has the prevalence of abdominal obesity (5), which is an independent predictor of health risks and mortality risk (6,7). However, it is yet unknown if the temporal increases in abdominal obesity may better explain the temporal changes in health risks. Thus, the first objective of this thesis was to explore abdominal obesity and its association with health risks and chronic conditions over time.

Obesity is associated with numerous health risks, and body composition information may be useful in further identifying individuals at high risk of developing chronic conditions including CVD, diabetes, metabolic syndrome or to monitor disease progression (8). Researchers often use body composition assessment tools such as bioelectrical impedance (BIA) devices to better understand and predict differences in health risk. Thus, it is essential that tools used for assessing body composition provide valid and reliable results (9). Therefore, the second objective of this thesis is to investigate factors that may influence BIA measured body composition.

Lifestyle management including physical activity (PA) is typically recommended as the first line for treatment of obesity (10). It is because PA is associated with many positive health outcomes, weight maintenance and reductions in mortality risks (11). It is crucial to use the right tools for PA assessment in different populations. Accelerometers are objective tools that are commonly used to measure PA. However, these tools do not account for individual differences in factors such as body mass or cardiorespiratory fitness (CRF) which could influence how PA is assessed (12). Thus, the third objective of this thesis is to investigate whether the current accelerometer universal intensity thresholds are biased against individuals with obesity.

The overall purpose of the thesis is to gain a better understanding of obesity and its association with health outcomes, and how obesity may influence select body composition measures and PA assessment measures.

2.0 Literature Review

2.1 Obesity and Health Outcomes

Obesity, defined by BMI, is associated with numerous health risk factors and increased mortality risk from chronic diseases including type 2 diabetes, hypertension, dyslipidemia, cardiovascular diseases and stroke (13). Obesity is one of the most common diseases in the U.S (14) and is the fifth leading cause of mortality globally (15). Previous research has predicted that the prevalence of type 2 diabetes in the U.S. will increase from ~14% in 2010 to up to 33% by 2050 (16). Conversely, recent evidence shows that the likelihood of developing certain obesity-related health risks may have decreased over the last twenty years (17,18). The prevalence of both hypertension and high cholesterol between 1960–62 and 1999–2000 was 12-21% lower across all BMI groups (2). Similarly, there was a linear decline in triglycerides among both men (1.38 mmol/L in 2003-2004 to 1.11 mmol/L in 2013-2014) and women (1.24 mmol/L in 2003-2004 to 1.02 mmol/L in 2013-2014) (19).

Similar to the general temporal trends in the health risks, previous research has demonstrated that individuals with obesity in 1999-2000 had better cardiovascular profiles than individuals with obesity in 1960-62 (2). In the later years, there was a linear decline in triglycerides and increase in HDL-C levels among individuals with obesity between 1988-1994 and 2007-2010 (19). The temporal trends with obesity and other health risk factors post 1999-2000 were not been fully explored but provide preliminary evidence that the better health profiles among individuals with obesity over time do not appear to track with rising obesity.

One of the possibilities for this result is that temporal trends in health risks may not be captured adequately by simple measures like BMI. It is because BMI does not account for the distribution of body composition and it may influence the risk of developing certain chronic conditions. Further, other factors including abdominal fat, PA, medications, smoking and diet are also independent predictors of health risk. Some studies have shown that there have also been temporal changes in these factors (20–23). Thus, these factors may change how obesity relates to health risks over time.

2.2 Abdominal Obesity and Chronic Conditions

Although BMI is the most widely used indicator of obesity, it does not take into account differences in body composition particularly related to body fat (BF) distribution. Fat that accumulates around the abdominal cavity commonly known as abdominal obesity is strongly associated with increased risk of hypertension, type 2 diabetes, dyslipidemia and metabolic syndrome (8,24).

Clinically, having a high waist circumference (WC) where a value of 102 cm or higher in men and a value 88 cm or higher in women is considered abdominal obesity. Even independent of obesity, abdominal obesity is associated with the above mentioned cardio-metabolic health risks and mortality risk (6). Between 2003-2014, the prevalence of abdominal obesity increased by 5% in men and 4% in women (Men: 59% to 64%; Women: 40% to 44%), while general obesity increased by only 2% in men and 5% in women over a similar time frame (Men: 33% to 35%; Women: 35% to 40%) (5,25). Further, there is evidence that there has been a disproportionate increase in WC for a given BMI over time (26). Between 1988–1994 and 2005–2006, individuals had a 0.9 cm higher WC in the U.S. for a given BMI (27). Thus, failing to account for differences in WC may in part explain the temporal differences in how BMI relates in health risks over time.

2.3 Body Composition Measurement

Body composition can also include estimates of percent body fat (%BF) or fat mass (FM), fat free mass (FFM), lean body mass, bone mineral content, and total body water (TBW) (28). There are different methods to measure body composition. Anthropometrics could include measures of height, body mass and circumferences while %BF, FFM and predicted muscle mass is often predicted using methods such as sum of skinfolds, BIA, and dual-energy X-ray absorptiometry (DXA).

Anthropometrics

BMI is calculated as a ratio of height and mass (kg/m^2) and is classified as underweight, normal, overweight or obesity. Underweight is defined as a BMI of 18.4 kg/m^2 or lower, normal is defined as a BMI of 18.5-24.9 kg/m^2, overweight is defined as a BMI of 25.0-29.9 kg/m^2 and obesity is defined as a BMI of 30.0 kg/m^2 or more (29). BMI is a cost-effective tool that requires minimal equipment and minimal technician experience. However, it does not take into account regional fat distribution, or muscle mass and therefore may misclassify individuals.

Sum of Skinfolds

Skinfold method is used to estimate FM and FFM and is based on the assumption that the total amount of body fat is directly proportional to the subcutaneous fat (30). A caliper measures the thickness of a fold of skin and subcutaneous fat. Based on the number and location of sites used to measure skinfolds, different prediction equations are then used to estimate %BF (30). The accuracy and reliability for the sum of skinfolds method depends on the technician skill, the skinfold sites used, the size of the individual being measured and also the prediction formula used (31,32). Although skinfolds are inexpensive and quick, it requires trained technicians and is subject to inter-observer error. In addition, due to the thickness of the fold, skinfolds may not be appropriate for assessing BF in individuals with obesity.

Dual-energy X-ray Absorptiometry

Dual-energy X-ray Absorptiometry (DXA) estimates three compartments of the body: bone mineral content, mineral-free lean mass and FM. These compartments are estimated based on the tissue attenuation of two different x-ray energies (33). The x-ray beams pass from the posterior to anterior of the body to a detector that is located above the participant (34). DXA has been considered a gold standard method for assessing body composition because of its validity and reliability in previous research (8). It is a quick, safe, can be used on almost all populations, and requires little pre-testing preparations for the individual (28,33). Although participants are exposed to very small amounts of radiation and are safely available for repeated use, DXA should not be used in pregnant women. Some other limitations are that the DEXA is costly, large, non-portable and the DEXA may require a trained certified technician to operate.

2.4 Bioelectrical Impedance Devices

Bioelectrical impedance (BIA) is a safe, fast, non-invasive and relatively inexpensive method for assessing body composition (35,36). First introduced in the 1980s as a method of estimating body composition, the use of BIA devices has become widespread by both researchers and general public (37). BIA devices use proprietary or published equations that use the relationship between total or segmental impedance and total body water (38). Over the years, the commonly used BIA published equations were developed using generally normal weight, healthy populations (38). BIA is based on the principle that when an alternating low-amplitude and high frequency potential is applied to the body, the resulting current passes predominantly through the path of least resistance which is the water-containing tissues/assumed to be primarily muscle or

FFM (39). FFM typically contains approximately 73% water and electrolytes which makes a good conductor of electrical current. Thus, impedance to the flow of electrical current passing through FFM can be used to estimate body composition, wherein higher impedance is correlated with higher FM (37,38).

BIA can be measured by both single-frequency and multi-frequency BIA devices. Most single-frequency devices use a frequency of 50 kHz that usually passes from two different points, commonly hand-to-hand, foot-to-foot or hand-to-foot via surface electrodes. Common single frequency devices are inexpensive and portable, also referred to as segmental impedance analyzers. Conversely, multi-frequency BIA devices estimate body composition using multiple frequencies as the different frequencies may better travel through the various tissues. However, previous research has shown that single frequency and multi-frequency impedance measures show similar estimates of body composition (28).

BIA Assumptions

The BIA equations assume proper hydration and fluid distribution and violating these assumptions may alter how BIA estimates FFM and TBW. An individual's hydration level and fluid distribution can vary throughout the day altering the resistive properties of the various body tissues (35,38,40). It is important to investigate how violating the hydration related assumptions may change the estimation of body composition. Factors that can influence the hydration status and fluid distribution are commonly linked to consumption of food and beverages, non-voided bladder, sweating, dehydration and exercise (9,41). Exercise can affect BIA readings in three ways: 1) loss of fluid from the body due to sweating, 2) shift in fluid balance between tissues 3) increased blood flow to the skeletal muscle and skin which increases heat and would decrease the impedance of the current (9,42). Because of the widespread use of BIA technology and these factors, the National Institute of Health recommends the following guidelines prior to taking BIA measurement:

- No eating or drinking for the 4 hours immediately before the test
- No exercise for the 12 hours immediately before the test
- Void bladder within 30 minutes prior to the test

BIA Assumptions and Obesity

The BIA prediction equations used for the BIA measurements are derived from mainly normal healthy weight population. Several studies have reported that BIA overestimates FFM and underestimates FM in individuals with obesity (37,40,43,44). The reasoning behind the variation in BIA estimation among individuals with obesity is not well understood. Baumgartner et al propose three hypotheses (40): 1) hydration level and fluid distribution between non-adipose and adipose tissues are altered in individuals with obesity and the criterion methods used for calibrating prediction equations do not account for these changes; 2) differences in body geometry may alter impedance patterns; and 3) high volumes of adipose tissue may contribute to a higher conductance in the body. Since current passes through the least resistance, the high volumes of adipose tissue may become a 'parallel tissue-resistor' resulting in an overestimation of muscle or FFM when BIA published equations are applied (45). Thus, the FM in individuals with obesity might be underestimated even further after violating any of the BIA guidelines.

2.5 Obesity and Physical Activity

Individuals with obesity are generally recommended weight loss to reduce the severity of health risk factors and other chronic conditions (46). Weight loss could lead to improvements in many cardio-metabolic risk factors including metabolic syndrome, insulin resistance, type 2 diabetes, dyslipidemia, and hypertension (46). Previous research has shown that weight loss of even 5% is clinically relevant and is associated with reductions in health risk factors (47). It is generally a product of negative energy balance where PA can be performed for energy expenditure.

PA is defined as any bodily movement produced by skeletal muscles that requires energy expenditure and increases heart rate and breathing (48). It is well established that PA is associated with many positive health outcomes including reducing obesity-related health risks, and better weight maintenance following weight loss (49,50). Adults who are physically active have a lower risk of CVD, type 2 diabetes, hypertension and dyslipidemia than adults who are not physically active (51–53). Further, PA can attenuate weight gain in those at risk for obesity but is generally associated with only modest weight loss (~2 kg) (54).

According to public health recommendations, different amounts of PA are recommended for health benefits and weight management (54): the moderate-to-vigorous physical activity intensity (MVPA) of at least 150 minutes/week is recommended to maintain and improving health; at least 150 - 250 minutes/week of MVPA for prevention of weight gain; at least 200-300 minutes/week for prevention of weight gain after weight loss; and at least 225—420 minutes/week to promote clinically significant weight loss (54). However, these PA guidelines are largely based on studies using self-report PA data and some on doubly labelled water measures in studies conducted by the institute of medicine (55,56). There is an emphasis and growing interest for assessing objective PA in interventions and public health initiatives (57).

2.6 Assessment of Physical Activity

Methods for the assessment of PA are generally divided into two broad categories: subjective and objective measures. Subjective or self-report is the most feasible and cost-effective method to measure PA (58,59) and is a valuable method for providing estimations of the type, duration, and intensity of PA in population-based studies (57). Factors including personal perceptions of activity intensity, recall bias or social desirability, could contribute to the over- or under-estimation of PA volume. For these reasons, self-report is commonly not considered as accurate as objectively measured PA (60,61).

The objective measures of PA include direct observation, doubly labeled water and activity monitors (i.e. wearable devices and smartphone applications using pedometers, accelerometers, fit bits, energy expenditure, pulse rate etc.) (59,62,63). Rapid technological advances in the last couple of decades have led to an increased use of activity monitors (59,63). The use of pedometers and accelerometers has become increasingly popular in assessing PA volume in both general public and research studies. Pedometers are devices that count each step by detecting changes in the hip tip. Their accuracy is highly dependent on the placement on the person's hip and keeping the pedometer vertical is vital (64). Tilting the pedometer or wearing it at an angle will affect pedometer accuracy drastically and the likelihood of tilt is larger in people with high waist circumference or obesity (64). Accelerometers on the other hand measure the frequency, duration and intensity of PA (65,66).

2.7 Accelerometers

Accelerometers are small devices that are generally worn on the hip in order to capture free-living PA (67). These devices are able to distinguish between various types of ambulatory activities, such as walking and running (67). Accelerometers are electro-mechanical devices that detect and record motion in a single or in multiple planes. They detect accelerations by containing sensors that measure linear or angular motions along a single or multiple axis of movement (68).

The sensors then generate an electric charge to mechanical movements like walking, and output a voltage proportional to the acceleration (65,66). The frequency of accelerations is summarized over a user-defined time, called an epoch, to provide activity counts per epoch commonly expressed as counts per minute (CPM) (68). The higher the count, the higher is the intensity of PA. Accelerometers can assess the intensity, frequency, and duration of PA, and can thus be used to describe both the sum of PA duration and the pattern (distribution at various intensities over a defined period, such as a day or a week) of PA.

Accelerometers by ActiGraph (Pensacola, FL) activity monitors are widely used in PA research. One of the original accelerometers, the uniaxial GT1M model measured activity counts only in the vertical plane (69,70). In 2008, ActiGraph enabled dual axes measurement in the vertical and antero-posterior axes, and PA was assessed using a composite vector magnitude of these two axes. In 2009, ActiGraph released the triaxial GT3X activity monitor. The GT3X measures acceleration in three individual orthogonal planes (vertical plane, antero-posterior plane and medio-lateral plane). It provides CPM values as a composite vector magnitude of these three planes (VM3) (71). Thus, GT3X accelerometers may allow for more accurate field-based PA estimates as it is capable of detecting movements in any plane.

2.8 Influence of Cardiorespiratory Fitness and Body Mass on Accelerometers

According to Freedson et al. (2011), accelerometer output is typically processed by calibrating the device in a laboratory by simultaneously recording accelerometer output (e.g., CPM) and physiological variable (e.g., oxygen consumption) (71). Oxygen consumption is often expressed in metabolic equivalent of tasks (MET), wherein 1 MET corresponds to an oxygen consumption of 3.5 milliliters of oxygen per kilogram of body mass per minute ($mL \cdot kg^{-1} \cdot min^{-1}$). (72). The relationship between CPM and METs are often used to create cut-points that denote differences in activity intensity. The VM3 accelerometer cut-points by Freedson are among the most commonly used: moderate intensity PA (MET: 3.00) = 2690 CPM, for vigorous intensity PA (MET: 6.00) = 6167 CPM, and for very vigorous PA (MET: 9.00) = >9642 CPM (71).

However, the use of a single CPM threshold does not account for the individual differences in how the CPM values relate with PA intensity. In particular, classification of PA using MET values does not account for age, sex, type of activity, individual perceived effort or relative intensity of the given activity (57). Samples from the accelerometer validation studies often consist of young male participants and it may or may not be reflective of the more general population as CRF levels can influence the relative perceived effort required for a given absolute PA intensity (73).

An individual with a higher level of fitness will be performing the given activity at a lower relative intensity compared to the individual who is less fit. For example, walking at a pace of 4.8 km/h corresponds to 3 MET (2690 CPM) may be perceived as moderate effort for one individual, and vigorous effort (higher relative %VO_2 peak workload) for another, depending on their CRF. Further, age is associated with declines in CRF and older populations are more likely to have a higher perceived effort at any given absolute intensity thresholds (74). The MET values of 6-9 are typically related to vigorous intensity PA, however, it is estimated that in older individuals who are between 65–79 years of age, vigorous intensity PA, corresponds to only 4.8 to 6.7 METs (74). Similar to age, CRF levels also differ between sexes where men have higher levels of CRF than women (75). Thus, low CRF values could lead to underestimating the relative PA intensity associated with any given CPM value (12).

Previous research has reported that individuals with obesity have lower CPM values when compared to individuals with normal weight (76). However, similar to CRF, body mass could also lead to changes in how PA is assessed using accelerometers (77). The force needed to generate an acceleration is positively related to the mass of the object (Force = mass x acceleration). Thus, individuals with high body mass would need to do more work than individuals with low body mass to achieve the same acceleration frequency.

This would mean that individuals with obesity who generally have low CRF and high body mass may work at a even higher relative intensity (%VO_2 peak) at any given CPM, therefore underestimating the volume of PA even further.

2.9 Self-report Physical Activity & Obesity

Research has typically shown that individuals with obesity tend to report more PA than is completed when PA is assessed using subjective measures (67,78). Given the large differences reported between self-report and accelerometer PA duration, individuals with obesity are often the victim of weight stigma and social desirability and are assumed to be over-reporting their PA levels (79). However, the large differences between PA volumes could be due to the fact that accelerometers do not account for the individual perceived effort or relative intensity of PA given the differences in body mass and CRF explained earlier. Rather, individuals with obesity may perform a high amount of PA but the total volume may not be captured accurately, given the assumptions that underlie objective measures of PA. As previously described, accelerometers do not account for CRF and body mass differences leading to underestimation of PA volume in individuals with obesity. Therefore, it is important to investigate if the standard CPM thresholds bias against individuals with obesity, and if the factors including CRF and body mass could explain some of the differences observed between subjective and objective PA measures.

2.10 Summary & Objective

In summary, both general and abdominal obesity have increased over time and they are both associated with greater prevalence of chronic conditions (5). However, it is yet unknown how the temporal changes in abdominal obesity relate with the temporal trends in chronic conditions. Secondly, BIA is one of the common body composition assessment methods and there are several guidelines related to ensuring proper fluid distribution and hydration levels in the body (80). However, the validity of these guidelines and their impact on BIA assessed body composition have not been thoroughly investigated, particularly in populations with obesity. Lastly, individuals with obesity are often recommended PA as the first line treatment strategy (54). PA is typically monitored using subjective measures including self-report and objective measures including accelerometers. The PA volume reported by self-report are generally higher than the accelerometers (79), and the differences could be related to differences in how accelerometers capture PA in individuals with obesity, because accelerometers do not account for individual differences in factors such as body mass or CRF (12). Therefore, the three objectives of the dissertation were:

Objective 1: To examine the temporal trends of obesity-associated health risks after accounting for temporal differences in factors including abdominal obesity, PA, total caloric intake, smoking and medications taken between 1999-2014.

Objective 2: To examine the effects of water intake, dehydration, food intake, exercise, and bladder voiding on acute BIA measurements and if the effects are influenced by BMI categories.

Objective 3: To determine CPM values during light (30-35% VO_2peak) and moderate to vigorous (MVPA) PA intensity (≥50% VO_2peak) physical activity. Further, to estimate and compare durations of objectively measured PA to the self-report measured PA across BMI using standard CPM thresholds and individualized CPM intensity thresholds that account for differences in CRF.

3.0 Manuscript 1: Changes in the Prevalence of Chronic Conditions Associated with Abdominal Obesity between 1999-2014

Abstract

Objective: To examine the temporal trends of obesity-associated chronic conditions after accounting for temporal differences in body mass index (BMI), & waist circumference (WC). **Method:** Pooled cycles (1999-2014) of the U.S. National Health and Nutrition Examination Survey (NHANES) were analyzed (n=36,959). The models were adjusted for total caloric intake, smoking, age, numbers of medications taken and being physically active. **Results:** The prevalence of diabetes increased only in women with general or abdominal obesity (BMI*time; WC*time, $p<0.05$) and there were no changes in men. Independent of BMI, the prevalence of hypertension remained similar over time in both sexes (time, $p > 0.05$), whereas for a given WC, there was a decrease in the prevalence of hypertension over time in women (WC*time, $p = 0.05$). Similarly, the prevalence of dyslipidemia decreased in men independent of BMI, while for a given WC, there was a decrease in the prevalence of dyslipidemia in both sexes (time, $p <0.05$). Over the same time frame, blood pressure, LDL and triglycerides decreased, while plasma glucose and HDL increased in both sexes independent of general and abdominal obesity ($p< 0.001$). **Conclusion:** Whereas obesity is associated with several chronic conditions, there may be other temporal changes that have altered how obesity is related with such markers of metabolic health. Further investigation is needed to better understand the causes of the temporal changes in these chronic conditions.

Key words: Obesity, Abdominal obesity, Chronic Conditions, Health Risk Factors, NHANES

Introduction

Obesity is notably associated with numerous health risk factors and increased mortality risk from chronic conditions including type 2 diabetes, cardiovascular disease and stroke (1,3,4). However, the relationship of these chronic conditions with BMI may have varied over time (2,19). For example, there was a 10.1% temporal increase in prevalence of diagnosed diabetes among adults with obesity from 1960-62 to 1999-2000 using the BMI metric (2). Conversely, between 1960 and 2000, the prevalence of hypertension and high cholesterol in adults with obesity has decreased (-14% and -12% respectively) (2). In a similar vein, there is evidence that the mortality risk associated with obesity may have also decreased over the years (17).

While not yet fully understood, the differences in the health risks associated with obesity over time may in part be associated with the limitations of simple measures of obesity such as BMI. This is supported by the finding that WC, a more sensitive correlate of health risk (81,82), has been increasing for a given BMI over time (26). Lifestyle factors such as total caloric intake, physical activity (PA), smoking and medication use have also varied over time (20,21,83,84). Thus, failing to account for differences in WC and these lifestyle factors over time, may in part explain the temporal differences in how BMI contributes to health risks over time.

The purpose of the current study is to therefore examine the temporal trends of obesity-associated health risks after accounting for temporal differences in factors including BMI, WC, total caloric intake, smoking, age, number of medications taken, ethnicity, education and PA between 1999-2014.

Methods

Overall Design and Study Population

The data was obtained from the National Health and Nutrition Examination Survey (NHANES). NHANES is a series of nationally representative cross-sectional surveys of civilians living in the contiguous U.S. As a stratified, complex, multistage, probability-based survey, NHANES oversamples older adults, low-income individuals and certain racial/ethnic groups. The complete details of the study design and procedures are reported elsewhere (10). Data for this study was obtained from pooling NHANES continuous surveys from 1999 to 2014.

Sample Size

Across all survey years, a total of 82,091 participants were interviewed. Analyses were based on the data collected from participants aged 18 years and older (n= 47,356). Participants were excluded additionally if data was missing on measured BMI (n=4,113), total caloric intake (n = 2,521), total grams of fat consumed (n=22), WC (n=992), education (n=35), number of prescription medications taken (n=28), and smoking status (n=2,687). The final sample size for complete case analysis was 36,959 persons aged 18 years and older (1999-2000, n = 4,040; 2001-2002, n = 4,362; 2003-2004, n= 4,185; 2005-2006, n = 4,261; 2007-2008, n= 5,099; 2009-2010, n= 5,429; 2011-2012, n= 4,519; 2013-2014, n=5,064).

Measures

Informed consent was obtained from all participants, and ethics approval was obtained from the NHANES Institutional Review Board for the NCHS Research Ethics Review Board for the NHANES continuous surveys.

Interview and examination measures

Questionnaires were used to assess age, sex, ethnicity (white or other), and education (≤ high school or > high school). Body mass, height and WC were measured by trained health technicians in a mobile examination center using standardized techniques and customized equipment. Body mass was measured on a digital weight scale (Mettler Toledo, Ohio, US). Standing height was measured in inches with a fixed stadiometer with a moveable headboard. WC was measured using a steel measuring tape to the nearest 0.1 cm at the high point of the iliac crest at minimal breathing.

Cholesterol data including total cholesterol (TC), triglycerides, HDL-C and LDL-C was conducted on venous blood serum samples and was standardized for cholesterol measurements according to the criteria of the CDC–National Heart, Lung, and Blood Institute Lipid Standardization Program. The samples were frozen at −30°C and shipped weekly on dry ice to the laboratory conducting the lipid analyses. TC and triglycerides were measured using enzymatic reactions. HDL-C and LDL-C were measured by the direct immunoassay method during 2007-2010, whereas in 1999-2002, the heparin manganese precipitation method was primarily used (19). Blood pressure was measured according to standard protocols of the CDC (86). Measurements were conducted in the mobile examination center on participants in a seated position. Diabetes was assessed by measures of fasting plasma glucose, hemoglobin A1C, two-hour glucose test and the serum insulin using human insulin immunoassay method in the morning examinations session only (87). The laboratory methods for all blood samples were consistent in the continuous surveys, and the details regarding specimen collection and processing instructions are described elsewhere (88).

Diet information was retrieved from 24-h dietary recall questionnaire with additional questions about how food was prepared. In NHANES 1999 - 2002, a multiple-pass computerassisted dietary interview format was used to collect detailed self-reported information about all foods and beverages that were consumed the day prior to the in-person interview (weekday or weekend). In NHANES 2003 onwards, 24-h self-reported dietary recalls were performed twice (3-10 days apart) using an automated multiple pass method. To keep the dietary data consistent with the NHANES 1999-2002, only day 1 data was used for dietary recalls in the following years. For all surveys, the data was used to estimate the total number of calories (kcal/day), fat (g), protein (g) and carbohydrates (g) from the foods and beverages consumed.

Smoking information was retrieved from the participants by asking, "Do you now smoke cigarettes?" and "Have you smoked at least 100 cigarettes in your entire life?" Both questions were asked to everyone including the non-smokers. Current smoking was defined as a positive answer to both questions.

PA information retrieved was self-reported where participants were asked questions based on exercise, sports, and physically active hobbies that were performed during leisure time on a typical day. PA categories (active or non-active) were formed where only activities that were at least moderate intensity were included in our definition of being active. Information was retrieved by asking, "Did you do any moderate activities for at least 10 minutes that cause only light sweating or a slight to moderate increase in breathing or heart rate?" or "Did you do any moderate-intensity sports, fitness, or recreational activities that cause a small increase in breathing or heart rate such as brisk walking, bicycling, swimming, or golf for at least 10 minutes continuously?" or "Did you do any vigorous-intensity sports, fitness, or recreational activities that cause large increases in breathing or heart rate like running or basketball for at least 10 minutes continuously?" or "Did you do any vigorous activities for at least 10 minutes that caused heavy sweating, or large increases in breathing or heart rate?" Active was defined as a positive answer to any of the four questions meaning active for at least 10 minutes of moderate or vigorous PA intensity on a typical day.

In all the NHANES surveys, information about prescription medication use was assessed during a household interview. Participants were asked if they had taken prescription medication over the past 30 days. Those who responded "yes" were asked to show the containers of the medication, and if unavailable, participants were asked to report up to 23 medication names. Medications were linked to a prescription medication database (Lexicon Plus) that includes all prescription medications classes. Medication classes for commonly used prescribed medications including antihypertensives, lipid-lowering medications, and antidiabetics were created using the prescription medication database. Antihypertensive drugs were coded to include agents for hypertensive emergencies, angiotensin converting enzyme, antiadrenergic agents, peripherally acting, centrally acting, beta-adrenergic blocking agents, calcium channel blocking agents, diuretics, peripheral vasodilators, antihypertensive combinations, angiotensin II inhibitors, vasopressin antagonists, aldosterone receptor antagonists, renin inhibitors, cholinergic agonists. Lipid-medication drugs were coded to include antihyperlipidemic agents, HMG-CoA reductase inhibitors, miscellaneous antihyperlipidemic agents, fibric acid derivatives, bile acid sequestrants, cholesterol absorption inhibitors, antihyperlipidemic combinations, and miscellaneous metabolic agents. Antidiabetic drugs were coded to include antidiabetic agents, and miscellaneous metabolic agents.

Definitions of Primary Outcomes

Hypertension was defined as: systolic blood pressure (SBP) of at least 140 mm Hg and/or diastolic blood pressure (DBP) of at least 90 mm Hg using the cuff-size–corrected measurements, previously diagnosed hypertension (by self-report) or the reported use of antihypertensive drugs in the past 30 days. Dyslipidemia was defined as: TC ($\geq$ 6.20 mmol/L), low HDL-C as sex-specific (men: <1.04 mmol/L; women: <1.29 mmol/L), high LDL-C ($\geq$ 4.14 mmol/L), high triglycerides ($\geq$1.7 mmol/L), previously diagnosed high cholesterol (by self-report) or the reported use of anti-lipid drugs used in the last 30 days. Type 2 diabetes was defined as: a plasma glucose level of at least 7 mmol/L (126 mg/dl or higher), hemoglobin A1C of at least 6.5%, previously diagnosed diabetes (by self-report) or reported use of antidiabetic drugs in the past 30 days.

Abdominal obesity was defined as high WC (men, $\geq$102 cm; Women, $\geq$ 88 cm). BMI categories were defined as normal weight (BMI, 18.5 to 24.9 kg/m^2), overweight (BMI, 25 to 29.9 kg/m^2) and obesity (BMI, $\geq$30 kg/m^2).

Statistical Analysis

Sample characteristics were shown as mean ± SE and prevalence ± SE stratified by sex and survey year. The differences between sample characteristics across survey years were assessed using one-way analysis of variance (ANOVA) with Tukey's post hoc tests for continuous variables and chi-square tests for categorical variables within each sex. Due to high collinearity between BMI and WC, two separate models were run with BMI categories (normal weight, overweight, and obesity) or abdominal obesity to determine the temporal trends of the health risks and prevalence of chronic conditions.

Multivariable linear regression analysis was used to determine the relationship between triglycerides (mmol/L), HDL (mmol/L), LDL (mmol/L), plasma glucose (mmol/L), SBP (mmHg), DBP (mmHg) and time. Analyses were conducted in men and women separately while adjusting for WC (or BMI), total caloric intake, PA, smoking, age, average number of medications taken in the last 30 days, ethnicity, and education. Similarly, multivariable linear regression analyses were also used to estimate the prevalence of each chronic condition (i.e. dyslipidemia, hypertension, & type 2 diabetes) in two separate models (BMI categories; WC categories) while adjusting for total caloric intake, number of medications taken in the last 30 days, PA, smoking, age, ethnicity, and education. For dyslipidemia, the model was adjusted for total grams of fat intake instead of total caloric intake.

All analyses applied clinic survey weights and were conducted using survey procedures (SAS version 9.4; SAS Institute, Cary, NC) to ensure the national representativeness of the data. Statistical hypotheses were tested using a two-sided $\alpha = 0.05$ level.

Results

Participant characteristics for each survey year are shown in **Table 1.1** for men and women separately. From 1999 to 2014, the proportion of individuals with abdominal obesity increased in both sexes (men; 37.4 ± 1.9% to 45.6 ± 1.1 %, women; 59.0 ± 2.3 to 67.5 ± 1.3%) **(Table 1.1**). More specifically, both BMI and WC increased from 1999 to 2005 in men and then it remained stable in the later years while both measures increased from 1999 to 2014 in women ($p < 0.05$). At the same time, the prevalence of dyslipidemia remained stable in men (57.9 ± 1.4 to 56.6 ± 1.4%) while there was a reduction (61.7 ± 1.7 to 54.7 ± 1.5%) in women **(Table 1.1**). The most dramatic changes were observed for the prevalence of type 2 diabetes which increased by 32.8% in men and 30.3% in women between 1999 to 2014 while the rates of hypertension increased by 12.9 % in men and remained stable in women **(Table 1.1**).

In our main analysis, the prevalence of chronic conditions (hypertension, dyslipidemia, & type 2 diabetes) and temporal trends in health risk factors (triglycerides (mmol/L), plasma glucose (mmol/L), SBP (mmHg), DBP (mmHg), HDL (mmol/L) and LDL (mmol/L)) with BMI and WC were explored **(Figure 1.1 to 1.3).** Overall, both BMI and WC were independently and positively associated with increases in prevalence of chronic conditions and health risks in both sexes ($p < 0.001$), even after adjustment for total caloric intake, PA, average number of medications taken in the last 30 days, total grams of fat consumed (only for dyslipidemia), smoking, age, ethnicity, and education.

Independent of BMI, the prevalence of hypertension remained similar from 1999 to 2014 in both sexes (time, $p > 0.05$, **Figure 1.1**). Similarly, for a given WC, the prevalence of hypertension remained similar over time in men (time, $p = 0.95$, **Figure 1.2**). However, there was a small decrease in the prevalence of hypertension that was only observed among women with abdominal obesity (53.5 to 50.3%) from 1999 to 2014 (abdominal obesity*time, $p = 0.05$). Over the same time frame, SBP (mmHg) and DBP (mmHg) decreased in both sexes (**Figure 1.3**, time, $p < 0.001$).

For a given BMI, the prevalence of dyslipidemia decreased only in men, whereas for a given WC, the prevalence of dyslipidemia decreased in both sexes (time, $p < 0.05$) **(Figure 1.1 & 1.2)**. Similar to the prevalence of dyslipidemia, the lipid risk factors have also improved over time ($p < 0.001$). For a given BMI or WC, triglycerides, and LDL decreased, while HDL increased over time in both sexes (**Figure 1.3**, time, $p < 0.001$).

For a given BMI or WC, the prevalence of type 2 diabetes increased in women (time, $p < 0.05$) while no change was observed in men (time, $p > 0.05$) **(Figure 1.1 & 1.2)**. For example, in the BMI model, the increase in the prevalence of diabetes was only observed among women with obesity (17.7% to 22.4) while there were minimal differences in the prevalence among normal weight and overweight from 1999 to 2014 (BMI*time, $p < 0.001$, **Figure 1.1)**. Similarly, in the WC model, the increase in prevalence was only observed among women with abdominal obesity (16.7 to 19%) while there was no change among women without abdominal obesity (3.1

to 3.5%) from 1999 to 2014 (abdominal obesity*time, $p < 0.001$, **Figure 1.1)**. In both sexes, there was also a temporal increase in plasma glucose **(Figure 1.3)**.

Discussion

Much of the rise in chronic conditions is often attributed to the rise in obesity. Obesity is often described using measures such as BMI. However, independent of BMI, we document a substantial decrease in the prevalence of dyslipidemia in men and increase in the prevalence of type 2 diabetes in women over the last 15 years. The decreased prevalence of dyslipidemia and increased prevalence of diabetes was also seen when we accounted for temporal differences in abdominal obesity. Thus, these findings suggest that there may be temporal changes (or co-occurring) that have altered how obesity relates to chronic conditions.

There was a temporal decrease in the prevalence of dyslipidemia in both sexes while the prevalence of hypertension decreased only among women with abdominal obesity. Others have previously documented that there has been a disproportionate increase in WC for a given BMI (27,89,90). Given that WC is often cited to be a stronger correlate of health risk, it would follow that there should also be a rise in dyslipidemia and hypertension that mirrors the increased prevalence of abdominal obesity over time. In the same vein, there were temporal decreases in measured health risk factors (e.g. triglycerides, LDL, SBP, and DBP) **(Figure 2)**, results that extend previous work showing temporal reductions in dyslipidemia and hypertension (2,19,91). Our results indicate that changes in the prevalence of general or abdominal obesity, total caloric intake, total grams of fat intake, number of medications taken, and PA had little effect on the overall trends in hypertension and dyslipidemia. The net result of these phenomena may be a population that is with high BMI but lower risks for these metabolic health markers. These results reinforce the notion that there is a wide range in health profiles that present between individuals with the same BMI or even WC.

The decrease in the prevalence of dyslipidemia could be associated to the introduction of more efficacious prescription medications and an increased use of lipid-lowering medications (21,92). Introduction of atorvastatin, a highly effective drug, in the early 2000s for dyslipidemia led to over 20% more prescriptions than any other statin medications by the year 2014 (92). Further, some improvements in lipids profile can be attributed to reductions in trans-fatty acids, increased consumption of nuts & seeds and fish & shellfish intake (23). Trans-fatty acids can raise LDL cholesterol and lowers HDL cholesterol while daily intake of 3-4 grams of omega -3 fatty acids derived from fish & nuts can reduce triglycerides by 20 -50% (93). Thus, the changes related to medications and certain dietary habits could potentially contribute to the observed improvements in triglycerides, LDL, and HDL measures.

The decrease in the prevalence of hypertension among women with abdominal obesity may in part be due to more effective control, reduction in the use of hormone replacement therapy and increased usage of certain medications. First, we observed that the temporal decrease in SBP was greatest among adults with hypertension, which may indicate better hypertension control over time. Second, the use of hormone replacement therapy among women declined to 5.06% in 2010 from 24.62% in 2000 (18). Given that the use of hormone replacement therapy was associated with the increased risk of coronary heart disease, and stroke in post-menopausal women, the decline in the use of hormone replacement therapy may reflect the decreased prevalence of hypertension among women (94). Lastly, in our prior study, we showed that there has been temporal increases in anti-hypertensive therapy among women with obesity (21). Certain anti-hypertensives such as angiotensin converting enzymes (ACE) inhibitors and angiotensin receptor blockers (ARBs) were associated with better blood pressure profiles for women with obesity than leaner women (95). Together, this suggests that medications may have played a role in reducing BP, but particularly among women with obesity. However, the use of ACE inhibitors are also associated with increased blood glucose levels in women (95). Thus, medications could also be one reason why there are different trends in blood pressure than type 2 diabetes, despite both being obesity-related comorbidities.

Contrary to the temporal trends in dyslipidemia and hypertension, the prevalence of type 2 diabetes had increased with a greater degree over time in women with obesity or abdominal obesity. This means that a woman with either obesity or abdominal obesity is more likely to have type 2 diabetes now than 15 years ago even after adjusting for total caloric intake, PA, age, smoking, ethnicity and number of medications taken. A higher prevalence of type 2 diabetes is reflected in the temporal increase in plasma glucose observed in this study and an increased likelihood of taking antidiabetics among women with obesity (21). Over the last 15 years, the proportion of undiagnosed diabetes cases decreased to 11% in 2005-2010 (96). This may suggest that there have been improvements in the screening, and diagnosis particularly among women with obesity. In addition to the use of ACE inhibitors being associated with increased blood glucose levels in women, there might be other factors that could contribute to the rise in type 2 diabetes. First, the increasing consumption of high-fructose corn syrup (HFCS) has been linked to ectopic fat accumulation leading to insulin resistance, and thus increased type 2 diabetes risk (97,98). Second, there is an emerging evidence between insulin resistance and gut microbiome (99). The gut microbiome may cause a greater energy extraction from the dietary substances and chronic low-grade inflammation, both leading to greater insulin resistance and type 2 diabetes (100). Finally, advancing maternal age has been associated with gestational diabetes mellitus and women with a history of gestational diabetes mellitus have a greater risk of developing type 2 diabetes (101,102). These factors may contribute to the increases in the prevalence of type 2 diabetes in women but nonetheless warrants further investigation.

Some strengths and limitations of the study are worth mentioning. One of the strengths of this study is that it used a large sample size and documented health risks over 15 years within a nationally representative sample of the U.S. To our best knowledge, it is the first study that has looked at the prevalence of chronic conditions with general and abdominal obesity using BMI and WC while accounting for major lifestyle factors. Further, the health risk data was obtained during laboratory examinations as well as through home interviews by trained technicians. Given that the definitions of the chronic conditions presented in the study are based on both measured and self-report values, the prevalence of the chronic conditions may be underestimated (103). It is important to highlight that the study is limited by the use of self-reported PA and dietary data and may result in over or under reporting of these measures. Unfortunately, as objectively measured physical activity is currently only available for NHANES 2003–2006, we cannot determine temporal changes in self-report bias in PA over time. Similarly, the 24 h food recall questionnaire may not accurately reflect an individual's typical diet.

In summary, our analysis showed that independent of obesity, the prevalence of diabetes has increased in women while the prevalence dyslipidemia has decreased in men over the last 15 years. Further, for a given level of abdominal obesity, the prevalence of hypertension has decreased in women. Our findings show that the decreased prevalence of dyslipidemia and hypertension do not reflect the increasing prevalence of obesity or abdominal obesity in women. It suggests that there may be other temporal changes that have altered how obesity is related with the chronic conditions. Further investigation is needed to better understand the causes of the temporal changes in the chronic conditions associated with obesity as determined by BMI and WC.

Table 1.1. Baseline Characteristics of US Adults by NHANES Surveys.

	NHANES (1999-2000)	NHANES (2001-2002)	NHANES (2003-2004)	NHANES (2005-2006)	NHANES (2007-2008)	NHANES (2009-2010)	NHANES (2011-2012)	NHANES (2013-2014)
Men **Sample (n)**	1904	2074	2025	2044	2517	2645	2273	2442
Age (years)	45.0 ± 0.5	45.1 ± 0.6	45.4 ± 0.5	45.5 ± 0.8	45.8 ± 0.5	46.3 ± 0.5	46.4 ± 0.9	45.4 ± 0.4
Ethnicity (%, white)	71.2 ± 2.7	73.5 ± 2.5	73.3 ± 3.2	73.3 ± 2.6	69.4 ± 3.6	68.6 ± 3.3	68.5 ± 3.9	66.9 ± 3.0
Education (%, > HS)	50.2 ± 2.7	56.2 ± 2.0	54.8 ± 1.6	56.9 ± 2.4	54.0 ± 3.1	58.1 ± 1.6*	61.4 ± 2.9*	60.8 ± 2.1*
BMI (kg/m^2)	27.9 ± 0.2	28.0 ± 0.1	28.2 ± 0.1	28.7 ± 0.2*	28.5 ± 0.1*	28.8 ± 0.2*	28.6 ± 0.2*	28.8 ± 0.1*
Physically active (%)	62.1 ± 1.9	68.5 ± 1.6*	66.7 ± 1.5*	68.9 ± 2.1*	57.0 ± 3.1*	56.9 ± 1.3*	58.2 ± 2.7*	56.7 ± 1.3*
Caloric Intake (Kcal/d)	2580± 31	2625 ± 38	2684 ± 31*	2683 ± 39	2566 ± 31	2556 ± 40	2586 ± 25	2493 ± 22*
Smoke (%)	27.1 ± 1.6	26.8 ± 1.3	29.0 ± 1.3	27.6 ± 1.6	25.9 ± 1.7	21.6± 1.0*	23.9 ± 1.6	19.7± 1.0*
Waist circumference (cm)	99.2 ± 0.5	99.7 ± 0.3	101.0 ± 0.4*	101.6 ± 0.8*	101.1 ± 0.5*	101.4 ± 0.6*	101.5 ± 0.6*	101.7 ± 0.4*
Abdominal Obesity (%)	37.4 ± 1.9	39.1 ± 1.1	43.3 ± 1.2*	45.1 ± 2.3*	43.7 ± 1.7*	44.1 ± 1.8*	44.6 ± 1.7*	45.6 ± 1.1*
Number of Medications Taken	1.1 ± 0.1	1.3 ± 0.1	1.6 ± 0.1*	1.5 ± 0.1	1.7 ± 0.1*	1.7 ± 0.1*	1.7 ± 0.1*	1.8 ± 0.08*
Chronic Conditions (%)								
Dyslipidemia	57.9 ± 1.4	57.5 ± 0.9	53.4 ± 1.9	56.7 ± 1.8	59.7 ± 1.2	58.0 ± 1.2	57.2 ± 1.5	56.6 ± 1.4
Type 2 Diabetes	9.0 ± 0.6	9.9 ± 0.7	11.0 ± 0.8	9.8 ± 0.8	12.6 ± 0.6*	13.4 ± 1.0*	12.6 ± 1.0*	13.4 ± 0.8*
Hypertension	36.3 ± 2.2	35.3 ± 1.9	40.4 ± 1.7	40.5 ± 1.6	40.5 ± 1.3	40.7 ± 1.8	41.0 ± 1.7	41.7 ± 1.1*
Women **Sam ple (n)**	2136	2288	2160	2217	2582	2784	2246	2622
Age (years)	46.9 ± 0.5	46.2 ± 0.5	46.8 ± 0.6	46.8 ± 0.8	47.4 ± 0.5	47.45 ± 0.5	47.8 ± 0.8	46.5 ± 0.4
Ethnicity (% white)	68.3 ± 3.3	72.5 ± 2.6	72.4 ± 3.6	71.2 ± 2.9	69.8 ± 3.7	68.0 ± 3.7	67.3 ± 3.9	66.3 ± 3.4
Education (%, > HS)	48.5 ± 2.2	56.3 ± 1.9*	56.5 ± 1.7*	59.0 ± 1.7*	56.2 ± 2.1*	59.1 ± 1.2*	66.6 ± 2.4*	63.9 ± 2.5*
BMI (kg/m^2)	28.6 ± 0.3	28.4 ± 0.2	28.6 ± 0.3	28.8 ± 0.3	28.8 ± 0.2	29.0 ± 0.3	29.2 ± 0.2	29.4 ± 0.3*
Physically active (%)	54.8 ± 2.2	63.2 ± 1.6*	65.6 ± 1.3*	67.4 ± 1.4*	48.9 ± 2.3	48.6 ± 1.4*	54.2 ± 2.5	53.5 ± 1.7*
Caloric intake (Kcal/d)	1835 ± 28	1844 ± 20	1860 ± 17	1812 ± 23	1813 ± 26	1801 ± 13	1864 ± 20	1858 ± 16
Smoke (%)	20.4 ± 1.3	21.5 ± 1.3	21.6 ± 1.3	20.1 ± 1.2	19.3 ± 1.3	18.0 ± 1.0	15.9 ± 1.3*	17.8 ± 1.5
Waist circumference (cm)	93.5 ± 0.8	93.5 ± 0.5	95.1 ± 0.5	94.8 ± 0.7	95.8 ± 0.5*	96.3 ± 0.3*	97.2 ± 0.6*	97.5 ± 0.6*
Abdominal Obesity	59.0 ± 2.3	59.2 ± 1.5	64.1 ± 1.8	61.5 ± 1.8	64.2 ± 1.6*	65.5 ± 1.3*	68.3 ± 2.1*	67.5 ± 1.3*

(%)								
Number of Medications Taken	1.8 ±0.1	1.9 ± 0.1	2.2 ± 0.1*	2.2 ± 0.1*	2.2 ± 0.1*	2.1 ± 0.1	2.1 ± 0.1	2.2 ± 0.1*
Chronic Conditions (%)								
Dyslipidemia	61.7 ± 1.7	54.5 ± 1.0*	53.8 ± 1.9*	52.9 ± 1.9*	58.1 ± 1.4	55.9 ± 1.1	58.5 ± 1.9	54.7 ± 1.5*
Type 2 Diabetes	8.5 ± 0.8	8.2 ± 0.7	10.0 ± 0.8	10.2 ± 0.9	11.7 ± 0.9*	10.9 ± 0.6*	11.7 ± 0.9*	12.2 ± 0.8*
Hypertension	38.3 ± 1.8	37.1 ±1.5	41.3 ± 1.6	38.0 ± 1.6	40.2 ± 1.3	37.1 ± 1.5	38.8 ± 1.2	40.3 ± 1.4

All the continuous values are presented as means ± SE and categorical values as prevalence (SE) %. HS = high school, BMI = body mass index, WC = waist circumference. The values are weighted to be nationally representative. * = significantly different from 1999-2000 ($p<0.05$). Physically active was defined as percentage of people being active for at least 10 minutes of moderate PA intensity on a typical day.

Figure 1.1

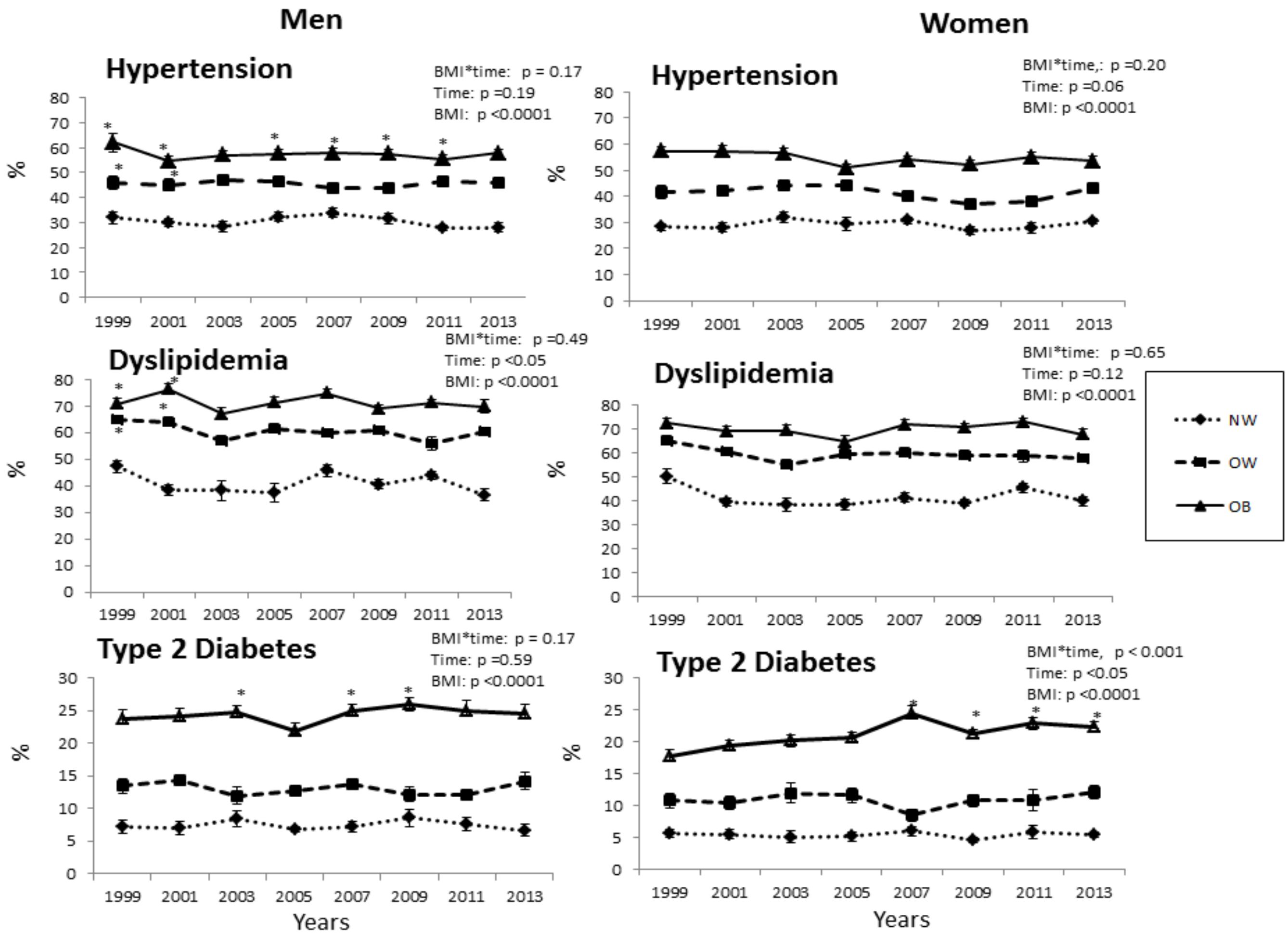

Figure 1.1. The prevalence (%) of type 2 diabetes, dyslipidemia and hypertension with BMI in both sexes. The model was adjusted for age, education, ethnicity, total calories consumed in a day, number of medications taken in the last 30 days, smoking, and being physically active. For dyslipidemia, total calories consumed in a day were replaced by total grams of fat intake in the model.

*: significantly different from normal weight in the year 1999, $p < 0.05$.

OB = Obesity, OW=Overweight, NW = Normal weight, BMI = Body Mass Index

Figure 1.2

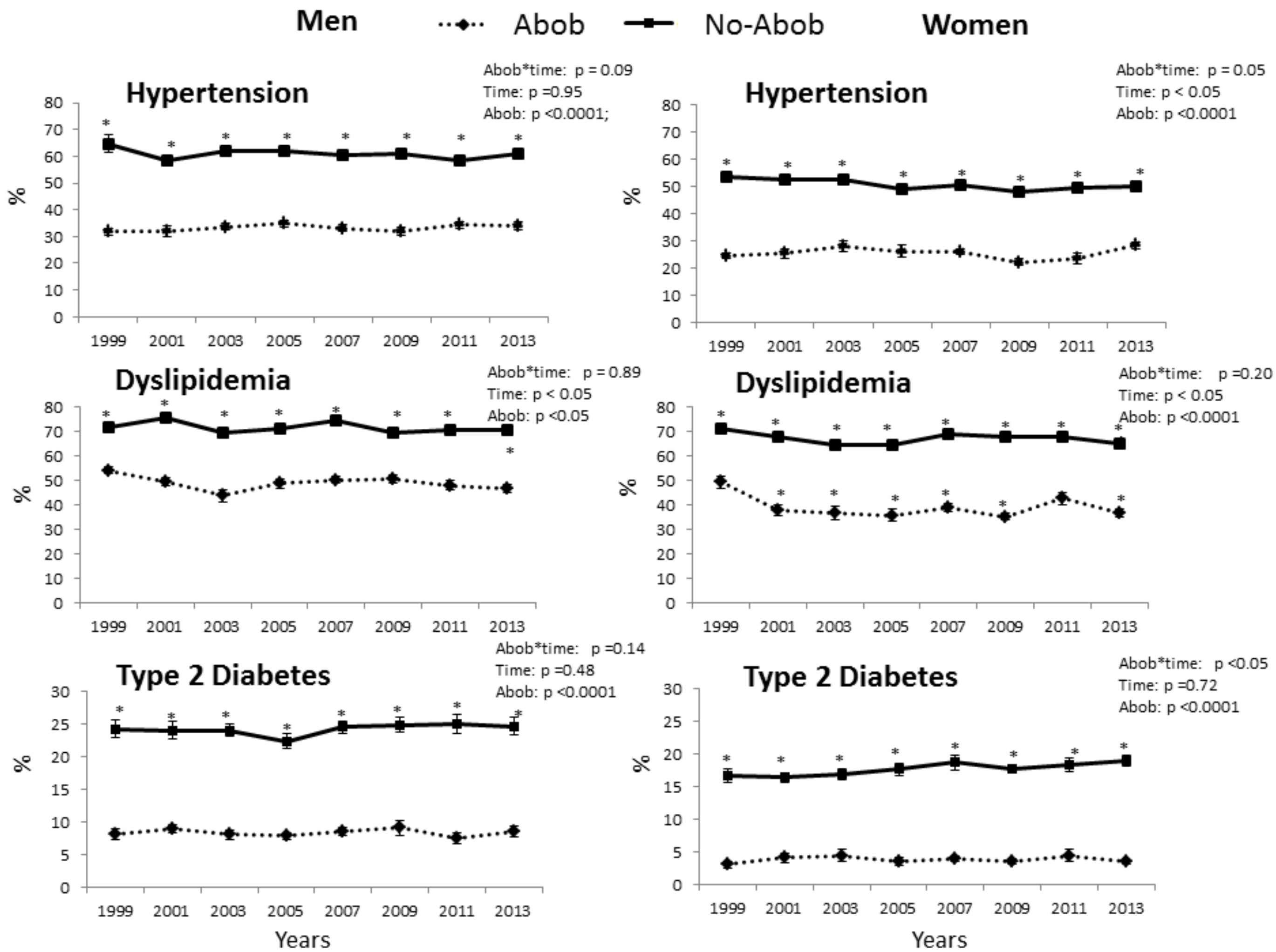

Figure 1.2. The prevalence (%) of type 2 diabetes, dyslipidemia and hypertension with abdominal obesity (abob) in both sexes. The model was adjusted for age, education, ethnicity, total calories consumed in a day, number of medications taken in the last 30 days, smoking, and being physically active. For dyslipidemia, total calories consumed in a day were replaced by total grams of fat intake in the model. *: significantly different from no-abob in the year 1999, $p < 0.05$.

Figure 1.3

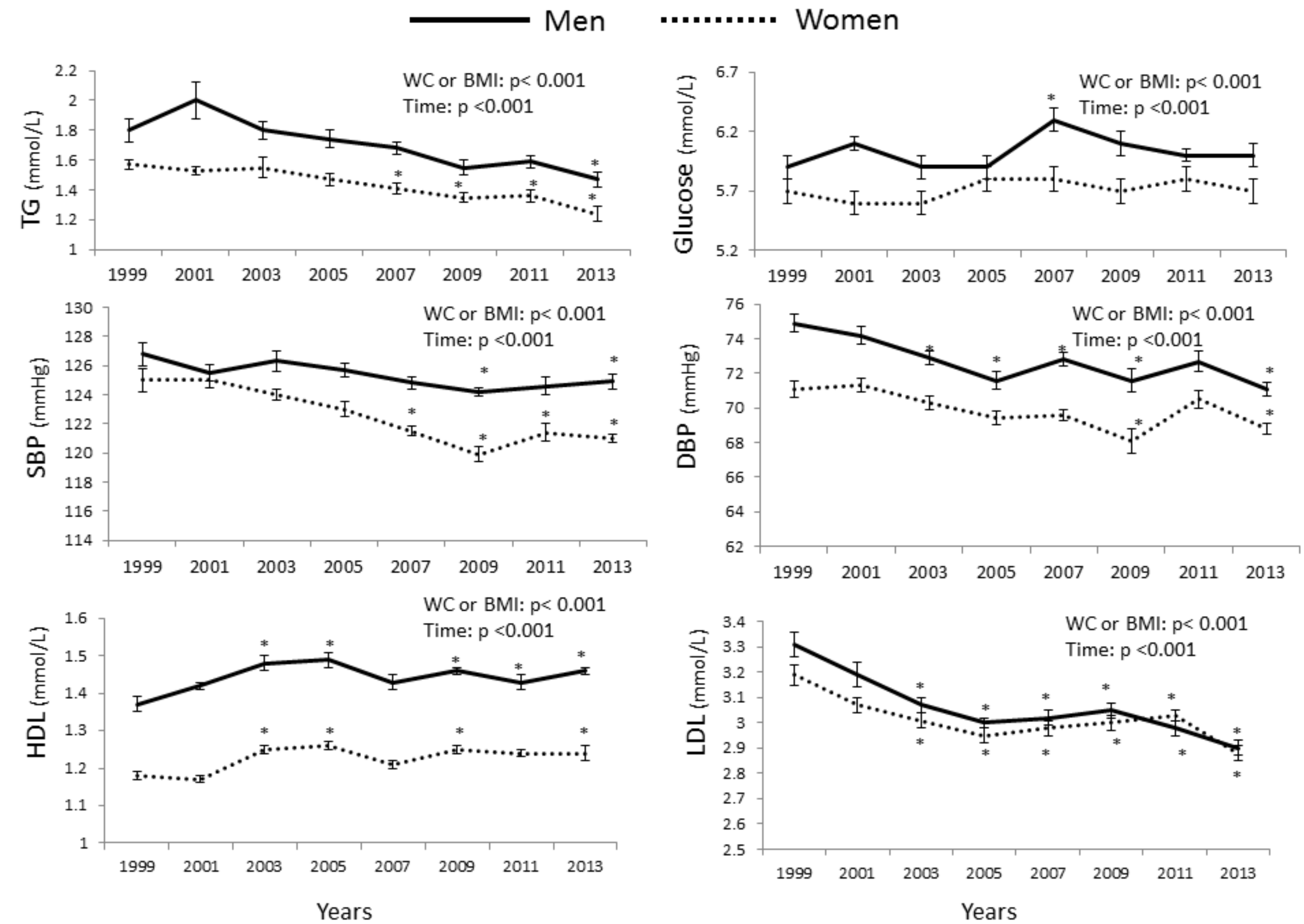

Figure 1.3. The trends of triglycerides (mmol/L), plasma glucose level (mmol/L), systolic blood pressure (mmHg), diastolic blood pressure (mmHg), HDL (mmol/L) and LDL (mmol/L) with time for both sexes. The models were adjusted for age, education, number of medications taken, ethnicity, total calories consumed in a day, smoking, and being physically active. The trends were very similar when BMI was replaced with WC in the model. For TG, HDL and LDL, total calories consumed in a day were replaced by total grams of fat intake in the model.

*: significantly different from the same sex in the year 1999, $p < 0.05$.

WC = Waist Circumference, BMI = Body Mass Index

4.0 Manuscript 2: No Differences in the Body Fat after Violating Core Bioelectrical Impedance Measurement Assumptions

Abstract

Objective: It is unclear to what degree acutely violating bioelectrical impedance analysis (BIA) measurement assumptions will alter the predicted percent fat mass (%FM) and whether this differs by body mass index (BMI) category. **Methods:** %FM was assessed under control, dehydration, moderate intensity treadmill exercise for 15 minutes, water and/or food intake, non-voided bladder acute conditions with three BIA devices (Tanita: BC-418, TBF-314, & Omron HBF-306CN) (n=40). **Results:** For all BIA devices, there were no differences in the %FM values between the control and the other conditions (-1.9 to 0.4%, p >0.05). There were no differences in %FM between control and the conditions when examined by BMI category (overweight: -2.8 to 0.1% and normal weight: -1.7 to 0.5%; BMI*trial, p=0.99). To determine the relative contribution of impedance and body mass to the differences in %FM, a model with standardized estimates was examined. Across the various conditions, differences in FM were more strongly associated with differences in impedance than body mass. **Conclusion:** %FM estimates were similar despite acutely violating the preliminary measurement BIA assumptions across a range of different BMIs. The minor variations in %FM are smaller than what would be expected with weight loss intervention.

Key words: Bioelectrical impedance, body composition, BMI, obesity

Introduction

Bioelectrical Impedance Analysis (BIA) is a convenient, non- invasive and non-intrusive device for estimating body composition (104,105). BIA devices use proprietary or published equations based on the relationship between total or segmental impedance and total body water volume (106). BIA equations for predicting body composition are based on the premise that when an alternating electric current is applied to the body, the amount of current that passes through the conductive water-containing tissues is related with the amount of fat free mass (FFM) presumed to be muscle tissue only. The impedance to the flow of electrical current can be used to estimate body composition where higher or greater electrical impedance is correlated with higher fat mass (38,106,107). These equations assume proper hydration and fluid distribution and violating this assumption may alter how BIA estimates FFM and total body water. Accordingly, the National Institute of Health recommends avoiding BIA measurements when participants are dehydrated, within 4-h of food and beverage consumption, have a full bladder and within 12 hours of moderate-to-strenuous exercise (80).

The commonly used BIA published equations were developed using normal weight (18.5 to 25 kg/m^2), generally healthy populations (38,106). Some studies suggest that BIA analyses underestimate the percent fat mass (%FM) in individuals with overweight or obesity (>25 kg/m^2), and may be related to differences in fluid distribution, resistive and volume properties among various body tissues (39,40). It is important to understand if violating these preliminary measurement BIA assumptions changes the estimation of body composition and if these discrepancies are greater among those with overweight or obesity as classified by body mass index (BMI).

Furthermore, the relative importance of the preliminary BIA measurement assumptions may vary across devices. Impedance can be assessed using foot to foot, hand to foot and hand-held devices. Some of the common BIA devices used in research studies are: (1) Tanita Body Composition Analyzer, Model: BC-418 (hand-to-feet), (2) Tanita, Model TBF-314 (foot-to-foot), and (3) Omron Fat Loss Monitor, Model: HBF-306CN (hand-to-hand). Because of the differences in the tissues through which the main electrical current travels through the body, the assumptions may influence BIA %FM differently depending on the device used. These devices vary by electrode characteristics (number, type and placement), electric current frequency (single or multiple frequencies) and body position at measurement (108). Thus, it is important to investigate the preliminary BIA assumptions across various devices.

Therefore, the aim of this study was to examine the effects of water intake, dehydration, food intake, exercise, and bladder voiding on acute BIA %FM & impedance measurements and if the effects are influenced by BMI categories.

Methods

Participants

Students and staff from York University were recruited via posters to participate in this study. Interested individuals were contacted through emails where the study objectives were further explained and questions about the visits answered. The inclusion criteria were: (a) age 18-70 years, (b) able to speak/read English, and (c) screened through Physical Activity and Readiness Questionnaire for Everyone (PAR-Q+, www.eparmedx.com). Anthropometric data was obtained on height, body mass, waist, hip, ankle, bicep, wrist and waist circumference. Height and body mass were measured using a wall mounted measuring tape and digital scale respectively. Waist circumference was obtained on iliac crest of participants. Weight status was determined by using the BMI equation: body mass (kg)/height (meters)^2. Participants completed a questionnaire on age, sex, education, ethnicity, fluid and food intake, and current medications.

Written informed consent was obtained by all participants and ethics approval was obtained from the Human Participation Review Sub- Committee, York University's Ethic Review Board (certificate #: e2012-283).

Protocol

The three BIA devices used included the : (1) Tanita Body Composition Analyzer, Model: BC-418 (hand-to-feet), (2) Tanita, Model TBF-314 (foot-to-foot), and (3) Omron Fat Loss Monitor, Model: HBF-306CN (hand-to-hand). These three BIA devices measure segmental impedance where the placement of polar electrodes are varied. The two Tanita devices output total and regional body composition and impedance data while the Omron machine only outputs total percent body fat.

Visit 1:

At the first visit, participants were tested under three conditions (water trial, non-voided bladder trial and exercise trial) along with the control trial. Participants were instructed to drink 3L of water the day prior to testing to ensure proper hydration. In addition, participants were instructed to (1) abstain from exercise on the day of the visit, (2) fast for 4-5 hours prior to their visit and (3) not void their bladder for at least 2 hours before the visit.

At the laboratory, participants were given 5 minutes to drink 1L of water and then shortly after underwent a BIA measurement (water trial). After 30 minutes they had a BIA measurement with their bladder still unvoided (non-voided bladder trial). Within 30-40 minutes of ingesting water, the volume of stomach contents usually return to the original state before the water intake (109). Participants then voided their bladder on a urine reagent test strip (10 LG Parameter

Urine Reagent Strips, Craig Medical Distribution, CA, USA) to test urine specific gravity (110). The following reference values were used to determine hydration status: 1-1.010 indicates relative hydration, and a value of 1.020 or greater indicates relative dehydration (111). Once the hydration levels were reached (1-1.010 on the urine reagent test strip), the BIA assessment was repeated (control trial).

Participants were then asked to run/speed walk on a treadmill at a moderate intensity (50-70% of age predicted HR_{max} using 220-age) for 15 minutes and then undergent BIA measurements again (exercise trial). Following the exercise for 15 minutes, the BIA measurement was repeated.

All the participants followed the same order of BIA measurements starting with water trial, then non-voided bladder trial, control trial and then followed by exercise trial on Visit 1. The order was kept consistent to keep the time between conditions consistent and limit any carry-over effect.

Visit 2**:**

Prior to coming to the laboratory for the second visit, particpants were asked to: (1) abstain from exercise on the day of the visit, (2) fast for 4-5 hours prior to their visit and (3) not void their bladder for 2 hours before the visit. In addition participants were instructed to not consume any fluid for 5-8 hours prior to the assessment. Upon arrival, participants voided their bladder on a urine reagent test strip to ensure that they were dehydrated prior to BIA assessment. Once the dehydration level was ensured, the BIA measurement was taken (dehydrated trial).

Afterwards participants were given 30 minutes to consume a meal ad libitum (325 g Dr. Oetker Ristorante Mozzarella Pizza (Kcal: 880, Fat: 44g, CHO: 76g, Protein: 36g), Pringles Original (Per 16 chips, Kcal: 150, Fat: 9g, CHO: 15g, Protein: 1g), and water. After confirming that participants had returned to adequate hydration status, we then measured BIA (food intake Trial).

Visit 3**:**

Participants underwent a Dual-energy X-ray Absorptiometry (DXA), total body composition assessment (bone mineral content, %FM, FFM) using a General Electric Lunar Prodigy (GE, USA).

Skinfold measurements were measured three times using caliper (Harpenden Skinfold Caliper, Model: CE 0120) at the triceps, biceps, subscapular, iliac crest and medial calf to estimate %FM. The %FM was calculated using Durnin JV and Womersley equation (32)**.**

Statistical Analysis

Statistical analysis was performed using SAS verion 9.4 (SAS Institute Inc., Cary, N.C., USA), with a level of statistical significance set at an alpha of 0.05. Means and standard deviations (M ±SD) were used to describe sample characteristics. A repeated measures ANOVA was used to compare %FM and impendance in each of the conditions (water intake, dehydration, food intake, exercise, and non-bladder voiding) compared to the BIA control trial for each BIA machine, and Sum of Skinfolds and DXA in both sexes. Post hoc analysis using Tukey multiple comparison test was used to determine differences among BMI groups in their %FM and impedance variations amoungst trials. Lastly, we conducted the multiple regression analyses to identify the relationship of change in impedance and body mass with %FM. The standardized estimates (expressed per standard deviation) were used to facilitate comparisons between the impedance and body mass beta estimates. The relationships between %FM, impedance and condition trials had one outlier: a female who was removed from all the analyses owing to the large variability in body mass fluctuations between the visits.

Results

The participant characteristics are shown in **Table 2.1** for men and women separately. The BMI ranged from 20.2 to 37.8 kg/m^2 for both men and women.

Influence of various factors on BIA measurements

Percent Fat Mass

The %FM was assessed using three BIA devices (Tanita BC-418, Tanita TBF -314, and Omron HBF) under control, dehydration, exercise, water and/or food intake, and non-voided bladder conditions are shown in **Figure 2.1** for men and women separately. For all BIA devices, there were no differences in the %FM values between the control and any of the condition trials (range: -1.9 to 0.7%, $p > 0.05$). Further, the differences in %FM between control and each condition trial was not significantly influenced by BMI (BMI*trial, $p=0.99$).

Impedance

Impedance tested using two BIA devices (Tanita BC-418, and Tanita TBF -314) under various conditions (control, dehydration, exercise, water and/or food intake, non-voided bladder) are shown in **Figure 2.2** for men and women separately. For both Tanita devices, there were no differences in the impedance values between the control and any of the condition trials (range: -26.6 to 3.1 Ω, $p > 0.05$). Similar to %FM values, the differences in impedance between control and each condition trial was not significantly influenced by BMI (BMI*trial, $p=0.99$).

Further analyses were conducted to understand if changes observed in %FM between the condition and control trials were more strongly related to changes in impedance or body mass.

In **Table 2.2,** the relationship between impedance and body mass with %FM in the control and condition trials are shown. The values of impedance and body mass for each condition are shown as the intra-individual difference between the control and the condition trial.

During the control trial, total body impedance was more strongly related to %FM than body mass (standardized estimates; impedance, 5.13 to 8.48%, body mass, 4.89 to 5.59%). Similarly, we observed that the changes in total body impedance from the control trial were more strongly related with changes in %FM than changes in body mass for both Tanita BC-418 and TBF-314 **(Table 2.2)**. For example, one standard deviation change in impedance was associated with a 0.16 to 1.32% difference in FM while one standard deviation change in body mass was associated with a 0.22 to 0.79% difference in FM under various BIA conditions **(Table 2.2)**.

Discussion

Our findings suggest that acutely violating the preliminary measurement BIA assumptions has minimal influence on the derived %FM and impedance values. Further, the minor differences in the measurements were similar among all participants regardless of their body mass.

The use of BIA devices to assess body composition is common in health and fitness facilities and research studies. Although the preliminary measurement BIA assumptions are well known and accepted, they are rarely followed in practice. BIA measurements are recommended to be avoided when participants are dehydrated, within 4-h of food and beverage consumption, and within several hours of moderate-to-strenuous exercise (80).

In terms of water and food intake, there is no consistency on the direction of change. Similar to other studies in the literature (35,112), we report non-statistically significant differences in %FM of ~1%, while others showed a statistically significant increase in %FM (~ 1.7%) after water and/or food intake (113,114). Studies with significant increases in %FM consumed high carbohydrate (white plain bread, fruit jam, and banana) or high fat (croissant, cheddar cheese, butter, full-fat Greek style yogurt) meals with water or high electrolyte sport drinks. Similarly, the present study used a high fat meal, while other studies with non-significant differences had non-specified/ad libitum food and beverage intake (35,112) . Nonetheless, %FM differences were modest and were inconsistent in their direction of change, and differences of approximately 1% associated with food and beverage intake are likely within the expected deviations with day-to-day variation (115). The composition of the diet is likely to influence body impedance and the rate of gastric emptying, however, one study reports that impedance values are similar even after many hours after consuming the meal (116).

The non-voided bladder condition did not significantly change the impedance or %FM values when compared to the control trial. Although, the consumption of 1L of water did increase body mass, it was not enough to statistically increase %FM. In this study, 1 kg difference in body mass is associated with a 0.68% difference in FM which is in line with a previous study theorizing that a non-voided bladder could affect BIA measurements by up to 1% (117). Thus, non-voided bladder is likely to have minimal effects on %FM estimates.

There are several changes that occur with exercise such as changes in skin blood flow, temperature, heat production and fluid loss (116), that may increase or decrease impedance. The literature on the effects of acute exercise on estimated %FM and impedance is mixed with studies showing decreased impedance by 28-40 Ω (118), or no change in impedance following moderate intensity aerobic exercise (118–120) as observed in this study. In the literature, the largest differences observed are less than 1% FM even with exercise moderate to vigorous intensity of 60 to 83% HR_{max} for as long as 45 minutes. These minimal differences suggest that moderate intensity exercise is likely being associated with minimal differences in predicted %FM.

For dehydration, theoretically one would expect an increase in impedance and %FM with low fluid status. In this study, impedance was not significantly increased in the dehydration condition, and in fact trended in the opposite direction (-22.4Ω to -7.4Ω) and %FM (-1.9 to 0.4%). This was the largest difference in %FM observed in the current study (maximum difference 1.9%, dehydration versus -0.2 to 1.01%, other conditions). A study conducted by Thompson et al (1991) also report a significant decrease in %FM in the dehydrated state when compared with the control state however the exact %FM difference was not reported (121). However, the study had its participants achieved the dehydration state by exercising for 30 minutes and then sitting in a steam room to decrease body mass by an average of 2.81% which is much larger than what we saw in our study (<1%). In this study, we examined each factor in isolation and it is unclear whether the differences in %FM may be larger when the core BIA assumptions are violated in combination. Nevertheless, the maximal 2% FM difference observed in this study is far lower than the 15 to 19.5% reduction in FM that would be typically expected in exercise intervention even with minimal weight loss (122). In the dehydration condition, the change of 2% FM is likely due to the reduction of average body mass of -0.74 kg among participants.

It has been known that there are different hydration levels, fluid distribution and volume properties in those within different BMI categories (104,123). Different tissues offer varying resistance; for example, adipose tissue is classified as a poor conductor of current because of the lower water content. Thus, BMI classified normal-weight individuals have hydration levels of ~73% (124) while the hydration levels are assumed to be lower in those with overweight and obesity (125–127). Thus, one would expect the effect of dehydration or exercise to vary in people with different BMI categories. However, despite our large range in BMI (20.2 to 37.8

kg/m^2) the difference in %FM that resulted by violating the preliminary BIA assumptions are similar among all participants. Further, these measures were generally comparable to DXA and sum of skinfolds (SOS) %BF assessments. The exception was the Omron HBF (hand-to-hand model) in women where the %FM values were significantly lower than DXA and SOS. This reinforces the notion that %FM obtained cannot be directly compared between the various devices, but also suggests that the acute violation of the core BIA assumptions may not have a large influence on the %FM obtained regardless of the measurement site used. Further, these variations in %FM are far smaller than what one would expect with clinical weight loss interventions (128). Retrospective power analyses suggest that 182 participants would be needed for the largest difference (-2%FM) to be significant and 11 million participants for the smallest difference (-0.008%). Regardless of the statistical significance, the clinical relevance of these variations are questionable as they are comparable to be what would be expected with the 2 to 5% day-to-day variation (18,33).

Some strengths and limitations of this study are worth mentioning. We are one of the few studies to examine the effect of acutely violating the core BIA assumptions on the estimation of body composition among multiple BIA devices. In the current study, three BIA devices with different measurement sites were used. Although there are several different devices available on the market, they all use measures of impedance and body weight to assess body composition. Since we observed no differences in impedance, it suggests that these observations likely hold true for other BIA devices using different algorithms. However, we are unsure if the differences in body composition would be larger if more than one core BIA assumption was violated at the same time. Further, although we had a large range in obesity using the BMI metric, the sample was generally normal weight or overweight using BMI. Finally, we are unsure if our results extend to older individuals or populations with chronic conditions.

It can be concluded that acutely preliminary measurement BIA assumptions have a very small effect (<2%) on the derived %FM and impedance values. These differences associated with acutely violating the core BIA assumptions are far smaller than what would be expected with weight loss interventions and is within what is expected with day- to- day variation.

Table 2.1. Sample Characteristics of Participants by Sex

	Men	Women
Total Sample	n=23	n=17
Age (years)	24.0 ± 5.2	22.5 ± 3.4
BMI (kg/m^2)	25.9 ± 3.5	22.8 ± 2.8*
BIA Body Fat (%)		
BC-418	19.7 ± 6.6	29.4 ± 6.9*
TBF-314	20.0 ± 6.7	27.1 ± 6.4*
Omron HBF	17.8± 6.7	24.4 ± 5.8*
DXA Body Fat (%)	20.7 ± 9.0	30.1 ± 8.4*
Skinfolds Body Fat (%)	19.0 ± 5.5	29.1 ± 5.4*
Waist Circumference (cm)	79.6 ± 15.5	76.2 ± 6.2
BIA Impedance (Ω)		
BC-418	560.2 ± 65.6	728.0 ± 88.8*
TBF-314	479.5 ± 52.7	581.3 ± 68.9*

All the continuous values are presented as means ± SD and categorical values as prevalence %.

BMI = body mass index, BIA = Bioelectrical Impedance

* = significantly different from men ($p<0.05$)

Table 2.2. Change in %FM with Changes in Impedance and Body Mass after violating the preliminary measurement BIA assumptions

Baseline	BIA	Total Body Impedance			Body Mass		
		Partial R	Parameter Estimate (%FM/Ω)	Standardized Estimate (%FM/SD of Ω)	Partial R	Parameter Estimate (%FM/SD of kg)	Standardized Estimate (%FM/SD of kg)
Control trial	BC-418	0.83	1.03	8.48%	0.70	0.68	5.59%
	TBF-314	0.59	0.69	5.13%	0.57	0.66	4.89%
Trial	**BIA**	**Change in %FM with Impedance**			**Change in %FM with BM**		
		Partial R	Parameter Estimate (%FM/Ω)	Standardized Estimate (%FM/SD of Ω)	Partial R	Parameter Estimate (%FM/SD of kg)	Standardized Estimate (%FM/SD of kg)
Water intake (condition 1)	BC-418	0.82	0.75	0.79	0.85	0.23	0.24
	TBF-314	0.81	0.53	0.34	0.85	0.62	0.40
Voided Bladder (condition 2)	BC-418	0.95	0.75	0.52	0.85	0.38	0.27
	TBF-314	0.75	0.54	0.16	0.83	0.72	0.22
Exercise (condition 3)	BC-418	0.85	0.80	0.55	0.55	0.32	0.22
	TBF-314	0.80	0.72	0.34	0.69	0.50	0.24
Dehydration (condition 4)	BC-418	0.92	0.90	1.31	0.81	0.54	0.79
	TBF-314	0.93	0.90	1.18	0.84	0.54	0.71
Food intake (condition 5)	BC-418	0.94	0.94	1.32	0.73	0.35	0.49
	TBF-314	0.92	0.94	1.13	0.66	0.35	0.42

Standardized estimates are expressed as %change in fat mass per one standard deviation change in impedance or body Mass. The values of impedance and body weight for each condition were shown as the intra-individual difference between the control and the condition trial.

FM = Fat Mass, BM = Body Mass

Figure 2.1

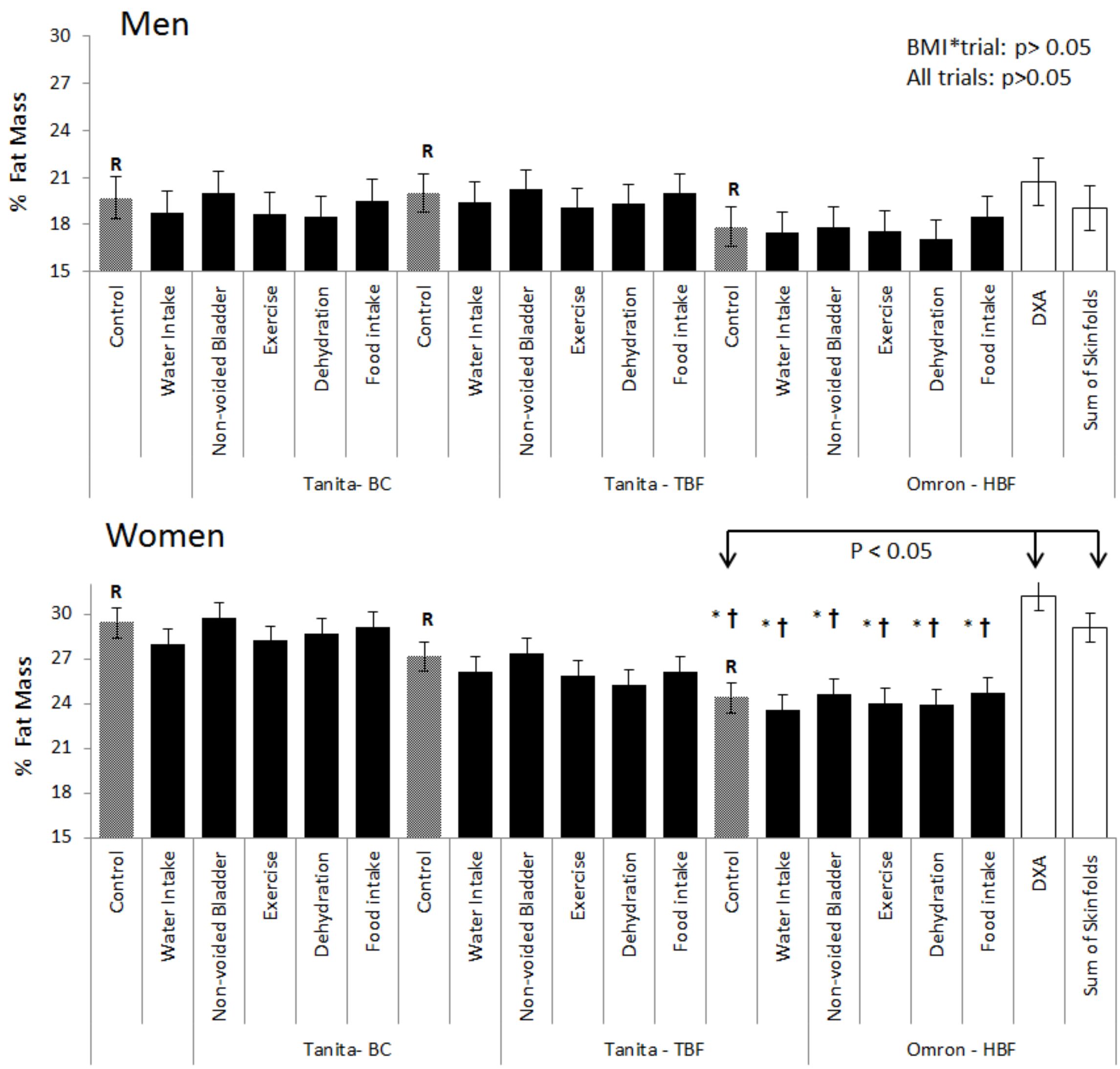

Figure 2.1. The average percent fat mass for each trial per BIA machine for men (n=23) and women (n=17). There were no differences between trials for each BIA machine for percent fat mass (p >0.05). BMI= Body Mass Index

* = Significantly different from DXA

†= Significantly different from sum of skinfolds

R = refers to the control or reference condition

Figure 2.2

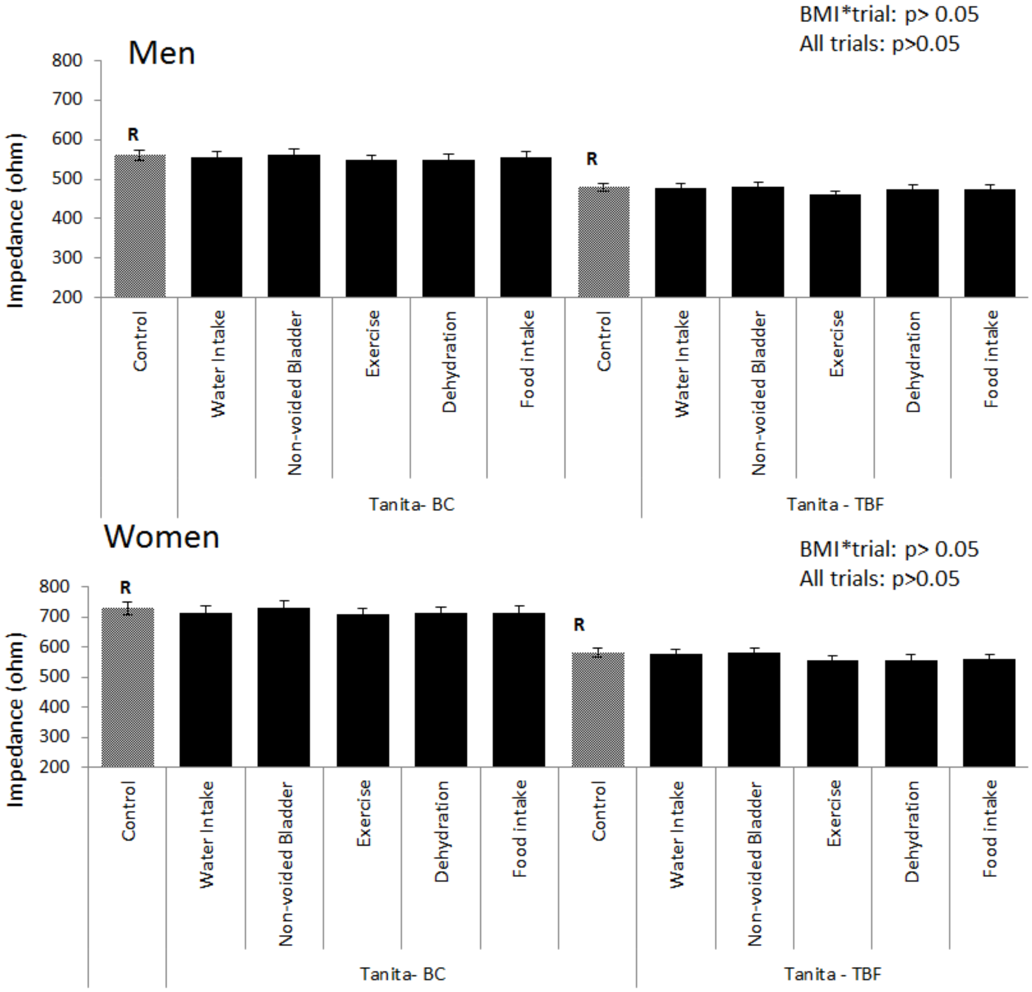

Figure 2.2. The average bioelectrical impedance for each condition per BIA Tanita machine for men and women. There were no differences between conditions for each BIA machine for impedance from the reference group (R) (p >0.05). BMI = Body Mass Index

5.0 Manuscript 3: Are Different Accelerometers Cut-Offs Needed to Accurately Determine Physical Activity Intensity?

Abstract

Objective: To determine if accounting for cardiorespiratory fitness (CRF) and body mass index (BMI) significantly impact the accelerometer cut-offs for assessing physical activity (PA) partcipation. **Methods:** After completing the incremental to maximum VO_2 test, participants ($\geq$ 20 years, n=41) performed ten 3-4 minute intervals alternating between light intensity (30-35%VO_2 peak) and moderate to vigorous intensity MVPA ($\geq$50% VO_2 peak) while wearing an accelerometer on the right hip. The CPM values derived using standard cut-offs and individual CRF cut-offs were compared by BMI in both sexes. **Results:** After accounting for CRF, the individualized cut-offs were tended to be higher than the standard cut-offs for only light intensity PA ($p < 0.05$). Wherein men with obesity had lower CPM values during light and moderate intensity PA compared to men without obesity, there were no differences in CPM values in women with obesity despite differences in CRF and body mass ($p > 0.05$). Moreover, no differences in PA duration between those with (28.8 ± 20.3 min/day) or without obesity (16.0 ± 16.6 min/day) were observed when applying individualized or standard CPM cut-offs (p=0.18). In contrast, self-reported PA duration was higher in men with obesity (178 ± 11.6 min/day) than men without obesity (115.8 ± 15.9 min/day, $p < 0.05$) while there was no difference in women ($p > 0.05$). **Discussion:** Our findings suggest that even when accounted for CRF, the PA duration was similar between individuals with or without obesity. Future research may be needed to better understand how to translate CPM values into PA intensity for people with overweight and obesity.

Key words: accelerometer, Obesity, CPM values, PA intensity, cardiorespiratory fitness

Introduction

It is well established that physical activity (PA) is associated with many positive health outcomes such as reducing obesity-related health risks and better weight maintenance following weight loss (11,130,131). Methods for the assessment of PA are generally divided into two categories: subjective and objective measures. Subjective or self-report PA is widely used in population based studies (57), however, it is not considered as accurate as objectively measured PA (60,61) as factors including personal perceptions of activity intensity, recall bias or social desirability, could contribute to the over- or under- estimation of PA volume (79).

Accelerometers are objective tools to measure PA and are commonly used in research settings to measure the frequency, duration and intensity (aka volume) of PA. Accelerometers generate an electric charge to mechanical movements like walking, and outputs a voltage proportional to the acceleration (65,66). The frequency of accelerations per minute is called counts per minute (CPM). In accelerometers, there are single universal CPM threshold values to denote light intensity PA (0-2689 CPM or MET value ≤ 3), moderate intensity PA (2690-6166 CPM or MET value = 3 to 6), and vigorous intensity PA (6167-9642 CPM or MET value = 6 to 9) (71). However, the use of a single threshold does not account for the individual differences in how the CPM values relate with PA intensity. For example, the force needed to generate an acceleration is positively related to the mass of the object (Force = mass x acceleration). Thus, individuals with high body mass would need to do more work than individuals with low body mass to achieve the same acceleration frequency. In addition, cardiorespiratory fitness (CRF) will further influence the relative work required for a given absolute PA intensity (73). For example, playing tennis corresponding to 5.0 MET (2690-6167 CPM) may be perceived as vigorous effort for one individual and very vigorous effort (higher relative % VO_2 peak workload) for another.

Accordingly, a study conducted by Ozemek et al. (41) showed that individuals with low CRF had lower CPM values than those with high CRF fitness when working at moderate or vigorous intensity (40 and 60% of heart rate reserve (HRR)) (12). This would imply that individuals with obesity who generally have low CRF and high body mass may work at a even higher relative intensity (%VO_2 peak) at any given CPM, therefore underestimating the volume of PA in those with obesity. Thus, both CRF and body mass may contribute even further to the discrepencies observed between subjective and objective measures of PA (42).

As far as we know, it is yet unknown if CRF could contribute to the discrepancies in CPM values between individuals with and without obesity.

Purpose and Aim

The purpose of the study is twofold:

1) To determine CPM values during light (30-35% VO_2peak) and moderate to vigorous (MVPA) PA intensity (≥50% VO_2peak) physical activity.

2) To estimate and compare durations of objectively measured PA to the self-report measured PA across BMI using standard and individualized CPM intensity thresholds that account for differences in CRF.

Methods

Data was obtained from recruiting participants at York University through posters. Interested individuals were contacted through email where the study objectives were further explained and questions about the visits were answered. Participants over the age of 20 years were screened using the 2014 /2015 Physical Activity Readiness Questionnaire for Everyone:

2014/2015PAR-Q+ and if necessary the ePARmed-X+ at www.eparmedx.com (132). Written informed consent was obtained and the study protocol ethical approval was obtained from York University Human Participants Research Committee (certificate # e2015 -145)

The participants were stratified by sex and obesity status. No-obesity group was defined by the body mass index (BMI) of ≤ 30 kg/m^2 and no abdominal obesity (waist circumference; men ≤ 88 cm, women ≤ 102 cm). Obesity group was defined by the BMI of ≥ 30 kg/m^2 or abdominal obesity (waist circumference; men ≥88 cm, women ≥ 102 cm). The data was collected at 2 different visits that were 7 days apart. Of the 62 participants that attended the 1st visit, 41 participants completed both visits and were included in these analyses. An honorarium of $25 was given to the participants at the completion of the study.

Protocol

First Visit

After screening for eligibility and receiving consent, participants underwent anthropometric and body composition measures. A series of anthropometric measures including height, body mass, leg length, stride length, waist circumference were collected.

Participants completed a 5 minute warm-up and then underwent a modified Balke maximal effort exercise test on a treadmill using indirect calorimetry while wearing an accelerometer and a heart rate monitor.

Participants were provided a GT3X+ Actigraph Accelerometer (Penascola, FL) to record PA over a one week period. The GT3X is a tri-axis accelerometer that measures accelerations in three individual orthogonal planes (vertical plane, antero-posterior plane and medio-lateral plane). It provides CPM values as a composite vector magnitude of these three axes. Participants wore a PA monitor on their right hip during waking hours for a period of seven days. The CPM values for 1-second epochs were retrieved and summed for the entire duration. Only participants with at least 4 out of 7 days of wear time were used in the analyses. One of the wear valid days had a weekend day and a minimum of 10 waking hours.

Second visit

On the second visit, participants returned the accelerometer, and performed ten 3-4 minute intervals alternating between walking/jogging at light (30-35%VO_2 peak) and moderate-vigorous intensity PA (MVPA, ≥50% VO_2 peak) on a level surface. Intensity was monitored using heart rate (HR) monitors with HR targets that corresponded to the appropriate VO_2 ranges assessed during the first visit. CPM values in 1-second epochs were taken over 1 minute after achieving steady state.

Self-reported PA from the previous week (same time-period the accelerometer was worn) was obtained using the International Physical Activity Questionnaire – long form (IPAQ). IPAQ self-reported PA was estimated in five domains: occupational PA; active transportation PA; domestic and yard work PA; leisure-time PA; sitting time; and three PA intensities: (1) walking; (2) moderate PA; (3) vigorous PA. IPAQ outcomes for specific domains, intensities, and totals were calculated in minutes per week (133). The IPAQ has been demonstrated to have adequate reliability ranging from 0.74-0.97 (134).

Objective PA Assessment

CPM measured during the light (57-63% HR_{max}) and moderate (64-76% HR_{max}) intensity bouts were aligned with the measured HR during the same 1-minute steady state period. To improve comparability with the global PA guidelines, CPM values that corresponded to 60% and 75% of HR_{max} were presented.

Accelerometer measured durations of moderate PA, vigorous PA, and MVPA intensities over 7 days were determined as moderate and/or vigorous activity performed in bouts of at least 10 minutes. The duration of 10 minutes had an allowance of up to 2 minutes below the intensity thresholds (67,135). The two intensity thresholds used were standard CPM cut-offs and individualized CPM cut-offs calibrated based on the individualized CRF level for each participant.

The standard CPM cut-offs were based on Freedson (2011) adult intensity cut-points; light; 0-2689 CPM, moderate; 2690-6166 CPM, vigorous; 6167-9642 CPM, and very vigorous; 9643 and above (69,71)

The individualized CPM cut-offs were based on the CRF levels and derived from the individual algorithms that corresponded to light (57% $HR_{max)}$ and moderate (76% HR_{max}) intensity (136). The PA volume was calculated using standard and individualized CPM cut-offs by using the ActiLife v6.13.3 (Pensacola, Florida) program.

Statistical Analysis

Continuous variables were reported as mean ± SD. Participant characteristics were stratified by sex and obesity status based on BMI, where ANOVA was used to compare continuous variables. The models were adjusted for age (years) and leg length (cm). Differences by PA assessment method and PA intensity by obesity status were assessed using repeated measures analysis of variance with least-squared differences *post hoc* comparisons tests.

All statistical analyses are conducted using SAS version 9.4. Statistical significance is considered at $p < 0.05$.

Results

Participant characteristics by obesity status and sex are presented in **Table 3.1.** In general, CRF was lower among those with obesity than those without obesity ($p<0.05$), and in women compared to men ($p<0.05$).

Measured CPM values during light and moderate intensity PA by obesity status

CPM values measured during PA bouts corresponding to light intensity (60% HR_{max}), and moderate intensity (75% HR_{max}) stratified by obesity status and sex are shown in **Figure 3.1**. During both light intensity and moderate intensity PA, men with obesity (light, 4004 ± 497; moderate, 6481± 835 CPM values) had significantly lower CPM values compared to men without obesity (light, 5589 ± 372; moderate, 9601± 625 CPM values, $p<0.05$) **(Figure 3.1).** However, in women there were no significant obesity-related differences in the CPM values during light or moderate intensity PA (light - women with obesity 4540 ± 475 vs women without obesity, 3335 ± 622 CPM; moderate - women with obesity, 7269 ± 505 vs women without obesity, 6247 ± 662 CPM;) (**Figure 3.1,** $p>0.05$).

Comparison of Standard and Individualized CPM cut-offs

The individualized CPM cut-offs that correspond to ACSM thresholds for light (57% HR_{max}), moderate (64% HR_{max}) and vigorous (77% HR_{max}) for each participant are shown in **Figure 3.2.** The vigorous intensity PA cut-offs were extrapolated for each individual based on their relative CRF and HR. For comparability, the standard CPM cut-offs proposed by Freedson are also shown on the Figure as shaded area. The vast majority of individualized CPM cut-offs were higher than the standard cut-offs for light PA intensity for both sexes ($p <0.05$). Wherein the differences between the two cut-offs were significantly lower in men with obesity than men without obesity for light intensity PA ($p <0.05$). Conversely, the difference between the standard and individualized CPM cut-offs was not different in women by obesity status for light intensity PA ($p > 0.05$). For moderate and vigorous PA intensities, there were no differences between the individualized and standard cut-offs ($p > 0.05$) where only 20 to 27% of the individuals had higher or lower individualized CPM values than the standard cut-offs.

Objective versus subjective measurement

Mean durations (minutes/day) of PA using individualized and standard CPM cut-offs, and self-report PA by obesity status for both sexes is shown in **Figure 3.3.** As expected, mean durations of PA using self-report were significantly longer than durations of PA estimated by accelerometer using either CPM cut-offs regardless of sex or obesity status (**Figure 3.3,** $p < 0.05$).

Self-reported moderate PA and MVPA intensity durations were significantly higher in men with obesity (MVPA, 178 ± 11.6 minutes/day) than men without obesity (MVPA, 115.8 ± 15.9 minutes/day) (**Figure 3.3,** $p < 0.05$). In women, there was no difference in self-reported moderate PA and MVPA intensity durations by obesity status (women with obesity, 144.7 ± 13.2 vs. women without obesity, 126.4 ± 17.4) ($p > 0.05$). It is opposite to what we see when PA volume is measured using the standard CPM cut-offs, wherein individuals with obesity had lower MVPA durations (men, 53.7 ± 20.3 minutes/day) than individuals without obesity though this difference did not reach significance (men, 89.9 ± 16.6 minutes/day, **Figure 3.3**, $p = 0.25$). Similarly, the PA volume based on individualized CPM cut-offs were not different between individuals with or without obesity in either sex ($p = 0.18$). Men with obesity had performed 28.8 ± 20.3 minutes/day of MVPA and men without obesity had performed 16.0 ± 16.6 minutes/day of MVPA. Further, regardless of the PA assessment method used, the proportion of individuals meeting the Canadian PA guidelines remained similar between individuals with or without obesity (range, 46% to 54%).

As the individualized CPM cut-offs were not different than the standard CPM cut-offs for moderate and vigorous PA intensities (**Figure 3.2),** it is expected that the PA durations using the individualized CPM cut-offs would not be different than PA durations with standard cut-offs for PA intensity across sex and obesity status (**Figure 3.3,** $p>0.05$). However when comparing within groups, the PA durations using the individualized CPM cut-offs were significantly shorter than the PA durations with standard cut-offs among men without obesity and women with obesity (**Figure 3.3**, $p< 0.05$). For example, men without obesity had significantly lower MVPA durations based on individualized cut-offs (16 ± 16.6 minutes/day) compared to MVPA durations based on standard cut-offs (89 ± 16.6 minutes/day) ($p <0.05$). Women with obesity had significantly lower MVPA durations based on individualized cut-offs (24.4 ± 13.8 minutes/day) compared to MVPA durations based on standard cut-offs (63.9 ± 13.8 minutes/day) ($p <0.05$).

Discussion

In our study, after accounting for individual differences in CRF, the individualized CPM cut-offs for denoting PA intensity were only higher than the standard CPM cut-offs for light PA intensity. Men with obesity have lower CPM values than men without obesity. However, this difference in CPM cut-offs by obesity status did not translate into difference in PA volume as there was no difference in PA durations by obesity status using standard or individualized CPM cut-offs. Similarly, the proportion of individuals meeting the PA guidelines remained similar across all PA assessment methods.

Our hypothesis was that individualized CPM values observed during PA should be lower for individuals with obesity when compared to individuals without obesity. Indeed, this was precisely what we observed, suggesting that accelerometers will underestimate PA in men with obesity. However, there was no difference in CPM values in women by obesity status. In fact, women with obesity had higher CPM values when compared to women without obesity. A previous study showed similar trends where the CPM values derived using standard CPM cut-offs for moderate PA intensity (60% peak) were higher in women with obesity (6241 CPM) than women without obesity (5659 CPM) (77). Sex differences have been previously reported when participants were asked to wear uniaxial or triaxial accelerometer during PA (137,138). The differences that contribute to sex differences in accelerations produced at the hip are typically linked to biomechanical features, gait characteristics and anthropometric measures (139), and could relate to both the amount and distribution of skeletal muscle and body fat (140). Women tend to have greater adiposity in the hip and lower body region and higher levels of subcutaneous fat (141,142) . A greater adiposity in the hip among women with obesity could lead to added distance from the center of mass (COM) (143). The increased distance from the COM may contribute to increase in accelerations, resulting in inflated accelerometer CPM values in women with obesity. Thus, given the differences in adiposity among women, accelerometers positioned at hip may not work well in women.

In accordance with previous literature, self-reported durations of PA were greater than accelerometers PA durations for all individuals and tended to be higher for individuals with obesity. It is often suggested that individuals with obesity tend to over-report PA while engaging in less over all PA compared to individuals without obesity (78,79,144). However, we do not see any difference in objectively measured PA durations by obesity status and it suggest that the difference from self-report could reflect the bias in the way accelerometers measure PA intensity and duration for individuals with obesity. The present findings are aligned with the previous research conducted by Raiber et al (42), where the magnitude of the discrepencies between self-report and accelerometer PA intensity and duration were reduced for individuals with obesity if they accounted for differences in estimated CRF from a sub-maximal test.

In the current study, for a given moderate or vigorous PA intensity, the individualized CPM cut-offs were not significantly different than the standard CPM cut-offs. However, the individualized CPM values ranged from 365 to 4997 CPM for light, 1675 to 10988 CPM for moderate and 4208 to 16804 CPM for vigorous PA intensities across sex and obesity status. Studies that examine various populations with different fitness levels based on body mass, age and sex report ranges of accelerometer CPM values for moderate intensity PA between 669 and 7520 CPM (12,145). Nevertheless, this extremely large range suggests that there may not be a single appropriate cut-off value to define PA intensity in a heterogeneous population. This large variability may contribute to the measurement error of accelerometers within a population and undermines the use of accelerometer in accurately measuring PA volume. This is in agreement with the idea that using absolute intensity PA standard CPM cut-offs are not appropriate for use in a population with ranging body mass (12).

Durations of PA achieved will depend on the CPM cut-offs used (146,147). Lower CPM cut-offs will result in longer durations of measured PA. Conversely, using higher CPM cut-offs values will mean that more PA would not qualify as PA for a given intensity, resulting in shorter durations of PA. Even after accounting for CRF of individuals with obesity, durations of MVPA in both sexes ranged from 171 to 202 minutes/week. These values are likely relevant given that adults should engage in 150 minutes/week for positive health effects and 150 - 250 minutes/week for prevention of weight gain (54). Previous research has stated that individuals with obesity typically do not perform enough PA for health benefits and 60 to 77% of Canadians with overweight or obesity do not meet the PA guidelines even when the PA is measured objectively (148). Our study showed that there are no differences between individuals meeting the PA guidelines by obesity status. Based on the individual CRF, 52% of individuals with obesity and 48% of individuals without obesity performed a minimum of 150 minutes of MVPA/week. Nonetheless, the current objective measures may not be able to adequately measure the PA volume and warrants further investigation.

Some strengths and limitations are worth mentioning. To our best knowledge, this is one of the first studies to compare the accelerometer measured CPM values based on individual's measured CRF to the commonly used Freedson's CPM values and examined discrepancies by obesity status. The individualized CPM values were derived by using VO_2 maximal exercise testing to avoid errors related to predicted maximum heart rate (220-age of participant [± 10 beats/min]) and mechanical efficiency (e.g. VO_2 at a given work rate). The exclusion of individuals who did not complete the VO_2 maximal exercise test due to factors such as mobility issues or heavier weight could result in a sample that is healthier than the general population.

In conclusion, after accounting for CRF, the individualized CPM cut-offs were not different than the standard cut-offs for moderate and vigorous PA intensities. Despite using the individualized CPM cut-offs, there were no differences in PA duration between individuals with or without obesity. Thus, future research is needed to better understand how to best translate CPM values into PA intensity plus duration and improve the use of accelerometers for assessing the impact of volume of PA participation in a population.

Table 3.1. Participant Characteristics by obesity status and sex

	No Obesity		**Obesity**	
Sample Size (n)	Men (n=14)	Women (n=7)	Men (n=8)	Women (n=12)
Age (Years)	26.6 ± 9.5	29.6 ± 12.5	32.0 ± 13.1	29.1 ± 9.6
BMI (kg/m^2)	25.4 ± 2.3	21.3 ± 1.4	33.7 ± 4.1	33.2 ± 5.1
Leg Length (cm)	104.9 ± 6.5	99.6 ± 5.2	103.2 ± 5.6	99.6 ± 5.0
Waist Circumference (cm)	88.3 ± 7.5	75.1 ± 9.2	112.9 ± 10.9	104.4 ± 12.4
VO_{2peak} ($mL.kg^{-1}.min^{-1}$)	53.9 ± 9.4	44.1 ± 7.2†	40.4 ± 14.3*	31.7 ± 7.3*†

Values are presented as mean ± SD. BMI= body mass index, VO_{2peak} = Maximal Oxygen Uptake

*= significantly different from same sex in no-obesity group ($p < 0.05$)

† = significantly different from same group but different sex ($p < 0.05$)

Figure 3.1

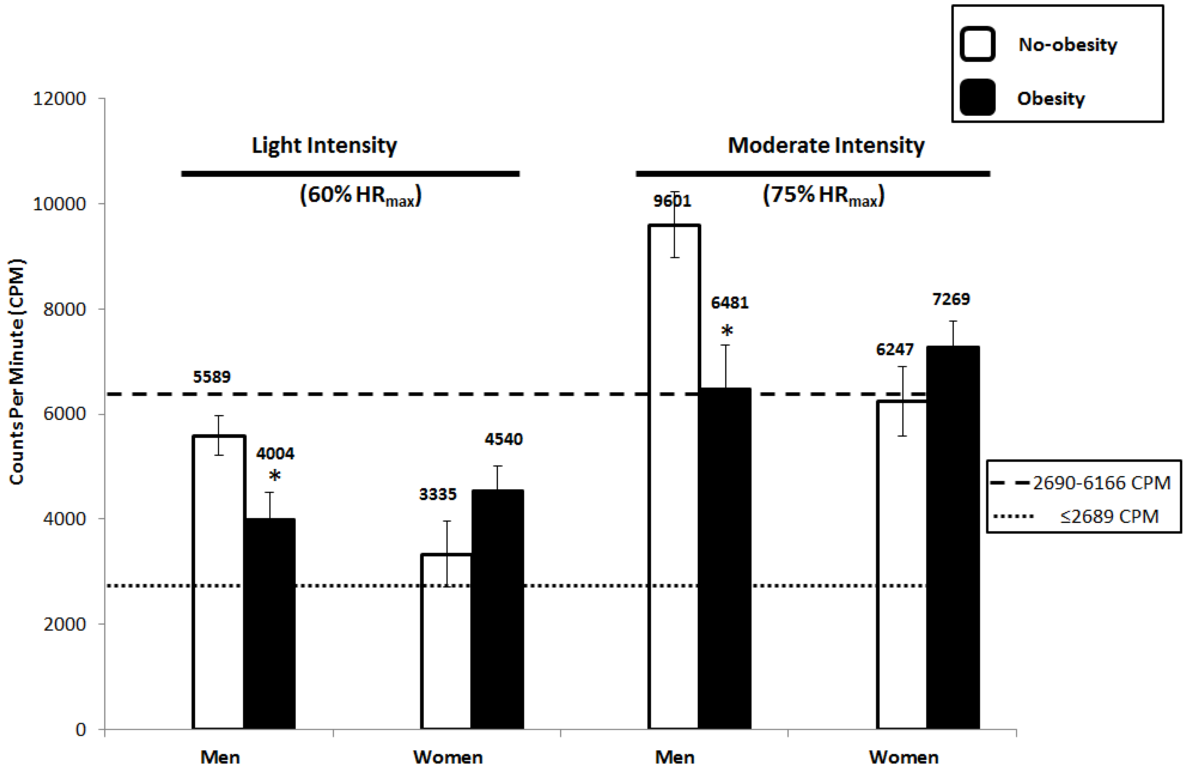

Figure 3.1. Accelerometer based individualized CPM values corresponding to 60% and 75% HR_{max} by sex and obesity status. The models were adjusted for age (years) and leg length (cm).

* = Statistically different from no-obesity group within same sex.

HR= Heart Rate, CPM = Counts Per Minute

Figure 3.2

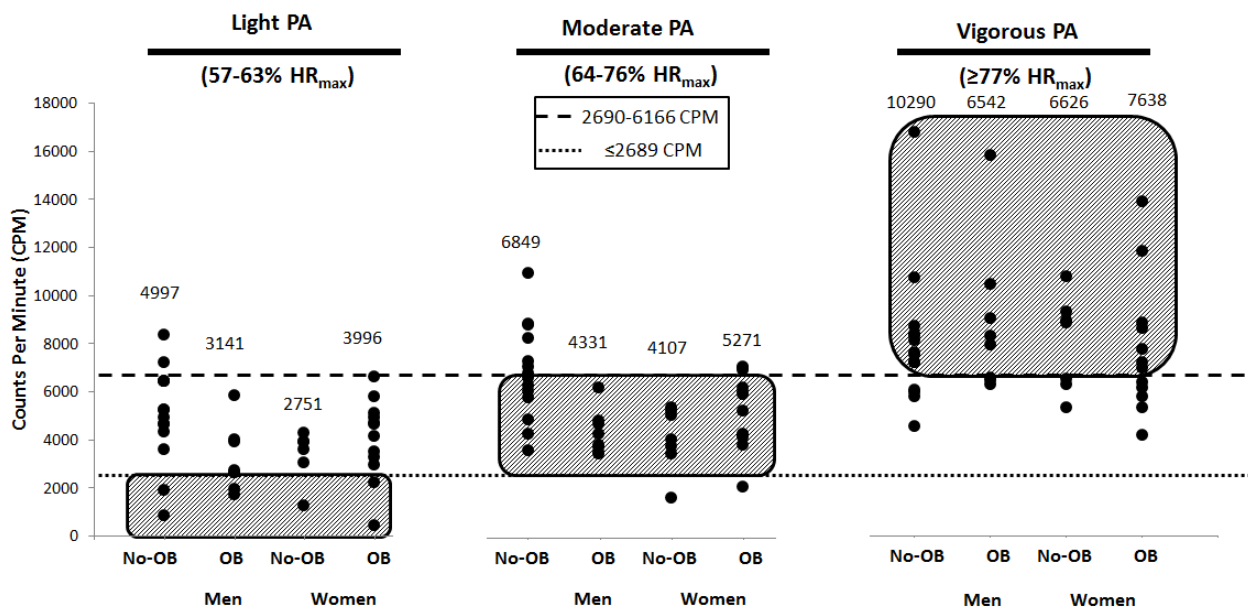

Figure 3.2. Accelerometer based individualized CPM cut-offs of all participants and obesity status. The black dots are the individualized CPM cut-offs for each participant and the numbers above the black dots are the average CPM values of the group. Shaded areas depict PA intensities range based on standard cut-offs. PA= Physical Activity, HR= Heart Rate, CPM = Counts Per Minute, OB = obesity.

Figure 3.3

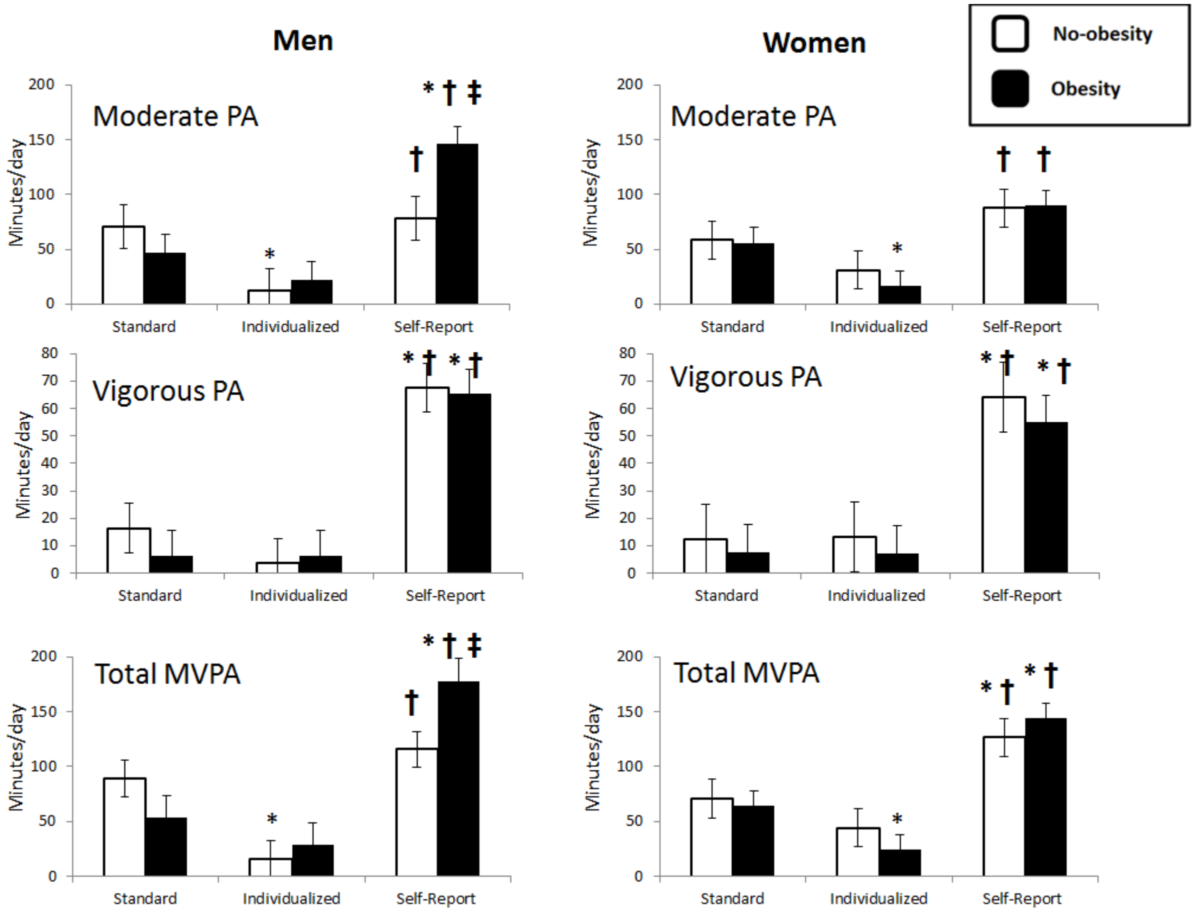

Figure 3. 3. Mean durations of moderate, vigorous and MVPA physical activity by obesity status and sex. PA = Physical Activity, MVPA = Moderate –to-vigorous Physical Activity

* = Statistically different from standard cut-offs between the same obesity group

† = Statistically different from individualized cut-offs between the same obesity group

‡ = Statistically different from no-obesity group within the same PA assessment method

6.0 General Discussion

The obesity rates using BMI increased at an alarming rate in the U.S. over the past three decades (2). The causes of obesity are multi-factorial and some of the factors are genetics, environmental, use of pharmaceutical drugs, physical inactivity and excess caloric intake (149). Obesity is often linked to lost productivity and foregone economic growth as a result of lost work days, lower productivity at work, mortality and permanent disability (150). Even in research and clinical settings, individuals with obesity are often linked to increase in measurement errors in outcome measures (79,151,152). Thus, obesity is thought to constitute a threat to public health in terms of prevalence, incidence and economic burden.

As the obesity rates have increased, obesity stigma has also increased by 66% in the U.S. over the past decade (153). Unfortunately, weight discrimination and bias against individuals with obesity has appeared to be socially acceptable and is reinforced by the media (154,155). Health care providers are not that different when it comes to weight discrimination and bias as compared to the general public. Research has shown that patients with obesity who perceive bias from their providers may cancel or delay appointments, as well as avoid preventative health care and screenings. Appointment delays and avoidance could further add to weight gain and obesity (156). Thus, the combined effect of obesity and its stigma has propelled us to explore obesity-associated health outcomes, and measurement tools used in research to clearly define obesity and its consequences.

The goal of obesity treatment (with or without weight loss) is to reduce obesity-associated health risk factors. Our study showed that certain obesity-associated health risks have decreased over time. Given the stigma with weight status in health care settings and decreased prevalence of certain chronic conditions, it would be more beneficial and welcoming for individuals with obesity if health care providers start drifting their conversations from weight status. Obesity is a multidimensional problem that requires a multidimensional response (53). Thus, health care providers should address this disease in a respectful and compassionate manner (157). Knowing that independent of obesity or weight status, certain health risks could be improved, the conversations between the health care providers and the patients should be more focused on the health outcomes. Our study reflects on the notion that there may be other factors that are attributing to the association of obesity with health risks over time. Thus, treatments could be more individualized, and the other factors may need to be more explored when providing health care to individuals with obesity.

The use of BIA devices in estimating body composition and hydrations levels can be helpful for prognosis of certain diseases such as chronic obstructive pulmonary disease (COPD), and sarcopenic obesity (158,159). Further, BIA could also be more sensitive in detecting pulmonary edema, fluid accumulation after cardiac surgery, and body fluids in hemodialysis patients (160–162). However, it is yet questionable whether assessing %FM of healthy individuals is beneficial in a clinical setting. Further, BIA may not be able to provide accurate measures for individuals with high levels of obesity to physicians for disease prognosis (163). Nonetheless, BIA is a common method used for estimating body composition among individuals that are healthy and with diseases in research & clinical trials. Our study showed that BIA assumptions may not hinder the acute body composition measures beyond its day to day variability, which is crucial in clinical and research settings.

It is important for individuals with obesity to engage in PA for health benefits. A single aerobic session can lead to reductions in blood glucose levels, triglyceride levels, blood pressure and improvements in insulin sensitivity and HDL levels (52,53). However, the current PA measures such as accelerometers are not reflective of the accurate PA performed by individuals with obesity even when accounted for their CRF levels. Thus, better measures are required to property assess PA because it allows researchers to investigate the dose–response relationship between PA and health outcomes, and help shapes public health initiatives and interventions (51).

In conclusion, despite increasing obesity using the BMI metric, the prevalence of obesity-associated chronic conditions has decreased over the years. There may be other co-occurring temporal changes that have altered how obesity relates to chronic conditions. Thus, targeted efforts are needed to better define obesity and its associated health consequences. Future studies are also needed to explore factors other than obesity and their associations with chronic conditions. Further, there are certain biases to individuals with obesity using BMI when it comes to measurements of body composition and PA. Even when accounted for the CRF levels, current measures are not able to adequately capture the PA intensity and duration in individuals with obesity. Thus, better measures are needed for individuals with obesity to accurately depict PA intensity and duration.

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Appendices

Appendix A: Research Ethics Approvals

YORK
UNIVERSITÉ
UNIVERSITY

Certificate #:	STU 2018 - 008
Approval Period:	01/24/18-01/24/19

ETHICS APPROVAL

To:	**Arshdeep Randhawa** Graduate Student of Kinesiology & Health Science, Faculty of Health
From:	Alison M. Collins-Mrakas, Sr. Manager and Policy Advisor, Research Ethics *(on behalf of Veronica Jamnik, Chair, Human Participants Review Committee)*
Date:	Wednesday, January 24, 2018
Title:	**Secular trends in obesity-associated health risks by BMI and WC between 1988-2014**

Risk Level: ☒ Minimal Risk ☐ More than Minimal Risk

Level of Review: ☒ Delegated Review ☐ Full Committee Review

I am writing to inform you that this research project, **"Secular trends in obesity-associated health risks by BMI and WC between 1988-2014"** has received ethics review and approval by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines.

Note that approval is granted for one year. Ongoing research – research that extends beyond one year – must be renewed prior to the expiry date.

Any changes to the approved protocol must be reviewed and approved through the amendment process by submission of an amendment application to the HPRC prior to its implementation.

For further information on researcher responsibilities as it pertains to this approved research ethics protocol, please refer to the attached document, **"RESEARCH ETHICS: PROCEDURES to ENSURE ONGOING COMPLIANCE".**

Yours sincerely,

Alison M. Collins-Mrakas M.Sc., LLM
Sr. Manager and Policy Advisor,
Office of Research Ethics

YORK UNIVERSITÉ UNIVERSITY **OFFICE OF RESEARCH ETHICS (ORE)**

Memo

To:	Jennifer Kuk, School of Kinesiology and Health Science
From:	Alison M. Collins-Mrakas, Sr. Manager and Policy Advisor, Research Ethics
Issue Date:	Not set
Expiry Date:	Not set
RE:	**Importance of BIA measure assumptions** **Certificate #: e2012-283**

I am writing to inform you that the Human Participants Review Sub-Committee has reviewed and approved the above project.

Yours sincerely,

Alison M. Collins-Mrakas M.Sc., LLM
Sr. Manager and Policy Advisor,
Office of Research Ethics

YORK U UNIVERSITÉ UNIVERSITY **OFFICE OF RESEARCH ETHICS (ORE)**

Memo

To:	Jennifer Kuk, Kinesiology and Health Science
From:	Alison M. Collins-Mrakas, Sr. Manager and Policy Advisor, Research Ethics
Issue Date:	Wed May 06 2015
Expiry Date:	Fri May 06 2016
RE:	**Are different accelerometer cut-offs needed to accurately determine physical activity intensity for different populations?** **Certificate #: e2015 - 145**

Yours sincerely,

Alison M. Collins-Mrakas M.Sc., LLM
Sr. Manager and Policy Advisor,
Office of Research Ethics

Appendix B: Questionnaires used for Study 2 & 3

1. Study Participant Data Collection Form – Study 2

Subject ID: ____ Date:______________

Age:_____________________ Sex: _________________________________

Height:__________________ Weight: ______________________________

Visit 1:

- ☐ Time since last Exercise bout: _________ hr
- ☐ Time since last meal ________ hr
- ☐ Water drank 3 L of water yesterday? Y N
- ☐ Time since last drink: ____________hr
- ☐ Time since Bladder last voided: ________ hr

Condition	BIA TANITA BC	BIA TANITA TBF	BIA OMRON	Urine Specific Gravity
Water (1)				
Control (3)				
Non-voided bladder (2)				
Exercise (4)				

Exercise Heart Rate: ___________ bpm

Length exercised: ______________ min

Speed, incline

Visit 2:

- ☐ Not Exercised
- ☐ Time fasted ___________
- ☐ Water drank (12 hrs)_________
- ☐ Not Drink water hrs __________
- ☐ Bladder not voided min. 2 hrs____________

Condition	BIA TANITA BC	BIA TANITA TBF	BIA OMRON	Urine Specific Gravity
Dehydrated				
After meal				

Amount of fluids drank:______________________________

Amount of Pizza Eaten:______________________________

2. **The Importance of BIA Measure Assumptions Questionnaire – Study 2**

Participant ID:____________ Date: __________

Name:________________________ Phone Number:______________________

Email:________________________

Please answer the following questions:

Gender: ☐ Female ☐ Male

Age: ______ Date of Birth: ___________ (mm/dd/yyyy)

Years and level of Education: _________________________

Ethnicity:

- ☐ Aboriginal ☐ African
- ☐ Asian
- ☐ Caribbean ☐ European
- ☐ Latin, Central, & South American ☐ Middle Eastern
- ☐ Pacific Islander
- ☐ Other (please specify):______________________________

How much water do you consume per day on average?________ Cups/Litres

How much fluids do you consume per day on average?________ Cups/ Litres

When was the last time you drank fluids? ______(time) ______(date) ______(amt)

When was the last time you ate? ______(time) ______(date)

What was the last thing you ate? ______

Please list current medications you are taking:

____

____

Would you be willing to take part in other studies?

☐ Yes

☐ No

3. Anthropometric data questionnaire -Study 2

Anthropometric Data

Participant ID:____________ Date:_______________

(mm/dd/yyyy)

Skinfolds (mm)

Location	1	2	3	Mean
Triceps				
Biceps				
Subscapular				
Iliac Crest				
Medial Calf				
			SUM:	

Circumference

Location	1	2	Mean
Waist			
Hip			
Ankle			
Bicep			
Wrist			
Chest			

Waist Diameter 1) _____________ 2)______________ Mean ___________

4. **Study Participant Data Collection Form (Visit 1) – Study 3**

Subject ID: _______________

BMI __________________

Visit date: __________________ Age: ____________years Sex: _________

Height: _________m _________ft.inch Weight: __________kg __________lbs

% Body Fat __________________(Omron) __________________(Tanita)

Limb Length (cm)

- Knee Height (above patella to floor)**:** ___________________
- Leg length (ASIS to floor): __________________
- Thigh length (inguinal ligament to top of patella): __________________
- Trunk length (top of trap to chair): __________________

Circumferences (cm)	**1**	**2**
• Waist (iliac crest):	____________	_____________
• Hip (Max Gluteal):	____________	_____________
• Thigh (Right Proximal):	____________	_____________
• Bicep (Right Midpoint):	____________	_____________

Body Diameters (cm)

- Abdominal depth: __________________
- Hip width :__________________

Stride length (step count per 5 meters): ____________steps/5m

Bruce Treadmill Test (Cardio coach monitor–modified Bruce protocol)

- VO2 max: _____________ml/kg/min Peak HR: ____________beats/min

Accelerometer (7-day wear)

- Start date: ____________________2017 End date: 2017

Notes: ____

____

Bruce Treadmill Test (Cardio coach monitor–modified Bruce protocol)

Warm up- for different speed, get the intial speed at a RPE score of 4-6.

- Real time: At start of VO2 test___________

- Timer time at start: __________
- Total test time (when the test is complete): ________ min:sec

Stage 1 (0-3 mins):

- speed: _______________ mph gradient:____________

Stage 2 (3-6 mins):

- speed: _______________ mph gradient:____________

Stage 3 (6-9 mins):

- speed: _______________ mph gradient:____________

Stage 4 (9-12 mins):

- speed: _______________ mph gradient:____________

Stage 5 (12-15 mins):

- speed: _______________ mph gradient:____________

Stage 6 (15-18mins):

- speed: _______________ mph gradient:____________

VO2 max: _____________ml/kg/min Peak HR: ____________beats/min

Study Participant Data Collection Form (Visit 2)

Visit date: ____________________ 2017 **Subject ID**: ________________

Treadmill Walk/jog

- ____________(2mph, 1% grade, 3 minutes):________________
- ____________(3mph 1% grade, 3 minutes) :________________

HR Targets (beats/min)

- MVPA intensity (≥50% of VO2max): ________________
- Light intensity (30-35% of VO2max): ________________

Field Testing

- Total test time: ________________

MVPA LIGHT PA

Bout	Stopwatch Time	Real Time	Bout	Stopwatch Time	Real Time
1			1		
2			3		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
10			10		

Appendix C: Additional Related Publications

1. Yu WW, **Randhawa AK,** Blair SN, Sui X, Kuk JL (2019). Age- and sex- specific all-cause mortality risk greatest in metabolic syndrome combinations with elevated blood pressure. *(accepted, 8299f2989ac8b6 PLoS ONE).*

2. Raiber L, **Randhawa AK,** Christensen R, Jamnik VK, Kuk JL (2018). Do moderate to vigorous intensity accelerometer count thresholds correspond to relative moderate to vigorous intensity physical activity? (*apnm-2017-0643*, *Applied Physiology, Nutrition and Metabolism*)

3. Parikh JS, **Randhawa AK,** Wharton S, Edgell H, Kuk JL (2018). The association between antihypertensive use and blood pressure is influenced by obesity. *(Journal of Obesity, https://doi.org/10.1155/2018/4573258*

4. **Randhawa AK,** Parikh JS, Kuk JL (2017).Trends in medication use by body mass index and age between 1988 and 2012 in the United States. *PLoS ONE* Sep 20;12(9):e0184089. doi: 10.1371/journal.pone.0184089.

5. Brown RE, **Randhawa AK**, Canning KL, Fung M, Jiandani D, Kuk JL (2017). Waist Circumference at five common measurement sites in normal weight and overweight adults: which site is most optimal? *(COB-17-OA-0037.R, Clinical Obesity)*

6. Jiandani D, **Randhawa AK**, Brown RE, Hamilton R, Matthew AG, Kuk JL, Alibhai SMH, Tufts E and Santa Mina D (2015). The effect of cycling on prostate-specific antigen (PSA) levels: a systematic review and meta-analysis. *Prostate Cancer and Prostatic Diseases* 18, 208-212 doi:10.1038/pcan.2015.16

7. Sohni S, **Randhawa AK,** Wharton S, Kuk JL. Association maternal factors and weight loss in adult offspring (under preparation, 2019)

8. Swaze S, Sohni S, **Randhawa AK,** Zaki K, Kuk JL. Taste Difference of organic vs non-organic food (under preparation, 2019)