COMPARING MEASURES OF OBESITY IN RELATION TO HEALTH CARE USE IN ADULTS FROM THE CANADIAN LONGITUDINAL STUDY ON AGING

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COMPARING MEASURES OF OBESITY IN RELATION TO HEALTH CARE USE IN ADULTS FROM THE CANADIAN LONGITUDINAL STUDY ON AGING

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Title: Comparing Measures of Obesity in Relation to Health Care Use in Adults from the Canadian Longitudinal Study on Aging

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Abstract

Background:

Obesity has been associated with increased health care use, but it is unclear whether this is consistent across all measures of obesity. The objectives of this thesis were to compare obesity defined by four anthropometric measures, body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), and percent body fat (%BF), and to estimate their associations with health care use among Canadian adults.

Methods:

A secondary data analysis was conducted from 30,097 individuals aged 45-85 years from the Canadian Longitudinal Study on Aging. Anthropometric measures were collected by trained research assistants and %BF, the reference standard, was measured using dual-energy x-ray absorptiometry. Obesity was defined as BMI≥30.0 kg/m^2, WC≥88cm for females and ≥102cm for males, WHR≥0.85 for females and ≥0.90 for males, and %BF>35% for females and >25% for males. Approximately 18 months after baseline data collection, self-reported health care use in the past 12 months was collected, including any contact with a general practitioner, medical specialist, emergency department, and being a patient in a hospital overnight. Pearson correlation coefficients and sensitivity and specificity analyses were conducted to compare anthropometric measures to %BF. Relative risks and risk differences were calculated for measures of health care use, adjusted for sex, age, education, income, urban/rural, marital status, smoking status, and alcohol use. Secondary analyses were also stratified by sex and age.

Results:

The prevalence of obesity defined by BMI was 29%, by WC was 42%, by WHR was 62%, and by %BF was 73%. BMI and WC were highly correlated with %BF (r=0.75 and r=0.70, respectively) and WHR was weakly correlated with %BF (r=0.29). BMI and WC cut points demonstrated high specificity (>93%) and lower sensitivity (<58%) in predicting obesity defined by %BF. WHR cut points demonstrated high sensitivity (95%) and lower specificity (28%) in males, but lower sensitivity (44%) and high specificity (83%) in females in predicting %BF-defined obesity. There was an increased relative and absolute risk of health care use for all measures of obesity and all health care services. For example, WC-defined obesity was associated with increased relative risk (RR) of hospital overnight stay (RR: 1.40, 95% CI: 1.28-1.54) and the risk difference (per 100) was 2.6 (95% CI:1.9-3.3). The risk of health care use was similar amongst females and males with obesity although relative risks and risk differences attenuated in the oldest adult group aged 75 and older compared to the youngest group aged 45-54.

Conclusion:

The prevalence of obesity among Canadian adults varied substantially by anthropometric measure. BMI and WC have stronger correlations and concordance with %BF than does WHR, however all measures were positively associated with increased health care use. Further research should be conducted on obesity cut points to discern the best measure to predict health care use.

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I would like to primarily thank my supervisor, Dr. Laura N. Anderson, for providing me with ongoing support, mentorship, and expertise in obesity research during my thesis work. She has provided me with an immeasurable amount of guidance, encouragement, and resources to achieve the most out of my master's degree. I would like to express my gratitude to my committee members: Dr. Lauren E. Griffith and Dr. G. Emmanuel Guindon. They have shared with me their expertise in epidemiology and health economics and have provided feedback that has not only improved the quality of my work but has also helped me grow as a researcher.

A thank you is also extended to my colleague and lab member, Vanessa De Rubeis, for her encouragement and eagerness to offer help. Thanks to the researchers at the Canadian Longitudinal Study on Aging (CLSA) at McMaster for their guidance and assistance with statistical code, specifically Henry (Hon Yiu), Dr. Alexandra Mayhew, and Rumaisa Aljed. Additionally, this research was made possible using the data/biospecimens collected by the CLSA. Funding for the CLSA is provided by the Government of Canada through the Canadian Institutes of Health Research (CIHR) under grant reference: LSA 94473 and the Canada Foundation for Innovation. This research has been conducted using the CLSA Baseline Comprehensive Dataset version 4.0 under Application Number 19CA004. The CLSA is led by Drs. Parminder Raina, Christina Wolfson and Susan Kirkland, and lastly, I appreciate the 50,000 Canadians that have participated in this study and continue to do so.

I would like to extend a final thanks to my family and friends who have reinforced and encouraged me. Thank you to my parents, Franca and Sam, and my brother, Vincent, for their endless support, both emotionally and financially. Thank you to my partner, Tyler, for always keeping me grounded and believing in me.

Preface

This master's thesis contains a manuscript that will be submitted to a journal for publication and is formatted as a "sandwich" thesis. The first chapter gives an in-depth background of my thesis topic and reviews previous literature. The second chapter is the manuscript, which contains an introduction, methods, results, and discussion. The third chapter contains additional results that were not included in the manuscript, followed by the fourth chapter that concludes this thesis. At the time of submission of this thesis, the manuscript is being prepared for submission to a peer-reviewed journal. A full table of contents is provided on the next page.

Disclaimer

The opinions expressed in this manuscript are the author's own and do not reflect the views of the Canadian Longitudinal Study on Aging.

Table of Contents

List of Tables and Figures

List of Abbreviations and Symbols

BMI	Body mass index
CI	Confidence interval
CLSA	Canadian Longitudinal Study on Aging
cm	Centimetres
DXA	Dual-energy x-ray absorptiometry
ED	Emergency department
GP	General practitioner
HCU	Health care use
kg	Kilograms
m	Metres
RR	Relative risk
r	Pearson correlation coefficient
WC	Waist circumference
WHO	World Health Organization
WHR	Waist-to-hip ratio

Declaration of Academic Achievement

I, Alessandra T. Andreacchi, declare this thesis work to be my own. I assisted with creating the study design, performed the statistical analysis, and wrote this thesis document, including the manuscript.

My supervisor, Dr. Anderson, led the creation of the study design and provided detailed guidance and feedback throughout the whole thesis process. Along with my thesis committee members, Dr. Griffith and Dr. Guindon, all three members provided feedback regarding the study design and on the manuscript and thesis document, in addition to editing and contributing to writing certain sections of the manuscript. Therefore, Dr. Anderson, Dr. Griffith, and Dr. Guindon are listed as co-authors of the manuscript.

Chapter 1: Background and Literature Review

1.1 Obesity in Canada

Obesity is a disease commonly defined as an excess accumulation of body fat that adversely affects a person's physical, mental and/or social health.[1] Obesity in Canadian adults is a public health concern as the prevalence is high and has steadily increased over the past four decades.[1] The 2016-17 Canadian Health Measures Survey classified 27% of Canadian adults as having obesity and 34% as overweight based on body mass index (BMI).[2]

Obesity management and prevention strategies have become a priority for public health since obesity in the general population is a well-known risk factor for many morbidities such as cardiovascular disease, type 2 diabetes, musculoskeletal disorders, and various forms of cancer, as well as premature mortality.[1,3,4] Additionally, obesity may affect an individual's quality of life, mental health, and lead to inequities in employment, education, and health care settings.[1,5]

Obesity is a large burden on the Canadian economy as it accounts for many direct health care costs, such as general practitioner and specialist visits, hospitalizations, and medications, in addition to indirect costs, such as costs related to disability, reduced quality of life, and premature death.[1] Obesity accounted for at least $7 billion in direct and indirect health care costs in Canada in 2006,[6] with an aggregated annual cost of obesity in Canada up to $11.08 billion.[7] These costs on Canada's publicly funded health care system may worsen in the future due to the large aging population. In 2014, there were over 6 million Canadians aged 65 or older and by 2030, the number is projected to rise to over 9.5 million; an increase from 15.6% to 23% of the population.[8]

1.2 Measuring Obesity

1.2.1 Body Mass Index

Most epidemiologic studies use BMI as an indicator of overweight and obesity in adults.[9] BMI is calculated from weight divided by the square of height (kg/m^2) and is a relatively simple anthropometric measure.[9] *The Canadian Guidelines for Healthy Weights* was released in 1988, which presented a weight classification system for use in Canada and was intended to classify BMI in people aged 20 to 64 years.[9] Then in 2000, the World Health Organization (WHO) released recommendations for obesity classification which Health Canada has adopted as *the Canadian Guidelines for Body Weight Classification in Adults* in 2003.[9,10] These updated and current guidelines are intended to assess the health risk of obesity in people aged 18 and over with no upper age limit.[9]

The current WHO and Health Canada BMI classification systems categorize BMI <18.5 kg/m^2 as 'underweight', BMI 18.5-24.9 kg/m^2 as 'normal weight', BMI 25.0-29.9 kg/m^2 as 'overweight', and BMI $\geq$ 30.0 kg/m^2 as 'obese'.[9,10] The obese category can be further subdivided into 'class I', 'class II', and 'class III' obesity with BMI of 30.0-34.9, 35.0-39.9, and ≥40.0 kg/m^2, respectively.[9,10] BMI is the most commonly used measure since weight and height are relatively easy to record and are done fairly accurately.[11,12] BMI is also easily self-reported, although height tends to be over-reported while weight is under-reported.[13] These biases cause BMI to be under-reported compared to BMI calculated from measured height and weight, and this under-reporting is important to consider since population health surveys have often used self-reported measures to calculate overweight and obesity prevalence estimates.[13–15]

Although BMI is a simple and convenient measure, it is a crude index of body composition, especially in the overweight category.[16] When using BMI, it is assumed that at a given height, higher weight is associated with increased body fat.[17] This assumption has brought much controversy to obesity researchers as BMI is unable to differentiate between fat, muscle, and skeletal weight.[16] Excess body fat accumulates differently amongst people and BMI is not able to differentiate between the type of fat, such as the more harmful visceral fat mass or the relatively less harmful subcutaneous fat.[18] Therefore, individuals with a similar BMI may have different body compositions and more importantly, markedly different metabolic profiles.[16]

Furthermore, there are implications for using BMI as an indicator of obesity in older adult populations. As individuals age, they experience a reduction in muscle mass and bone mass, while fat mass increases.[18,19] In particular, there is an age-dependent increase in visceral abdominal fat and a decrease in subcutaneous abdominal fat even when BMI does not change.[18] Older adults also experience age-related height decline that will inaccurately register an increase in BMI when weight remains the same.[20] An American population-based study using the 1999-2004 National Health and Nutrition Examination Surveys highlighted the poor diagnostic accuracy of BMI in identifying obesity in older populations.[21] Other anthropometric measures, such as waist circumference (WC), waist-to-hip ratio (WHR), or direct measures of percent body fat (%BF) may be better indices of obesity-related health risk than BMI alone, but are not always feasible due to time, resource, and cost constraints.[22]

1.2.2 Waist Circumference

WC is another common anthropometric measure used to identify those with increased health risk associated with excess abdominal fat.[1] WC is a better indicator of the amount of visceral fat, and considerable evidence demonstrates that individuals classified as overweight or obese with abdominal obesity are at risk for cardiometabolic diseases.[16,23] As per the current WHO and Health Canada guidelines, the obesity-related WC cut points are ≥88cm for females and ≥102cm for males.[9,10] Many organizations and guidelines, such as Health Canada, WHO, and the National Heart, Lung, and Blood Institute of the National Institutes of Health use BMI in conjunction with WC to predict obesity-related health risk.[9,10,16,24] The combined BMI and WC classification system indicates that the health risk increases in a graded fashion when moving from the normal weight BMI category through obese BMI categories, and that within each BMI category, men and women with high WC values are at a greater health risk than are those with normal WC values.[24]

1.2.3 Waist-to-Hip Ratio

WHR is another measure used to assess abdominal obesity, although the use of WHR or WC as the best measure has been debated.[16] The most commonly accepted cut points for increased abdominal fat are WHR $\geq$0.85 for females and $\geq$0.90 for males.[25] The use of WC has been recommended over WHR by Health Canada and in many guidelines as a better marker of abdominal fat content for many reasons, and the *Canadian clinical practice guidelines on the management and prevention of obesity in adults and children* provides some rationale for the recommended use of WC.[10,16,24] First, WHR is an estimate of the 'relative' accumulation of abdominal fat, while WC is an 'absolute' measure.[16] This means that two individuals with different BMI values could have similar WHRs but differing amounts of visceral fat, and thus variation in their metabolic health risk profile. The two individuals would have very different WCs and therefore, different total abdominal fat. Secondly, any weight loss resulting in a loss of abdominal fat will be reflected by a decrease in WC but not necessarily by a change in WHR.[16] Third, WHR requires two measurements which introduces more potential for error than WC.[16] Lastly, WC is a limited measure in assessing extremely obese patients since changes in such large WC values are more difficult to interpret, although the change in this variable over time is a better index for change in abdominal fat than any changes in WHR.[16]

1.2.4 Percent Body Fat

Body fat can be directly measured using techniques such as dual-energy X-ray absorptiometry (DXA), hydrostatic weighing, air-displacement plethysmography, and bioelectrical impedance analysis.[26] Validation studies have indicated that %BF from DXA can be considered the gold standard of assessing adiposity.[21,27] Universal cut points for body fat are lacking, although commonly reported cut points in literature and cut points proposed by the WHO to define obesity for %BF are >35% for females and >25% for males.[28] Age, sex, and race-specific cut points have also been proposed in the literature.[29] Despite the accuracy of techniques like DXA, they are rarely used in clinical settings or population-based research because it is extremely costly and time consuming.[30]

1.3 Relationship Between BMI, WC, WHR, and %BF

Multiple measures can be used to define obesity and it is important for obesity research to understand the similarities and differences amongst them. Most often, the validity of various anthropometric measures has been assessed using %BF as the reference or 'gold' standard.[21] Researchers have explored the relationship between an anthropometric measure, such as BMI, and the reference standard, %BF, most commonly by assessing their correlation or by assessing diagnostic performance using measures such as sensitivity and specificity. A review of the literature was conducted and identified a 2010 systematic review and meta-analysis that assessed the diagnostic performance of BMI to detect %BF from 25 studies. No known systematic reviews were found that compared other measures, such as WC or WHR, to %BF. Table 1 summarizes the systematic review plus nine additional studies (which were not included in the systematic review) that assessed the diagnostic performance or correlation between BMI, WC, and/or WHR compared to %BF.

We identified one systematic review of 25 articles and eight primary research articles that compared either BMI, WC, and/or WHR to %BF in adult and older adult populations.[21,26,31–37] Similar to the studies in the systematic review, half of the primary research studies we identified (n=4) examined only the relationship between BMI and %BF.[31,32,36,37] Three studies examined the relationship between BMI, WC, and %BF,[21,33,35] and one study examined the relationship between BMI, WC, WHR, and %BF.[34] Most studies (n=5) were American[21,31,32,35,37] and three studies focused exclusively on women.[31–33] It is known that the relationship between BMI and %BF is non-linear and curved,[38,39] although five studies used linear correlation coefficients, such as Pearson's correlation, to assess the relationship.[32–36] As in the systematic review, almost all of the additional studies (n=7) performed analyses that focused on diagnostic accuracy, such as sensitivity, specificity, and receiver operating curves.[21,31–34,36,37]

Among the studies that assessed correlations (n=5), the linear correlation coefficients ranged from 0.66-0.87 for the relationship between BMI and %BF (n=5),[32–36] from 0.63-0.86 for the relationship between WC and %BF (n=3),[33–35] and was 0.48 for the relationship between WHR and %BF (n=1).[34] BMI and WC had similar correlations with %BF in the three studies that compared both BMI and WC with %BF.[33–35] Two of these studies also compared the relationship between BMI and WC and found that they were either similarity or more strongly correlated with each other than with %BF.[34,35]

Amongst all studies in Table 1, the sensitivity and specificity values varied as the obesity cut points used for each measure also varied between studies. Overall, specificity was greater than sensitivity when BMI or WC estimated %BF. In the systematic review of 25 articles (n=31,968 individuals), commonly used BMI cut points to diagnose obesity yielded a pooled sensitivity to detect high adiposity of 50% (95% CI: 43%-57%) and a pooled specificity of 90%

(95% CI: 86%-94%).[26] Only one cross-sectional Iranian study (n=1,360; mean age 33 ±12) compared the diagnostic accuracy of BMI (≥24.38 kg/m^2), WC (≥82.25 in women and ≥85.75 in men) and WHR (≥0.82 in women and men) to %BF (undefined cut points) and found that BMI showed the most accuracy for estimating %BF.[34] Although there is a promising relationship between continuous measures of BMI and %BF, when cut points are used to define obesity, BMI underestimates the 'true' prevalence of obesity defined by %BF and may poorly identify obesity in older adults.[21,31] An American study with older adults aged 60 and older using data from the National Health and Nutrition Examination Surveys 1999-2004 (n=4,984) investigated the diagnostic performance of BMI (≥30 kg/m^2) and WC (≥88cm for females and ≥102 cm for males).[21] Their findings suggests that traditional measures, such as BMI and WC, poorly identify obesity, defined by %BF (≥35% in females and ≥25% in males), in adults 60 years and older.[21]

1.4 Differences in Obesity by Sex and Age

The prevalence of obesity varies across sex and age.[2,40,41] Data from the 2014/2015 Canadian Health Measures Survey reveals that the prevalence of obesity based on BMI is slightly higher in men than women (29.4% vs 27.8%), although women have higher rates of class III obesity than males (5.5% vs 2.6%).[40] The 2016/2017 Canadian Health Measures Survey also reveals that the prevalence increases with age, from 20% in 18-39 year old adults, to 31% in 40-59 year old adults, to 33% in 60-79 year old adults.[2] In particular, reports from Statistics Canada and the Public Health Agency of Canada, based on Canadian Community Health Survey data, indicate that the prevalence of obesity increases to about age 65, where after the prevalence declines.[41,42]

There is also plenty of debate regarding whether an 'obesity paradox' exists among the older adults.[17,43,44] Despite the known positive association between obesity and mortality in the general population,[4] many studies claim there exists an 'obesity paradox', where high BMI in individuals with chronic disease appears to be protective and is associated with a lower risk of mortality, while low BMI is associated with higher mortality relative to normal weight.[17,44] The relationship between BMI and mortality in the elderly may be U-shaped or reverse J-shaped, where the risk of mortality is highest at extreme obesity or underweight.[17,43] There have been many proposed explanations for this so-called paradox. One of which is called the 'survival effect', such that overweight and obese individuals who survive to old age may have characteristics that are protective of the adverse effects of overweight and obesity, while individuals who are more susceptible to the complications of obesity may have already died.[17] Since obesity-related conditions take years to develop, another explanation for the obesity paradox is that these health risks and comorbidities in elderly with late onset obesity have not yet been able to manifest.[17,43] Conversely, methodological explanations that discredit the obesity paradox are surfacing, such as misclassification bias due to using BMI as a measure of obesity, reverse causation, or collider stratification bias.[44] More research with thorough methodological rationale is needed to better understand the complexities of obesity in older populations.

1.5 Obesity and Health Care Utilization

1.5.1 Andersen Model of Health Care Utilization

It is important to understand the factors that lead to the utilization of health services, especially as they relate to obesity. The Behavioural Model of Health Services Use is a widely acknowledged model developed by Ronald M. Andersen that suggests three important factors lead to service use.[45,46] Individuals use health services based due to their predisposition to use services (predisposing factors), factors that enable or impede use (enabling factors), and their need for care (need factors).[45] Predisposing factors include demographic characteristics, such as age and sex, social structures, such as education and ethnicity, and health beliefs which influence health and the use of resources.[47] Enabling factors include personal/family and community resources that provide a means to healthcare services, which includes income, having a regular doctor, and marital status.[47] Need factors represent a need for healthcare services, which includes perceived need, such as self-reported health, as evaluated need, such as diagnosed chronic diseases, smoking status, and alcohol use.[47] In this thesis project, Andersen's Behavioural Model serves as a guide in selecting the covariates that may affect the relationship between obesity and health care use (HCU).

1.5.2 Previous Studies on the Association Between Obesity and Health Care Use

Obesity is associated with increased HCU and costs, but it is unclear which type of service is used most, for example, outpatient use including visits to a general practitioner or specialist, or inpatient use including visits to the emergency room or overnight stay in hospital.[1,7] Further, the measures of obesity, such as BMI, WC, WHR or %BF, that are most strongly associated with increased HCU are not well understood. Table 2 provides a review of the literature on the association between obesity and HCU.

We identified 19 studies that evaluated the association between obesity and HCU in adults using a variety of different statistical approaches. Most studies (n=16) that examined the relationship between obesity and HCU only used BMI to define obesity.[48–64] Only two studies included in this literature review used WC in addition to BMI in their analyses.[65,66] For example, a study from Spain that investigated the association between both BMI and WC and visits to primary care physicians in adults 60 years and older found an increase in the odds of primary care visits among male adults with BMI-defined obesity (≥ 30 kg/m^2) (Odds Ratio (OR): 1.35, 95% CI: 0.92-1.97), and also when using WC (>102 cm in men, >88 cm in women) to define obesity (OR: 1.28, 95% CI: 1.02-1.62).[66] The results were higher among females, with BMI-defined obesity (OR: 1.43, 95%: CI 1.04-1.98) and WC (OR: 1.36, 95% CI: 1.06-1.73) both associated with primary care visits.[66] These associations were adjusted for age, educational level, size of place of residence, tobacco use, alcohol consumption, and presence of chronic disease.[66]

Similar results were observed in a study from the Netherlands among adults 18-65 years of age that investigated the association between BMI and WC, and HCU.[65] Obesity defined by BMI (≥ 30 kg/m^2) was associated with primary care visits (OR: 1.36, 95% CI: 1.15-1.61) as well as obesity defined by WC (>102 cm in men, >88 cm in women) (OR: 1.24, 95% CI: 1.03-1.42).[65] Significant increases in hospitalizations were also demonstrated using BMI- (OR: 1.60, 95% CI: 1.34-1.91) and WC-defined obesity (OR: 1.63, 95% CI: 1.40-1.90).[65] There were no apparent trends in the magnitude of the associations for BMI- and WC-defined obesity although all of these associations demonstrated slightly smaller confidence intervals when using WC to define obesity rather than BMI. More sex- and age-stratified research is needed on the associations between various anthropometric measures and HCU to truly discern the best measure for older adult populations.

The literature on the association between obesity and HCU needs to be better developed as there are many limitations in the methodology of existing research. For example, most of previous literature has utilized self-reported height and weight to calculate BMI.[48–51,54,56,58–60,63,64] A multitude of research has already demonstrated that height tends to be overestimated while weight is underestimated, leading to an underestimation of BMI, especially in women.[13–15] Additionally, there is a broad and inconsistent range of covariates included in the analyses of past studies. Some researchers argue against controlling for chronic conditions, indicating that they are mediators on the pathway between obesity and HCU,[48,58,63] while others have controlled for them as this may help determine the independent effect of obesity on HCU.[48,52–55,59,61,66] Self-rated health is an important need factor, as defined by Andersen's Behavioural Model of Health Services Use, that has proven to be an important predictor of HCU[45,46] and obesity.[51,67] Most studies in this literature review did not consider any metric of self-rated health in their analyses,[50,53,58–66] which may be because some researchers believe self-rated health is also a mediator[51,58] or due to the use of survey data for secondary data analyses which limits the type of variables that can be included as covariates or controlled for in analyses. Finally, many of the existing studies have not focused on or included older adults in their study populations. Out of the four Canadian studies included in this literature review, two studies by Twells and colleagues and one study by Trakas and colleagues, using data from the 2001 Canadian Community Health Survey and the 1994 National Population Health Survey, respectively, investigated the association between BMI and various indicators of HCU in adults only up to 64 years of age.[48,49,51] The fourth Canadian study by Chen and colleagues used data from the 2003 Canadian Community Health Survey, but was only able to investigate the association between BMI and inpatient stay/inpatient length of stay in individuals 20 years and older.[50] The lack of research on older adults prevents the relationship between obesity and HCU from being explored in a population where the complications of obesity are multifaceted and adiposity is not accurately examined.[30,44]

1.5.3 Summary

Overall, there are many gaps in the current literature on obesity and HCU in adults and older adults that need to be addressed. Many studies have only used BMI to define obesity, while other anthropometric measures, such as WC, WHR, and %BF, have rarely been considered in literature, if considered at all. Self-reported anthropometric measures are most commonly used, which may introduce measurement error and lead to misclassification of obesity.[14] As well, many important variables have not been considered in past studies, such as presence of chronic conditions or self-reported health, which may have an important impact on the association between obesity and HCU. Finally, many studies have not stratified by age or sex, which prevents this association from being examined as men and women age. To our knowledge, this study is the first that will go beyond only using BMI to classify obesity to comprehensively investigate the association between multiple anthropometric measures and inpatient and outpatient indicators of HCU in a Canadian adult and older adult population.

1.6 Thesis Objectives

Primary Objective

The primary objective of this thesis was:

1) To evaluate the association between anthropometric measures, including BMI, WC, WHR, and %BF, with health care use in the past 12 months among community-living Canadians aged 45-85 years of age. Health care use included:

(a) any visits with a general practitioner/family physician;

(b) any visits with a medical specialist (such as cardiologist, gynecologist, and psychiatrist);

(c) any visits to an emergency department;

(d) having been a patient in a hospital overnight.

Secondary Objective

The secondary objectives were:

2) To investigate if the associations between the anthropometric measures and health care use differed by sex and by age.

3) To evaluate the associations between anthropometric measures, including BMI, WC, WHR and %BF.

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1.8 Tables

Table 1. Brief literature review of the validity of anthropometric measures, comparing BMI, WC, and/or WHR, to %BF (n=9).

Author (year)	Country	Sample Size	Age Range	Correlation Between BMI & BF	Obesity Cut Point	Sensitivity (%)	Specificity (%)
Okorodudu (2010) * systematic review & meta-analysis	United States (25 articles from 12 countries)	31,968	N/A	N/A	- calculated pooled sensitivity and specificity from studies that used similar cut-points	50% (43-57)	90% (86-94)
Blew et al (2002)	United States	317 * females only	40-66	0.81	- BMI ≥30 - %BF > 35%	20.4	100
Shah et al (2012)	United States	1,393	18+	N/A	- BMI ≥30 - %BF > 35% for females, >25% for males	- females: 51 - males: 35	females: 95 males: 100
Silva et al (2017)	Brazil	501	17+	0.72	- BMI ≥27.08 for females, ≥27.5 for males - %BF > 35% for females, >25% for males	- females: 83.3 - males: 68.3	females: 87.5 males: 86.3
Banack et al (2018)	United States	1,329 * females only	53-95	N/A	- BMI ≥30 - %BF > 35%	32.4 (29.5-35.3)	99.3 (98.6-99.8)

Author (year)	Country	Sample Size	Age Range	Correlation with %BF		Obesity Cut Point	Comparing BMI to %BF		Comparing WC to %BF	
				BMI	WC		Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
Chen et al (2006)	China	1,122 * females only	41-63	0.66	0.63	- BMI ≥24 - %BF > 34% - WC ≥80cm	69 (65-72)	76 (72-81)	68 (64-71)	76 (72-80)
Flegal (2009)	United States	12,901	20+	- females: 0.84 (20–39 yrs) to 0.72 (+80 yrs) - males: 0.79 to 0.72	- females: 0.80 to 0.65 - males: 0.86 to 0.74	- used age and sex-specific percentile values of BMI and WC that correspond to %BF	N/A	N/A	N/A	N/A
Batsis et al (2016)	United States	4,984	60+	N/A	N/A	- BMI ≥30 - %BF > 35% for females, >25% for males - WC ≥88cm for females, ≥102cm for males	- females: 38.5 - males: 32.9	- females: 98.8 - males: 99.6	- females: 80.5 - males: 59.7	- females: 85.5 - males: 95.5
Ehrampoush et al (2016)	Iran	1,360	mean age 33±12	0.87	0.73	- BMI ≥24.4 - %BF: undefined - WC ≥82.3cm for females, ≥85.8cm for male - WHR ≥0.82	- females: 63.9 - males: 88.1	- females: 89.8 - males: 81.3	- females: 66.9 - males: 86.9	- females: 78.9 - males: 75.0
				WHR vs %BF= 0.48			**WHR vs %BF: Sensitivity (%):** - females: 67.2, males: 95.2		**WHR vs %BF: Specificity (%):** - females: 56.2, males: 67.3	

Table 2. Literature review of the association between anthropometric measures and HCU (n=19).

Author (year)	Country	Study Design	Sample Size	Age Range	Obesity Measure	HCU Outcome	Covariates	Association
Trakas et al (1999)	Canada	cross-sectional	12,318	20-64	BMI ≥27 (self-reported)	1) # of GP visits 2) # of GP and specialist visits 3) # annual hospital admissions * reported for the past year	age, sex, region, smoking status, physical activity level education level, household income level	1) OR: **1.40 (1.29-1.52)** 2) OR: **1.32 (1.22-1.43)** 3) OR: **0.83 (0.72-0.96)**
Chen et al (2007)	Canada	cross-sectional	113,603	≥20	BMI ≥30 (self-reported)	1) cumulative incidence of being an inpatient during the past 12 months 2) length of inpatient stay (1 night, 2-3, 4-7, >7)	age, marital status, household size, number of bedrooms, income adequacy, educational level, immigrant status, visible minority, marital status, smoking status, alcohol use, exercise and allergy history	Women: 1) OR **1.25 (1.14-1.37)** 2) OR for 1-night stay: **1.34 (1.13-1.59)**, OR for 2-3 nights: 1.16 (0.99-1.37), OR for 4-7 nights: **1.45 (1.21-1.73)**, OR for >7 nights 1.21 (0.99-1.47) Men: 1) OR **1.24 (1.10-1.40)** 2) OR for 1-night stay: 1.05 (0.85-1.28), OR for 2-3 nights: **1.56 (1.22-2.01)**, OR for 4-7 nights: **1.41 (1.11-1.80)**, OR for >7 nights **1.27 (1.01-1.60)**
Twells et al (2010)	Canada (Newfound-land and Labrador)	cross-sectional	2,345	20-64	BMI i) 30-34.9 ii) ≥35 (self-reported)	1) % with a regular doctor 2) # of visits with a GP 3) % hospitalized overnight 4) # of nights spent in hospital * reported for the past 12 months	N/A	1) i) 77.9% ii) 80.1% 2) median (25th, 75th %ile) i) 3 (1,5)* ii) 4 (2,6)* 3) i) 9.6% ii) 9.9% 4) median (25th, 75th %ile) i) 4 (1,7) ii) 4 (2,14) * p<0.001 compared to normal BMI category
Twells et al (2012)	Canada (Newfound-land and Labrador)	retrospective cohort (5-year follow-up)	2,345	20-64	BMI i) 30-34.9 ii) ≥35 (self-reported)	1) # of visits to a GP 2) # of visits to a specialist 3) # of inpatient admissions 4) # of nights in hospital	age, sex, marital status, health region of residence, level of education, level of income, disability days, self-perceived health, health utility index, smoking status, drinking behavior, consumption of fruits and vegetables, level of physical activity. *model 2 adjusted for # of chronic conditions	Model 1 1) beta coefficient (standard error) i) -0.0036 (0.0691) ii) 0.4269 (0.0871) **[p<0.001]** 2) -0.0211 (0.0835) ii) 0.1857 (0.1161) 3) i) -0.1916 (0.1271) ii) 0.2573 (0.1542) 4) i) 0.6299 (0.1546) **[p<0.001]** ii) obese class II: -0.2053 (0.1900)

Table 2 continued.

Author (year)	Country	Study Design	Sample Size	Age Range	Obesity Measure	HCU Outcome	Covariates	Association
Quesenberry et al (1998)	United States	cross-sectional	17,118	≥20	BMI i) 30-34.9 ii) ≥35 (self-reported)	1) # of outpatient uses 2) # of inpatient uses * encompasses 3 months before and 9 months after survey	age, sex	1) i) RR **1.17 (1.11-1.22)** ii) RR: **1.24 (1.17-1.32)** 2) i) RR **1.34 (1.20-1.49)** ii) RR: **1.74 (1.50-2.02)**
Luchsinger et al (2003)	United States	cross-sectional	8,754	65-100	BMI i) 30-34.9 ii) ≥35 (self-reported)	# of hospitalizations	age, sex, smoking status, heart disease	i) RR: 0.96 (0.82-1.12) ii) RR: **1.50 (1.20-1.88)**
Andreyva et al (2004)	United States	cross-sectional	7,971	54-69	BMI i) 30-34.9 ii) 35-39.9 iii) ≥40 (self-reported)	1) # of outpatient visits 2) any inpatient stay 3) # of inpatient days *recalled over a 2-year period	age, gender, ethnicity, income, education, insurance status, marital status, census region, survey wave, current smoking and drinking behaviors	Men: 1) i) RR **1.04 (1.03-1.05)** ii) RR **1.38 (1.36-1.40)** iii) RR **1.25 (1.12-1.33)** 2) i) RR: **1.07 (1.05-1.09)** ii) **RR: 1.11 (1.01-1.16)** iii) RR: **1.39 (1.25-1.45)** 3) i) RR: **1.00 (1.00-1.04)** ii) RR: **1.47 (1.29-1.52)** iii) RR: **1.45 (1.22-1.54)** Women: 1) i) RR **1.15 (1.14-1.19)** ii) RR **1.34 (1.30-1.35)** iii) RR **1.22 (1.14-1.27)** 2) i) RR **1.19 (1.18-1.20)** ii) RR **1.29 (1.28-1.29)** iii) RR **1.27 (1.23-1.28)** 3) i) RR **1.20 (1.13-1.40)** ii) RR **1.58 (1.53-1.60)** iii) RR **1.47 (1.46-1.58)** *reference is preceding weight class
Raebel et al (2004)	United States	retrospective case-control	1,764 (539 with obesity, 1225 without obesity)	21-84	BMI 27.9-68.6 (self-reported for participants without obesity)	1) outpatient visits (composed of clinic office visits, outpatient surgical procedures, and emergency department visits) 2) hospitalizations * recorded for past year	N/A	1) IRR: **1.09 (1.03-1.15)** 2) OR: **3.85 (2.02-7.37)**
Bertakis and Azari (2005)	United States (California)	prospective cohort	509	mean age (SD) of those with obesity: 43.44 (14.20), without obesity: 40.51 (14.99)	BMI ≥30 (measured)	1) # of primary care visits 2) # of specialty care visits 3) # of emergency department visits 4) # of hospitalizations * reported over 1 year	sex, age, ethnicity, income, physical health status, mental health status, depression	Mean # of visits (SD) in obese vs. non-obese 1) 4.21 (3.51) vs. 3.26 (2.87), **p=0.0005** 2) 3.17 (4.58) vs. 2.20 (4.07), **p=0.0006** 3) 0.35(0.92) vs. 0.25 (0.77), p=0.1902 4) 0.21 (0.61) vs. 0.16(0.62), p=0.1409

Table 2 continued.

Author (year)	Country	Study Design	Sample Size	Age Range	Obesity Measure	HCU Outcome	Covariates	Association
Ahn et al (2012)	United States	cross-sectional	3,439	Baby boomers: aged 43-61, and older adults: aged 62+	BMI ≥30 (measured)	1) # of outpatient visits in the past year (0-1, 2-3, ≥4) 2) self-reported hospitalization in the past year (Y/N) *exposure is HCU, outcome is obesity	sex, ethnicity, poverty income ratio, smoking, self-reported general health, hypertension, cholesterol, PHQ-9 for depression	Baby Boomers: 1) OR for 2-3 visits: 1.22 (0.992-1.494); ≥4 visits: OR 1.15 (0.795-1.677) 2) OR 0.92 (0.641-1.313) Older Adults: 1) i) OR for 2-3 visits: 1.17 (0.834-1.649); ≥4 visits: OR 1.05 (0.622-1.772) 2) OR: 0.69 (0.437-1.005) *neither obese nor diabetes is reference group
Musich et al (2016)	United States	cross-sectional survey linked to medical and pharmacy claims	9,484	≥65	BMI ≥30 (self-reported)	1) any inpatient admission 2) any ED visit * recorded for 12 months post-survey	gender, age, income, metro location, race, education, living arrangement, need help to complete survey *full model controlled for chronic conditions and functional variables	Partial Model 1) OR: **1.15 (1.08-1.23)** 2) OR: 1.02 (0.96-1.09) * ref is normal BMI category (18.6-24.9)
Suehs et al (2017)	United States	retrospective cohort using administrative claims data	172,866	≥65	BMI i) 30-34.9 ii) 35-39.9 iii) ≥40 (using ICD-9-CM codes)	1) any inpatient hospital visits in 12-month post-index period 2) any ED visit in 12-month post-index period	age, gender, region, plan benefit type, deyo-charlson comorbidity index score, total number of meds received during baseline period	1) i) OR: **1.15 (1.11-1.20)** ii) OR: 1.45 (1.37–1.52) iii) OR: 3.41 (3.26–3.58) 2) i) OR: 1.00 (0.96-1.03) ii) OR: 1.07 (1.02-1.12) iii) OR: 1.43 (1.37-1.51) * ref is normal BMI category (19-24.9)
Wong et al (2019)	United States	cross-sectional	447	18-64	BMI continuous (measured)	1) # of visits to a doctor or health care professional at a doctor's office (excluding overnight hospitalization, emergency room, home visit, and telephone calls) * reported for the past 12 months	self-rated health, depression, comorbidities, marital status, number of children in the home, income, insurance coverage, and age	1) beta coefficients (p-value): a) white men: -0.10 (0.77); b) minority men: -0.20 (0.07); c) white women: -0.24 (0.35); d) minority women: -0.15 (0.17)
Wildenschild et al (2011)	Denmark	cross-sectional surveys (4 years of surveys)	37,477	≥16	BMI ≥30 (self-reported)	self-reported overall health care utilization (Y/N) * in the past 3 months	age, survey year, marital status, educational level, employment status, smoking status	Women: OR: **1.51 (1.36-1.68)** * no age stratification for women MEN OR for age 45-64: **1.56 (1.32-1.85)**; OR for age 65+: 1.27 (0.99-1.63)

Table 2 continued.

Author (year)	**Country**	**Study Design**	**Sample Size**	**Age Range**	**Obesity Measure**	**HCU Outcome**	**Covariates**	**Association**
Vals et al (2013)	Estonia	cross-sectional survey	6,500	16-64	BMI ≥30 (self-reported)	1) visit to GP 2) visit to specialist 3) hospitalization 4) made an ambulance call * any utilization in the past 12 months	education, average household income, ethnic identity, age, study year	Women: 1) OR **1.71 (1.40-2.21)** 2) OR: **1.28 (1.06-1.55)** 3) OR **1.54 (1.16-2.05)** 4) OR **1.45 (1.01-2.07)** Men: 1) OR **1.32 (1.04-1.68)** 2) OR **1.28 (1.01-1.61)** 3) OR 0.95 (0.67-1.36) 4) OR 0.79 (0.50-1.26)
Lengerke et al (2005)	Germany	cross-sectional survey	947	25-74	BMI i) 30-34.9 ii) ≥35 (measured)	1) visits to GP* 2) # of days in hospital * any utilization vs none; recorded for half a year	sex, age, social class, health insurance, place of residence	1) i) OR: **1.84 (p<0.01)** ii) OR 1.42 2) i) OR: 1.14 ii) OR: 2.39
Wolfenstetter et al (2012)	Germany	prospective cohort (10- or 7-year follow-up)	5,147	25-74	BMI i) 30-34.9 ii) ≥35 (measured) * BMI development from baseline to follow up	1) # of visits to GP 2) # of visits to internist 3) # of visits to other physicians * self-reported in the last 12 months	age, sex, socioeconomic status, incident diabetes, incident cancer	beta (p-value) 1) i) **1.48 (<0.0001)** ii): **1.83 (<0.0001)** 2) i) **2.07 (<0.0001)** ii) 1.61 (0.0639) 3) i) 1.21 (0.0573) ii) 1.29 (0.0578) * reference is those remaining in normal weight group
Nigatu et al (2017)	Netherlands	prospective cohort (6-year follow up)	2,706	18-65	BMI ≥30 WC ≥102 in men and ≥88cm in women (measured)	1) primary care visits 2) specialty care visits 3) any hospitalization * any utilization recalled from the past 6 months	age, age-squared, and gender	BMI 1) OR: **1.36 (1.15-1.61)** 2) OR: 1.14 (0.98-1.34) 3) OR: **1.60 (1.34-1.91)** WC 1) OR: **1.24 (1.03-1.42)** 2) OR: 1.10 (0.99-1.22) 3) OR: **1.63 (1.40-1.90)** * reference group is non-obese and not depressed

Table 2 continued.

Author (year)	Country	Study Design	Sample Size	Age Range	Obesity Measure	HCU Outcome	Covariates	Association
León-Muñoz et al (2005)	Spain	prospective cohort (2-yr follow up)	2,919	≥60	BMI ≥30 WC >102 in men and >88cm in women (measured)	1) visits to primary care physician* 2) visits to hospital specialist* 3) Ever admitted to the hospital 4) >1 hospital admission 5) duration of hospital stay >6 days during last admission * recorded for past 2 years; categorized into binary outcomes using category close to the median as a cut-off	age, educational level, size of place of residence, tobacco use, alcohol consumption, and presence of chronic disease	OBESITY BY BMI Men: 1) OR: 1.35 (0.92-1.97) 2) OR: 0.93 (0.66-1.32) 3) OR: 1.33 (0.91-1.96) 4) OR: 0.87 (0.41-1.86) 5) OR: **2.41 (1.19-4.86)** Women: 1) OR: **1.43 (1.04-1.98)** 2) OR: 1.17 (0.86-1.58) 3) OR: 1.31 (0.93-1.85) 4) OR: 1.03 (0.54-1.97) 5) OR: 0.74 (0.39-1.40) OBESITY BY WC Men: 1) OR: **1.28 (1.02-1.62)** 2) OR: 1.03 (0.82-1.30) 3) OR: 1.05 (0.81-1.35) 4) OR: 1.17 (0.71-1.92) 5) OR: **2.14 (1.33-3.54)** Women: 1) OR: **1.36 (1.06-1.73)** 2) OR: 1.05 (0.84-1.32) 3) OR: 1.20 (0.92-1.56) 4) OR: 0.84 (0.52-1.37) 5) OR: 0.89 (0.55-1.44)

Chapter 2: Manuscript - Body Mass Index, Waist Circumference, Waist-to-Hip Ratio, and Body Fat in Relation to Health Care Use in the Canadian Longitudinal Study on Aging (CLSA)

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Running title: Obesity Measures and Health Care Use

Candidate's role in the manuscript: I contributed to developing the research question, critically reviewed the literature, conducted all statistical analysis, interpreted the study findings, and wrote the first draft of the manuscript.

2.1 Abstract

Background/Objectives:

Obesity has been associated with increased health care use (HCU), but it is unclear whether this is consistent across all measures of obesity. The objectives of this study were to compare obesity defined by four anthropometric measures, body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), and percent body fat (%BF), and to estimate their associations with HCU among Canadian adults.

Subjects/Methods:

Baseline data (2012-2015) from 30,092 participants aged 45 to 85 years from the Canadian Longitudinal Study on Aging were included in the analyses. Anthropometrics were collected and %BF measured using dual-energy x-ray absorptiometry was considered to be the reference standard. Obesity was defined as BMI≥30.0 kg/m^2, WC≥88cm for females and ≥102cm for males, WHR≥0.85 for females and ≥0.90 for males, and %BF>35% for females and >25% for males. Approximately 18 months after baseline data collection, self-reported HCU in the past 12 months was collected, including general practitioner, specialist, emergency department visits, and being an overnight hospital patient. Pearson correlation coefficients and sensitivity and specificity analyses compared measures to %BF. Relative risks and risk differences adjusted for age, sex, education, income, urban/rural, marital status, smoking status, and alcohol use were calculated.

Results:

Obesity prevalence varied by measure: BMI (29%), WC (42%), WHR (62%), and %BF (73%). BMI and WC were highly correlated with %BF and demonstrated high specificity and lower sensitivity in predicting %BF-defined obesity in females and males. WHR was weakly correlated with %BF and demonstrated high sensitivity and lower specificity in males, with the opposite trend for females. There were significantly increased relative and absolute risks of HCU for all measures of obesity and all health care services.

Conclusions:

The prevalence of obesity varied substantially depending on the anthropometric measure used to define obesity. BMI and WC have stronger correlations and concordance with %BF than does WHR, however all measures were positively associated with increased HCU.

2.2 Introduction

Obesity is a public health concern worldwide with a global prevalence that exceeds 23% based on body mass index (BMI).[1] Obesity is recognized as a disease and is also an established risk factor for many chronic diseases and premature mortality.[2–4] Most epidemiologic studies use BMI to measure obesity and assess disease risk;[5] however, BMI does not provide information about the type or distribution of body fat, nor does it differentiate between muscle, skeletal weight, and fat.[6] Other anthropometric measures, such as waist circumference (WC), waist-to-hip ratio (WHR) and percent body fat (%BF), are alternative measures for assessing obesity and may be more useful for older adults who experience changes in body composition and age-related height decline, which is not considered by BMI.[6–8]

Previous studies have investigated the association between obesity and health care use (HCU).[9–27] Most studies have found that obesity is associated with a significant increase in HCU, but it is unclear whether this increase is consistent across all healthcare services, such as outpatient use including visits to a general practitioner or specialist, or inpatient use including visits to the emergency room or overnight stay in hospital. It is also not well understood which measures of obesity, such as BMI, WC, WHR, or %BF, are most strongly associated with increased HCU. Previous Canadian,[22,23] American,[9–11,18–20] and European studies[13,14,17,24] have evaluated a range of outpatient and inpatient HCU outcomes with most results showing increased HCU associated with obesity, although the outcomes assessed are variable and difficult to compare across studies. Most of previous studies have only evaluated BMI-defined obesity,[9–13,15,16,18–27] and many of these studies were further limited by the use of self-reported height and weight to measure BMI [10,12,15,16,18,19,21–25], which may introduce additional measurement error and bias.[28–30] A few studies included WC in addition to BMI.[14,17] To our knowledge, no studies have comprehensively evaluated a range of anthropometric measures, including %BF, to define obesity and understand the relationship between obesity and HCU. Further, between 2015 and 2050, the proportion of the world's population 60 years and over is expected to almost double from 12% to 22%,[31] although many of the studies on obesity and HCU have not included adults aged 75 years and older in their analyses.[10,13,17,21–24,26,27]

The primary objective of this study was to evaluate the association between anthropometric measures, including BMI, WC, WHR, and %BF, with HCU in the past 12 months among Canadians aged 45-85 years of age. HCU included: (a) any visits with a general practitioner; (b) any visits with a medical specialist; (c) any visits to an emergency department; and (d) having been a patient in a hospital overnight. The secondary objectives were to investigate if the associations between the anthropometric measures and HCU differed by sex and by age, and to compare the associations between anthropometric measures, including BMI, WC, WHR, and %BF.

2.3 Methods

2.3.1 Data Source & Study Participants

The Canadian Longitudinal Study on Aging (CLSA) is a national, longitudinal research platform that included 51,338 participants aged 45 to 85 years at baseline from the 10 Canadian provinces. Eligibility criteria included participants being able to physically and cognitively participate on their own. Individuals living on federal First Nations reserves or in institutions such as long-term care, full-time members of the Canadian Armed Forces, and those unable to respond in English or French were excluded. Participants were recruited into one of two cohorts. Tracking cohort participants (n=21,241) were randomly selected from the 10 provinces and completed interviews by phone. The Comprehensive cohort (n=30,097) consists of participants that were randomly selected from within 25-50 km of 11 data collection sites in seven Canadian provinces.[32] Provincial health registries and random digit dialing were the primary sampling frames for this cohort.[33] Comprehensive cohort participants completed in-person interviews, as well as in-depth physical assessments and biological specimen collection. The analyses for this study was limited to Comprehensive cohort participants as the required anthropometric measures were not collected in the Tracking cohort. This study uses data collected during baseline (September 2011 to May 2015) as well as data on HCU collected during a Maintaining Contact Questionnaire administered approximately 18 months after baseline data collection. Five participants were excluded due to implausible WC or WHR measures. Individuals who had at least one of the four body measures and completed the maintaining contact questionnaire were included in analyses. The final cohort consisted of 30 092 individuals.

2.3.2 Ethics

All participants provided written informed consent upon enrollment into the CLSA. Further, secondary data analysis for this specific project was approved by the Hamilton Integrated Research Ethics Board, Hamilton, Ontario (HiREB# 2019-7221-C).

2.3.3 Measurement of Exposure Variables

The exposure in this study was obesity. Obesity was assessed using four anthropometric measures: BMI, WC, WHR, and %BF. All measures were collected by trained staff using standard operating procedures.

Body Mass Index (BMI)

Standing height and weight were measured using a Seca 213 stadiometer and 140-10 Healthweigh Digital Physician Scale, respectively.[34] BMI was calculated as weight divided by the square of height (kg/m^2) and categorized using the current World Health Organization

(WHO) and Health Canada BMI classification systems; BMI ≥30.0 kg/m^2 was classified as having obesity and BMI <30 kg/m^2 was classified has not having obesity.[4,5]

Waist Circumference (WC)

WC was measured in centimeters to the nearest tenth of a cm on top of one layer of clothing or directly on the skin using a 245cm long measuring tape. WC was measured around the position of the natural indent in the waist area, which was the narrowest part of abdomen half-way between the last floating rib and the iliac crest. Female participants more than 12 weeks pregnant or any participant unable to stand upright unassisted did not have WC measured.[35] As per the current WHO and Health Canada guidelines, a WC ≥88cm for females and ≥102cm for males were categorized to classify abdominal obesity.[4,5,8]

Waist-to-Hip Ratio (WHR)

WHR was obtained by the ratio of WC to hip circumference. For women, hip circumference was measured around the largest circumference of the hips and buttocks. For men, hip circumference was measured at the hip bones.[35] WHR was categorized into a binary categorical variable based on WHO recommendations, with a WHR ≥0.85 for females and ≥0.90 for males to classify abdominal obesity.[8]

Percent Body Fat (%BF)

Whole %BF was measured using the Hologic Discovery A Dual Energy X-Ray Absorptiometry (DXA) machine. Weight over 204 kg, height over 1.88 m, pregnancy, exposure to an x-ray with contrast material or participation in a nuclear medicine study within the last seven days before the DXA scan were all contraindications to receiving the scan.[36] Universally accepted %BF cut-points are lacking,[37] although the commonly accepted cut points of %BF >35% for females and >25% for males were used to define obesity.[38]

2.3.4 Measurement of Outcome Variables

Participants were asked the following questions regarding their HCU: "During the past 12 months, have you had contact with any of the following about your physical or mental health" … a) "General practitioner, family physician", and b) "Medical specialist (such as a cardiologist, gynaecologist, psychiatrist)", c) "Have you been seen in an Emergency Department during the past 12 months?", and d) "Were you a patient in a hospital overnight during the past 12 months?".[39] Each of the four HCU variables, including any general practitioner (GP) visit, specialist visit, emergency department (ED) visit, and overnight hospital stay, were categorized as 'Yes' or 'No'.

2.3.5 Other Variables

All covariates were selected *a priori* based on the literature and considered the Andersen's Behavioral Model of Health Services Use to guide the covariate selection.[40,41] The following variables were hypothesized to be potential confounders: education, household income, urban/rural living, marital status, province of recruitment, smoking status (current smoker, never-smoker, and former smoker), and alcohol use in the past 12 months (regular use consuming a drink at least once a month, occasional drinkers who had at least one drink but did not drink once a month, and non-drinkers who did not report consuming alcohol).[42]

Chronic conditions and self-rated general health were hypothesized to be on the causal pathway between obesity and HCU, and therefore, were considered as potential mediators and were not adjusted for in the primary analysis. Participants were dichotomized as either having no chronic health conditions or one or more of the following chronic conditions: (i) osteoarthritis, (ii) osteoporosis, (iii) chronic obstructive pulmonary disease, (iv) heart disease, (v) hypertension, (vi) peripheral vascular disease, (vii) diabetes, (viii) cerebrovascular disease, (ix) neurological

(Parkinson's disease, multiple sclerosis, epilepsy, and migraine headaches), (x) kidney disease, (xi) cancer, and (xii) depression. All chronic conditions were measured using self-reported physician diagnoses with the exception of depression which was operationalized using a score of 10 or more on the Center for Epidemiologic Studies Short Depression Scale.[43]. Self-rated general health was categorized as 'excellent', 'very good', 'good', 'fair or poor'. Finally, we hypothesized that there may be effect modification by age and sex since differences in obesity and HCU exist between males and females and at different ages.[44,45] All analyses were also age and sex stratified.

2.3.6 Statistical Analysis

The CLSA provided analytical weights which were used for descriptive estimates and regression modeling, and allowed for the results to reflect the eligible Canadian population. Descriptive statistics were reported as means and standard deviations for continuous variables, and as frequencies and percentages for categorical variables. Scatterplots with Pearson correlation coefficients were generated to observe the relationship between BMI, WC, WHR, and %BF, and obesity-related cut points were defined on each plot to understand the classification of obesity by each anthropometric measure. Sensitivity and specificity were calculated to assess the diagnostic accuracy of BMI (≥ 30.0 kg/m^2), WC (≥88cm for females and ≥102cm for males) and WHR (≥0.85 for females and ≥0.90 for males) cut points compared to %BF cut points (>35% for females and >25% for males).

For each type of HCU (GP visit, specialist visit, ED visit, and overnight hospital stay), relative risks (RR) and 95% confidence intervals (CI) were estimated from generalized linear regression models with a log link distribution separately comparing groups with obesity to those without obesity based on the anthropometric measures, BMI, WC, WHR, and %BF. A generalized linear model with an identity link distribution was also used to obtain risk differences (RD) per 100 and 95% CIs. Each regression model was adjusted for 1: age, sex, education, household income, urban/rural living, smoking status, alcohol use, marital status, and province of recruitment, and 2: those variables plus chronic conditions and self-rated general health.

In addition to the binary obesity measures, relative risks were computed for each decile of the continuous anthropometric measure with the reference group being the decile closest to the 'normal' body measure category. Graphs depicting the relative risks for the effect of each anthropometric measure on HCU were generated to visualize how the risk of HCU changes with increasing body measures. All statistical analyses were conducted using SAS University Edition statistical software (SAS Institute Inc., Cary, NC, USA) and R Studio Version 1.1.456 (RStudio, Inc., Boston, MA, USA).

2.4 Results

Among females, 28% had BMI ≥30 kg/m^2, 45% had WC ≥88cm, 37% had WHR ≥0.85, and 75% had %BF >35%. Among males, 30% had BMI ≥30 kg/m^2, 39% had WC ≥102cm, 88% had WHR ≥0.90, and 71% had %BF >25% (Table 1). For most types of services, females tended to report more HCU in the previous 12 months than males, as 91.1% vs. 86.1% had any contact with GP, 49.2% vs. 46.8% had any contact with a specialist, and 18.9% vs. 17.9% had an emergency department visit, although the proportion reporting any overnight hospital stay was similar at 7.1% vs. 7.3%, respectively.

In females, the Pearson correlation coefficients for BMI, WC, and WHR with %BF were 0.75 (95% CI: 0.74-0.75), 0.70 (95% CI: 0.69-0.71), 0.29 (95% CI: 0.27-0.30), respectively. In males, the Pearson correlation coefficients were 0.70, (95% CI: 0.70-0.71), 0.75 (95% CI: 0.74-0.76), and 0.46 (95% CI: 0.45-0.48), respectively (Supplementary Table S1). Scatterplots with vertical and horizontal cut point lines provide information about the concordance between obesity defined by BMI, WC, and WHR, and obesity defined by %BF (Figure 1). In both females and males, the sensitivity was <58% when using BMI or WC cut points to compared to %BF, but the specificity was >93% (Table 2). This suggests that only about half (<58%) of individuals who have obesity by %BF are being identified as having obesity according to BMI or WC (increased false negatives), while almost all (>93%) of individuals who do not have obese by %BF are correctly identified as not having obesity by BMI or WC (decreased false positives). In contrast, when WHR cut points were used to define obesity compared to %BF, the sensitivity was 44% in females and 95% in males, and the opposite trend appeared for specificity, with values of 83% in females and 28% in males.

Relative risk estimates indicate that adults with obesity defined by BMI, WC, WHR, and %BF were significantly more likely to have had any contact with a GP, any contact with a specialist, any visits to an ER, or to have been a patient in a hospital overnight in the previous 12 months, compared to adults without obesity (Table 3: Model 1). After adjusting for hypothesized mediators in Model 2, including chronic conditions and self-rated general health, all relative risks attenuated. Estimates were no longer statistically significant for contact with a GP when obesity was defined by BMI, WHR and %BF, for contact with a specialist when obesity was defined by all measures, and for overnight stay in hospital when obesity was defined by WHR and %BF (Supplementary Table S2). Sex stratified analyses revealed similar findings with no significant differences in risk of HCU between females and males, with non-overlapping confidence intervals being the criteria for significant differences (Supplementary Table S3). In age stratified analyses, the relative risks for all types of HCU were attenuated in the oldest adult group (aged 75+) compared to the youngest group (aged 45-54) (Supplementary Table S4). For example, in individuals aged 45-54, 55-64, 65-74, and 75+ with %BF-defined obesity, the relative risk for having visited the ED in the last 12 months was 1.31 (1.15-1.49), 1.32 (1.16-1.50), 1.05 (0.92-1.22), and 0.90 (0.77-1.06), respectively; however, this trend was not observed for the association between %BF and contact with a GP.

For BMI, WC, WHR, and %BF, plots of the relative risks of HCU for each decile of the measure compared to a reference group closest to the 'normal' body measure category are presented in Supplementary files (Supplementary Figures S1, S2, S3, and S4, respectively), separately for females and males. For all anthropometric measures, an overall trend existed such that the risk of all types of HCU, except for contact with a GP, increased as the anthropometric measure increased. For all measures, as the anthropometric increased, the relative risk of having had contact with a GP remained around 1.

In adjusted analyses, consistent with the measures of relative risk, there were significantly increased risk differences for HCU in adults with any definition of obesity compared to those without obesity (Table 4). For adults with obesity defined by BMI, WC, and WHR, the absolute risk of HCU was greatest for risk of having contact with a specialist, compared to adults without obesity. For example, in adults with BMI $\geq$30 kg/m^2, the HCU risk difference (per 100) for contact with a specialist was 4.6 (95% CI: 3.0-6.1) and was significantly different from the lowest risk difference for contact with a GP of 1.9 (95% CI: 1.1-2.7). For adults with obesity defined by %BF, the absolute risk of HCU was greatest for risk of having visited an ED, compared to adults without obesity, as the risk difference was 3.3 (95% CI: 2.1-4.5). This risk difference is significantly different from the lowest risk difference of having been a patient in a hospital overnight of 1.3 (95% CI: 0.6-2.0). The absolute risk of HCU between females and males with obesity were not significantly different based on non-overlapping confidence intervals (Supplementary Table S5).

In age-stratified analyses, the HCU risk difference is attenuated in older participants (Supplementary Table S6).

2.5 Discussion

The prevalence of obesity in our study population varied greatly depending on the anthropometric measure used to define obesity. Obesity defined by BMI largely underestimated the prevalence of obesity when defined by the reference standard %BF, although these findings are similar to prevalence values in studies that assessed both BMI and %BF.[46,47] Differences in the prevalence of obesity defined by BMI, WC, WHR, and %BF, and differences in the prevalence between sexes for WHR-defined obesity (37% vs 88% for females and males, respectively) illustrate that these measures may be evaluating different aspects of obesity and/or are reflective of issues with obesity cut points. This is further supported through comparisons of BMI, WC, WHR, and %BF. For both females and males, continuous measures of BMI and WC were highly correlated with %BF (r>0.70) and the commonly accepted BMI and WC cut points demonstrated high specificity (>93%) and lower sensitivity (<58%) in predicting obesity defined by %BF. WHR was weakly correlated with %BF (r<0.46 for females and males), and commonly accepted WHR cut points had high sensitivity (95%) and lower specificity (28%) in predicting %BF-defined obesity in males, but lower sensitivity (44%) and high specificity in females (83%). These findings comparing WHR to %BF indicate the uncertainty of using WHR cut points to assess obesity status.

Our results are similar to findings from a sample of 1,360 individuals from Iran, which reported correlation coefficients between BMI and %BF, WC and %BF, and WHR and %BF of 0.87, 0.73, and 0.48, respectively.[48] Additionally, similar to findings from a study using data from the National Health and Nutrition Examination Survey 1999-2004, we found that %BF was significantly more correlated with BMI than with WC in women but was significantly more correlated with WC than with BMI in men.[49] For the comparison of anthropometric measures using cut points, our findings of high specificity and lower sensitivity of BMI with respect to %BF was similar to a systematic review of 25 studies that reported a pooled specificity of 90% (95% CI: 86-94%) and a pooled sensitivity of 50% (95% CI: 43-57%) comparing BMI to %BF, although they did not evaluate by sex.[50] There is a well-known trade-off between sensitivity and specificity; therefore it is important to weigh the implications of lowering sensitivity that comes at the expense of potentially missing the diagnosis of 'true' cases of obesity by %BF (increased false negatives), versus lowering specificity that comes at the expense of potentially misclassifying non-obese individuals by BMI as obese by %BF (increased false positives). Compared to BMI, WC had higher sensitivity and slightly lower but still high specificity in predicting %BF. Our sensitivity findings for WC were slightly lower than estimates from previous studies of 67-81% in females and 60-87% in males and our specificity findings were generally on the higher end when compared to previous estimates of 76-86% in females and 75-96% in males.[46,48,51] Slight differences in estimates may be attributed the different WC and %BF obesity cut points used by some of these studies.[48,51] Few studies have evaluated WHR, and one study from Iran revealed comparable findings such that sensitivity and specificity were extremely variable between sexes yielding estimates of 67% and 56% in females and 95% and 67% in males, respectively.[48] Similarly, WHR did not demonstrate high specificity in predicting %BF as BMI and WC did.[48] Inconsistencies in specificity and sensitivity values comparing anthropometric measures, such as comparing WC and WHR to %BF, suggest that more research needs to be conducted on the diagnostic accuracy of WC and WHR so that we may better understand if the cut points being used to define obesity are appropriate and which anthropometric measure is most concordant with %BF.

It is difficult to compare our associations to those of previous literature since most studies have only evaluated the relationship between obesity and HCU using BMI,[9–13,15,16,18–27] and to our knowledge, only two studies have used WC in addition to BMI.[14,17] Of studies that evaluated the relationship between BMI-defined obesity and GP visits,[11,13,14,21,23,24,26] specialist visits,[11,14,17,23,24] ED visits,[11,16,20] and/or overnight hospitalizations,[9–12,14–17,20,21,23,24] most found significant positive relationships with GP visits[11,13,14,17,21,23,24,26] and overnight hospitalizations,[10,12,16,17,19,20,24] and fewer found significant positive relationships with specialist visits[11,24] and ED visits.[20] Direct comparisons of associations are difficult because the measurement of the HCU outcome has varied substantially between studies. For example, for GP visits, some studies evaluated any GP visits in a given time period,[13,17,24] some evaluated the number of GP visits in a given time period,[11,21,23,26] where the recall time has also varied, and some have used other methods such as comparing high to low use with the median number of visits as the cut point.[14] Some studies have even looked at different indicators of HCU, such as the number of nights in hospital[10,12,13,23], overall HCU,[25] or outpatient and inpatient visits generally,[9,10,18,19,21,27] while others used different obesity cut points,[19,21] making direct comparisons even more difficult. Furthermore, we cannot directly compare our findings as most of these studies reported odds of HCU.[9,12,13,16,19–21,24,25] The odds ratio estimates the relative risk when the outcome is rare, although the odds ratio is known to overestimate the true effect when the outcome frequency is large.[52] For example, visiting a GP is the most common type of HCU in our study, reported by 87% of participants, and of studies that evaluated the association between BMI-defined obesity and odds of GP use,[13,14,17,21,24] the odds ratio ranged from 1.32-1.83 which greatly overestimates our relative risk of 1.01 (95% CI: 1.00-1.02). The variables adjusted for in previous studies also differ from those we attempted to adjust for. Using chronic conditions as an example, many studies have adjusted for this variable as it may help determine the independent effect of obesity on HCU,[9,14–16,20,23,26,27] while others did not adjust for chronic conditions as they either did not have access to this variable or believed it was a mediator on the causal pathway between obesity and HCU.[10,23,25] Our findings suggest that both chronic conditions and self-rated general health are potential mediators of the relationship between obesity and HCU as the relative risks all attenuated after adjusting for these two covariates in Model 2.

We also used risk differences to assess absolute effects instead of only using a relative measure, such as relative risk. Relative risks are difficult to compare because they only indicate how much more or less likely individuals with obesity are to use a health care service compared to those without obesity, and the baseline risks of HCU vary across the different types of HCU and age groups. Risk differences may provide a better effect estimate as they directly indicate the difference in the risk of HCU between those with and without obesity, although their clinical meaningfulness depends on the baseline risk of HCU. Using the association between BMI-defined obesity and contact with a GP as an example, there was a high unadjusted baseline risk of HCU as 88.6% of participants reported having any contact with a GP in the previous 12 months. A risk difference of 1.9% represents the difference in the risk of having any contact with a GP between those with BMI-defined obesity and those without, and represents a change in risk that may not be as clinically meaningful considering how common it was for participants to report having contact with a GP in the previous 12 months. Conversely, the unadjusted baseline risk of being hospitalized overnight in the previous 12 months was 7.2%. A risk difference of 2.6% may represent a more meaningful difference in risk since it was fairly rare for participants to report being hospitalized.

Although we didn't find any differences in our relative or absolute measures of association between sexes, we found attenuated relative risks in the oldest adult group compared to the youngest adult group. When compared to individuals without obesity in the same age group, individuals with obesity aged 75+ have a smaller but increased risk of HCU than those aged 45-54 with obesity. These findings may suggest that obesity is not a strong predictor of HCU in older adults. This possible explanation is supported through examining the proportions of HCU by age group such that the oldest adult group tended to have higher proportions of HCU than younger groups. Moreover, since the CLSA is known to be a predominantly healthy and educated community-dwelling population,[32] these findings of lower relative risk estimates may be indicative of a selection bias such that older adults enrolled into the CLSA are healthy individuals that utilize less health care resources. Nonetheless, we must be cautious when comparing these relative risk estimates between age groups as the baseline risk of HCU in these groups may differ and an absolute estimate, such as a risk difference, may be more valuable. Our absolute estimates revealed that for each type of HCU, there were smaller risk differences in the oldest adult group than in the youngest group. This indicates that the excess risk of HCU is not as large in adults aged 75+ with BMI-defined obesity (compared to adults aged 75+ without obesity) and is greater in adults aged 45-54 with obesity (compared to adults aged 45-54 without obesity), further supporting our proposed explanations.

Limitations of this study include the relatively short prospective follow-up period with an average of approximately 16 months. Our study also utilizes self-reported binary HCU in the last 12 months. Although self-reported HCU has proven to be fairly accurate compared to administrative claims and is more reliable than self-reporting the frequency of visits in a given time period,[53,54] our moderately long recall period of 12 months and self-reports from an adult and older adult population who may have cognitive competency concerns, are limitations to having accurate recall of HCU.[55] Future research using linked administrative data will improve on these limitations but is not yet feasible with the CLSA cohort.

Strengths of this study include the use of the large population based CLSA dataset, which enabled age and sex stratification, and weighted data so that our results may be generalized to the eligible Canadian population. This rich dataset of variables enabled us to adjust for many different confounders and to separate the effects of potential mediators in our analyses. We were also able to obtain %BF, measured using DXA, for more than 30,000 adult and older adult participants. This study went beyond only using the most common measure to assess obesity, BMI, and compared numerous anthropometric measures, including WC, WHR and %BF, that were recorded by trained staff, and evaluated their associations with inpatient and outpatient indicators of HCU.

To our knowledge, this is the first Canadian study that has conducted comparisons of BMI, WC, WHR, and %BF in adults and older adults and has found significant positive associations with both outpatient and inpatient indicators of HCU. Further research should be directed towards comparing the validity of different measures used to define obesity so that appropriate measures and cut points can be used in clinical settings, research, and population health planning.

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2.7 Tables and Figures

Table 1. Descriptive statistics of the demographic, health, anthropometric, and HCU variables for CLSA Comprehensive cohort (n=30 092).

Demographics	**Females** **15 297 (50.8)**	**Males** **14 795 (49.2)**	**Total** **30 092**
Age, *n (%)*			
45-54	6 129 (40.1)	6 261 (42.3)	12 390 (41.2)
55-64	4 473 (29.2)	4 630 (31.3)	9 104 (30.2)
65-74	2 924 (19.1)	2 398 (16.2)	5 322 (17.7)
75+	1 771 (11.6)	1 505 (10.2)	3 276 (10.9)
Age, *mean (SD)*	59.9 (0.09)	59.3 (0.09)	59.6 (0.06)
Education, *n (%)*			
Less Than Secondary School Graduation	767 (5.0)	589 (4.0)	1 355 (4.5)
Secondary School Graduation	1 493 (9.8)	1 137 (7.7)	2 631 (8.8)
Some Post-Secondary Education	1 074 (7.0)	1 007 (6.8)	2 081 (6.9)
Post-Secondary Degree or Diploma	11 946 (78.2)	12 043 (81.5)	23 990 (79.8)
Household Income, *n (%)*			
Less than $20,000	763 (5.3)	434 (3.0)	1 196 (4.2)
$20,000 or more but less than $50,000	3 053 (21.5)	2 001 (14.1)	5 055 (17.8)
$50,000 or more but less than $100,000	4 855 (34.2)	4 591 (32.3)	9 446 (33.2)
$100,000 or more, but less than $150,000	2 912 (20.5)	3 530 (24.9)	6 442 (26.7)
$150,000 or more	2 633 (18.5)	3 649 (25.7)	6 281 (22.1)
Country of Birth, *n (%)*			
Not in Canada	2 444 (16.0)	2 745 (18.6)	5 188 (17.2)
Canada	12 850 (84.0)	12 049 (81.4)	24 899 (82.8)
Province at Recruitment, *n (%)*			
Alberta	1 333 (8.7)	1 621 (11.0)	2 954 (9.8)
British Columbia	3 195 (20.9)	3 059 (20.7)	6 254 (20.8)
Manitoba	1 526 (10.0)	1 587 (10.7)	3 113 (10.3)
Newfoundland	1 206 (7.9)	1 006 (6.8)	2 213 (7.4)
Nova Scotia	1 705 (11.1)	1 373 (9.3)	3 078 (10.2)
Ontario	3 227 (21.1)	3 189 (21.5)	6 416 (21.3)
Quebec	3 104 (20.3)	2 959 (20.0)	6 063 (20.1)
Marital Status, *n (%)*			
Single	1 230 (8.1)	1 090 (7.4)	2 321 (7.7)
Married/Common-law	10 741 (70.2)	12 285 (83.1)	23 025 (76.5)
Widowed	1 321 (8.6)	379 (2.5)	1 700 (5.7)
Divorced	1 607 (10.5)	729 (4.9)	2 336 (7.8)
Separated	393 (2.6)	308 (2.1)	701 (2.3)
Ethnicity, *n (%)*			
Not White	659 (4.3)	802 (5.4)	1 461 (4.9)
White	14 628 (95.7)	13 977 (94.6)	28 604 (95.1)
Urban/Rural Classification, *n (%)*			
Rural	1 458 (55.7)	1 162 (7.9)	2 620 (8.8)
Urban	13 826 (90.3)	13 460 (92.1)	27 103 (91.2)

Smoking Status, *n (%)*			
Yes (currently smoke)	1 309 (8.6)	1 521 (10.2)	2 830 (9.4)
No (never have)	7 957 (52.0)	7 074 (47.8)	15 031 (50.0)
Former (not now but have in the past)	6 032 (39.4)	6 198 (42.0)	12 229 (40.6)
Type of Drinker, *n (%)*			
Regular (at least once a month)	10 781 (72.6)	11 820 (81.3)	22 601 (76.9)
Occasional	2 287 (15.4)	1 272 (8.8)	3 559 (12.1)
Did not drink in the last 12 months	1 783 (12.0)	1 439 (9.9)	3 222 (11.0)
Chronic Conditions, *n (%)*			
None	3 820 (26.5)	4 825 (34.3)	8 645 (30.3)
1 or more	10 613 (73.5)	9 951 (65.7)	19 868 (69.7)
Self-Rated General Health, *n (%)*			
Excellent	3 253 (21.3)	2 868 (19.4)	6 121 (20.3)
Very Good	6 509 (42.6)	6 096 (41.2)	12 605 (41.9)
Good	4 236 (27.7)	4 479 (30.3)	8 715 (29.0)
Fair/Poor	1 291 (8.4)	1 342 (9.1)	2 633 (8.8)
Days between DCS Visit and MCQ, *mean (SD)*	500 (1.74)	458 (1.75)	479.6 (1.25)
ANTHROPOMETRIC MEASURES			
BMI			
BMI <30 kg/m^2	10 986 (72.1)	10 316 (70.0)	21 302 (71.1)
BMI ≥30 kg/m^2	4 252 (27.9)	4 423 (30.0)	8 675 (28.9)
Waist Circumference			
females <88cm, males <102cm	8 385 (55.2)	8 976 (61.1)	17 361 (58.1)
females ≥88cm, males ≥102 cm	6 816 (44.8)	5 727 (38.9)	12 542 (41.9)
Waist-to-Hip Ratio			
females <0.85, males <0.90	9 562 (62.9)	1 774 (12.1)	11 336 (37.9)
females ≥0.85, males ≥0.90	5 639 (37.1)	12 928 (87.9)	18 567 (62.1)
Body Fat Percentage			
females ≤35%, males ≤25%	3 687 (25.1)	4 115 (29.0)	7 802 (27.0)
females >35%, males >25%	11 023 (74.9)	10 091 (71.0)	21 115 (73.0)
HEALTH CARE UTILIZATION			
Contact with a general practitioner			
No	1 295 (8.9)	1 970 (13.9)	3 264 (11.4)
Yes	13 295 (91.1)	12 195 (86.1)	25 490 (88.6)
Contact with a medical specialist			
No	7 414 (50.8)	7 535 (53.2)	14 949 (52.0)
Yes	7 173 (49.2)	6 634 (46.8)	13 807 (48.0)
Seen in an Emergency Department			
No	11 836 (81.1)	11 640 (82.1)	23 477 (81.6)
Yes	2 758 (18.9)	2 534 (17.9)	5 291 (18.4)
Patient in a hospital overnight			
No	13 570 (92.9)	13 140 (92.7)	26 711 (92.8)
Yes	1 043 (7.1)	1 040 (7.3)	2 082 (7.2)

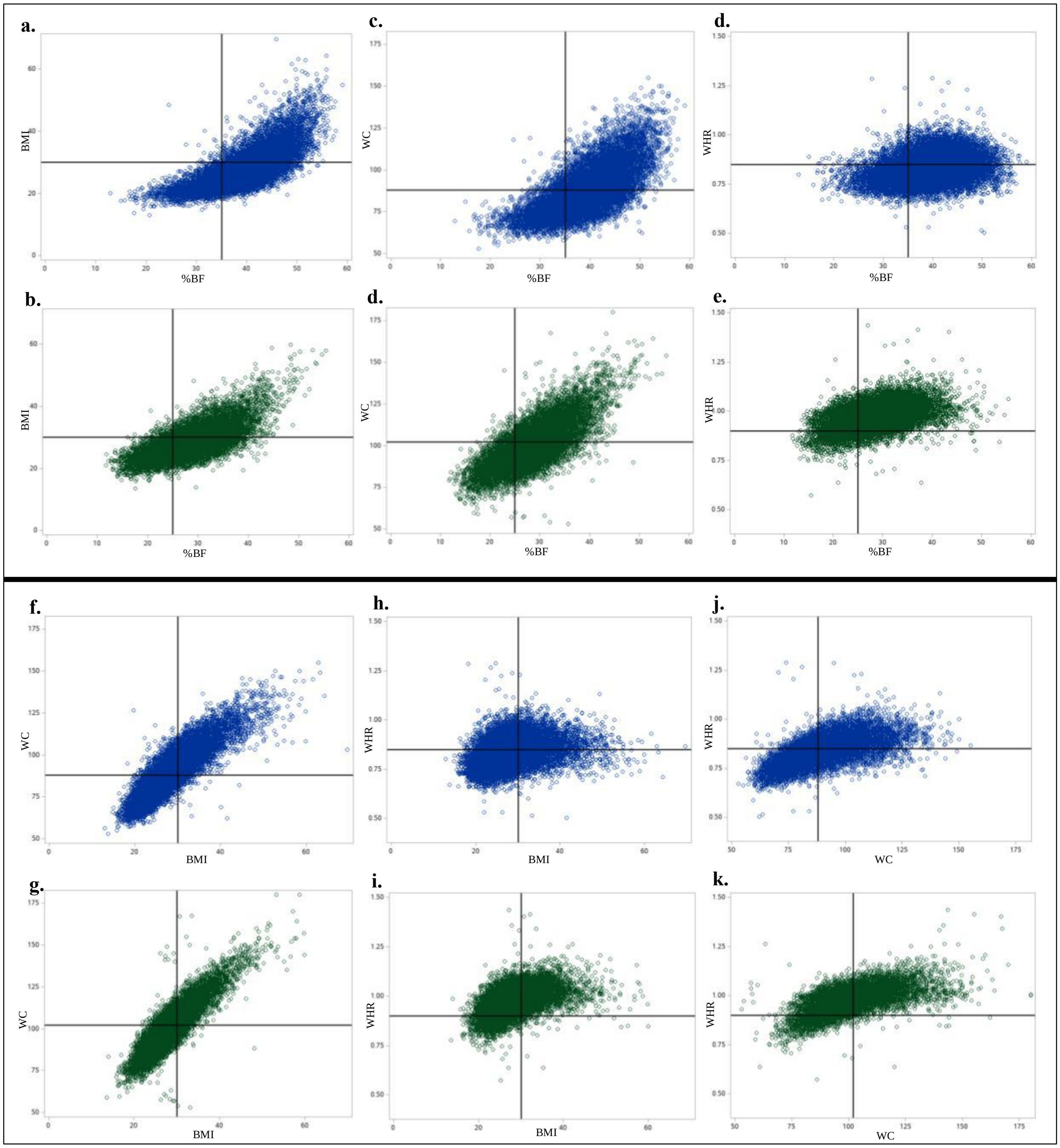

Figure 1.
a-k. Scatterplots comparing anthropometric measures, separately for females (blue) and males (green). The black vertical and horizontal lines represent obesity cut points (BMI ≥30 kg/m^2, WC ≥88cm for females ≥102cm for males, WHR ≥0.85 for females and ≥0.90 for males, %BF >35% for females and >25% for males). Figures 1a-1e compare BMI, WC, and WHR to the reference standard, %BF. Figures 1f-1k compare BMI and WC, BMI and WHR, and WC and WHR.

Table 2. Sensitivity and specificity values (95% confidence interval) for BMI, WC, and WHR compared to %BF (n=30 092).

	Reference Standard (%BF) (>35% for females or >25% for males)					
	Females		**Males**		**Total**	
	Sensitivity	**Specificity**	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**
BMI (<30 kg/m^2)	37.0 (36.1-37.9)	98.9 (98.6-99.2)	40.3 (39.4-41.3)	95.3 (94.6-95.9)	38.6 (38.0-39.3)	97.0 (96.6-97.4)
WC (females ≥88cm, males ≥102)	57.6 (56.7-58.5)	92.9 (92.1-93.7)	52.2 (51.3-53.2)	93.9 (93.2-94.7)	55.0 (54.4-55.7)	93.4 (92.9-94.0)
WHR (females ≥0.85, males ≥0.90)	44.1 (43.2-45.0)	83.4 (82.2-84.6)	94.5 (94.0-94.9)	27.9 (26.5-29.2)	68.2 (67.5-68.8)	54.1 (53.0-55.2)

- Values expressed as % (95% CI).

Table 3. Relative risks for the association between obesity defined using BMI, WC, WHR, and %BF cut points and HCU among adults aged 45 to 85 at baseline from the Comprehensive cohort of the CLSA (n= 30 092).

	Contact with GP RR (95% CI)		**Contact with Specialist** RR (95% CI)		**Visit to ED** RR (95% CI)		**Overnight in Hospital** RR (95% CI)	
	Unadj[a]	Model 1[b]	Unadj[a]	Model 1[b]	Unadj[a]	Model 1[b]	Unadj[a]	Model 1[b]
BMI								
≥30 kg/m²	1.04 (1.03-1.05)	1.01 (1.00-1.02)	1.10 (1.07-1.14)	1.10 (1.06-1.13)	1.28 (1.20-1.36)	1.25 (1.18-1.33)	1.44 (1.30-1.59)	1.38 (1.25-1.52)
WC								
females ≥88cm, males ≥102cm	1.05 (1.04-1.06)	1.02 (1.01-1.03)	1.17 (1.13-1.20)	1.13 (1.10-1.16)	1.31 (1.23-1.39)	1.24 (1.17-1.31)	1.56 (1.42-1.73)	1.40 (1.28-1.54)
WHR								
females ≥0.85, males ≥0.90	0.98 (0.97-0.99)	1.01 (1.00-1.02)	1.06 (1.02-1.09)	1.10 (1.07-1.14)	1.16 (1.09-1.24)	1.19 (1.11-1.28)	1.33 (1.20-1.48)	1.23 (1.10-1.38)
%BF								
females >35%, males>25%	1.05 (1.03-1.07)	1.01 (1.00-1.03)	1.12 (1.07-1.16)	1.06 (1.03-1.10)	1.28 (1.19-1.38)	1.22 (1.13-1.32)	1.52 (1.34-1.74)	1.24 (1.09-1.41)

[a] Unadjusted model.
[b] Model 1 is adjusted for sex, age, education, household income, urban/rural, smoking status, alcohol use, marital status, province of recruitment, time.
- Reference group for BMI is <30 kg/m², for WC is <88cm for females and <102 cm for males, for WHR is <0.85 for females and <0.90 for males, and for %BF is ≤35% for females and ≤25% for males.
- Acronyms: Body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), percent body fat (%BF), relative risk (RR), confidence interval (CI), general practitioner (GP), emergency department (ED).

Table 4. Risk difference for the excess risk of HCU in those with obesity compared to those without obesity defined by BMI, WC, WHR, and %BF (n= 30 092). Risk per 100 people.

	Contact with GP RD (95% CI)		**Contact with Specialist** RD (95% CI)		**Visit to ED** RD (95% CI)		**Overnight in Hospital** RD (95% CI)	
	Unadj[a]	Model 1[b]	Unadj[a]	Model 1[b]	Unadj[a]	Model 1[b]	Unadj[a]	Model 1[b]
BMI ≥30 kg/m^2	2.7 (1.7-3.6)	1.9 (1.1-2.7)	4.8 (3.2-6.2)	4.6 (3.0-6.1)	4.6 (3.4-5.7)	2.5 (1.7-3.3)	2.8 (2.1-3.6)	2.6 (1.7-3.4)
WC females ≥88cm, males ≥102cm	3.9 (3.0-4.8)	1.9 (1.1-2.7)	7.6 (6.2-8.9)	5.9 (4.5-7.4)	4.6 (3.6-5.7)	3.8 (2.7-4.9)	3.3 (2.6-3.9)	2.6 (1.9-3.3)
WHR females ≥0.85, males ≥0.90	-1.2 (-2.1– -0.3)	1.2 (0.3-2.1)	3.4 (2.1-4.8)	5.1 (3.4-6.8)	2.6 (1.6-3.7)	3.0 (1.7-4.3)	2.0 (1.4-2.7)	1.7 (1.0-2.4)
%BF females >35%, males>25%	3.9 (2.7-5.0)	1.8 (0.7-2.8)	5.4 (3.8-6.9)	2.9 (1.2-4.5)	4.3 (3.2-5.4)	3.3 (2.1-4.5)	2.6 (1.9-3.3)	1.3 (0.6-2.0)

[a] Unadjusted model.
[b] Model 1 is adjusted for sex, age, education, household income, urban/rural, smoking status, alcohol use, marital status, province of recruitment, time.
- Reference group for BMI is <30 kg/m^2, for WC is <88cm for females and <102 cm for males, for WHR is <0.85 for females and <0.90 for males, and for %BF is ≤35% for females and ≤25% for males.
- Acronyms: Body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), percent body fat (%BF), risk difference (RD), confidence interval (CI), general practitioner (GP), emergency department (ED).

2.8 Supplementary Tables and Figures

Table S1. Pearson correlation coefficients (r) (95% CI) for the relationships between BMI and %BF, WC and %BF, and WHR and %BF (n=30 092).

	%BF		
	Females	**Males**	**Total**
BMI (kg/m^2)	0.75 (0.74-0.75)	0.70 (0.70-0.71)	0.51 (0.50-0.52)
WC (cm)	0.70 (0.69-0.71)	0.75 (0.74-0.76)	0.21 (0.20-0.22)
WHR	0.29 (0.27-0.30)	0.46 (0.45-0.48)	-0.32 (-0.33- -0.31)

Table S2. Relative risks for the association between obesity defined using BMI, WC, WHR, and %BF cut points and HCU comparing adjusted Model 1 and Model 2 (n= 30 092).

	Contact with GP RR (95% CI)		**Contact with Specialist** RR (95% CI)		**Visit to ED** RR (95% CI)		**Overnight in Hospital** RR (95% CI)	
	Model 1[a]	Model 2[b]	Model 1[a]	Model 2[b]	Model 1[a]	Model 2[b]	Model 1[a]	Model 2[b]
BMI								
≥30 kg/m^2	1.01 (1.00-1.02)	1.00 (0.99-1.01)	1.10 (1.06-1.13)	0.98 (0.95-1.01)	1.25 (1.18-1.33)	1.13 (1.06-1.20)	1.38 (1.25-1.52)	1.17 (1.05-1.29)
WC								
females ≥88cm, males ≥102cm	1.02 (1.01-1.03)	1.00 (1.00-1.01)	1.13 (1.10-1.16)	1.02 (0.99-1.05)	1.24 (1.17-1.31)	1.12 (1.06-1.20)	1.40 (1.28-1.54)	1.20 (1.09-1.33)
WHR								
females ≥0.85, males ≥0.90	1.01 (1.00-1.02)	1.00 (0.99-1.01)	1.10 (1.07-1.14)	1.02 (0.99-1.06)	1.19 (1.11-1.28)	1.12 (1.04-1.20)	1.23 (1.10-1.38)	1.12 (0.99-1.26)
%BF								
females >35%, males>25%	1.01 (1.00-1.03)	1.00 (0.99-1.01)	1.06 (1.03-1.10)	0.97 (0.94-1.00)	1.22 (1.13-1.32)	1.13 (1.04-1.22)	1.24 (1.09-1.41)	1.06 (0.93-1.21)

[a] Model 1 is adjusted for sex, age, education, household income, urban/rural, smoking status, alcohol use, marital status, province of recruitment, time.
[b] Model 2 is adjusted for Model 1, chronic conditions and self-rated general health.
- Reference group for BMI is <30 kg/m^2, for WC is <88cm for females and <102 cm for males, for WHR is <0.85 for females and <0.90 for males, and for %BF is ≤35% for females and ≤25% for males.
- Acronyms: Body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), percent body fat (%BF), relative risk (RR), confidence interval (CI), general practitioner (GP), emergency department (ED).

Table S3. Sex stratified relative risks for the association between obesity defined using BMI, WC, WHR, and %BF cut points and HCU (Model 1) (n= 30 092).

		Contact with GP RR (95% CI)	**Contact with Specialist** RR (95% CI)	**Visit to ED** RR (95% CI)	**Overnight in Hospital** RR (95% CI)
BMI $\geq$30 kg/m^2	Females	1.01 (1.00-1.02)	1.10 (1.06-1.15)	1.28 (1.18-1.39)	1.55 (1.35-1.78)
	Males	1.02 (1.00-1.03)	1.10 (1.05-1.14)	1.22 (1.12-1.33)	1.25 (1.09-1.43)
	Both	1.01 (1.00-1.02)	1.10 (1.06-1.13)	1.25 (1.18-1.33)	1.38 (1.25-1.52)
WC females ≥88cm, males ≥102cm	Females	1.02 (1.00-1.03)	1.12 (1.08-1.16)	1.22 (1.12-1.32)	1.46 (1.27-1.68)
	Males	1.02 (1.01-1.03)	1.15 (1.10-1.19)	1.27 (1.16-1.38)	1.37 (1.20-1.56)
	Both	1.02 (1.01-1.03)	1.13 (1.10-1.16)	1.24 (1.17-1.31)	1.40 (1.28-1.54)
WHR females ≥0.85, males ≥0.90	Females	1.01 (1.00-1.02)	1.10 (1.06-1.15)	1.16 (1.07-1.26)	1.21 (1.06-1.39)
	Males	1.01 (0.99-1.04)	1.16 (1.09-1.25)	1.36 (1.16-1.59)	1.41 (1.10-1.81)
	Both	1.01 (1.00-1.03)	1.06 (1.03-1.10)	1.22 (1.13-1.32)	1.24 (1.09-1.41)
%BF females >35%, males>25%	Females	1.01 (1.00-1.03)	1.06 (1.01-1.12)	1.24 (1.11-1.38)	1.34 (1.11-1.63)
	Males	1.02 (1.00-1.03)	1.07 (1.02-1.13)	1.21 (1.09-1.34)	1.17 (0.99-1.39)
	Both	1.01 (1.00-1.02)	1.10 (1.07-1.14)	1.19 (1.11-1.28)	1.23 (1.10-1.38)

Model 1 is adjusted for sex, age, education, household income, urban/rural, smoking status, alcohol use, marital status, province of recruitment, time.
- Reference group for BMI is <30 kg/m^2, for WC is <88cm for females and <102 cm for males, for WHR is <0.85 for females and <0.90 for males, and for %BF is ≤35% for females and ≤25% for males.
- Acronyms: Body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), percent body fat (%BF), relative risk (RR), confidence interval (CI), general practitioner (GP), emergency department (ED).

Table S4. Age stratified relative risks for the association between obesity defined using BMI, WC, WHR, and %BF cut points and HCU (Model 1) (n= 30 092).

		Contact with GP RR (95% CI)	**Contact with Specialist** RR (95% CI)	**Visit to ED** RR (95% CI)	**Overnight in Hospital** RR (95% CI)
BMI ≥30 kg/m^2	45-54	1.03 (1.01-1.05)	1.09 (1.02-1.16)	1.31 (1.16-1.47)	1.48 (1.16-1.88)
	55-64	1.02 (1.00-1.03)	1.15 (1.10-1.21)	1.26 (1.14-1.39)	1.52 (1.28-1.80)
	65-74	1.01 (1.00-1.02)	1.11 (1.06-1.17)	1.22 (1.09-1.37)	1.59 (1.35-1.87)
	75+	1.01 (1.00-1.03)	0.97 (0.91-1.04)	1.15 (1.01-1.32)	0.91 (0.75-1.10)
	All	1.01 (1.00-1.02)	1.10 (1.06-1.13)	1.25 (1.18-1.33)	1.38 (1.25-1.52)
WC females ≥88cm, males ≥102cm	45-54	1.03 (1.01 (1.05)	1.17 (1.10-1.25)	1.26 (1.12-1.41)	1.57 (1.25-1.97)
	55-64	1.02 (1.01-1.04)	1.14 (1.09-1.20)	1.34 (1.22-1.49)	1.58 (1.33-1.87)
	65-74	1.02 (1.01-1.03)	1.13 (1.08-1.19)	1.22 (1.09-1.36)	1.61 (1.36-1.90)
	75+	1.01 (1.00-1.03)	1.02 (0.96-1.07)	1.05 (0.93-1.18)	0.91 (0.77-1.07)
	All	1.02 (1.01-1.03)	1.13 (1.10-1.16)	1.24 (1.17-1.31)	1.40 (1.28-1.54)
WHR females ≥0.85, males ≥0.90	45-54	1.01 (0.99-1.03)	1.19 (1.11-1.27)	1.32 (1.15-1.50)	1.54 (1.18-2.02)
	55-64	1.02 (1.00-1.04)	1.13 (1.07-1.19)	1.15 (1.03-1.29)	1.34 (1.09-1.66)
	65-74	1.01 (1.00-1.02)	1.05 (0.99-1.12)	1.16 (1.02-1.32)	1.19 (0.97-1.46)
	75+	1.00 (0.99-1.02)	0.96 (0.90-1.03)	1.02 (0.88-1.18)	0.88 (0.72-1.07)
	All	1.01 (1.00-1.03)	1.06 (1.03-1.10)	1.22 (1.13-1.32)	1.24 (1.09-1.41)
%BF females >35%, males>25%	45-54	1.02 (1.00-1.04)	1.10 (1.03-1.18)	1.31 (1.15-1.49)	1.40 (1.07-1.82)
	55-64	1.02 (1.00-1.04)	1.07 (1.01-1.14)	1.32 (1.16-1.50)	1.28 (1.03-1.59)
	65-74	1.02 (1.00-1.03)	1.04 (0.98-1.11)	1.05 (0.92-1.22)	1.26 (1.00-1.59)
	75+	1.02 (1.00-1.04)	0.97 (0.90-1.04)	0.90 (0.77-1.06)	0.93 (0.74-1.16)
	All	1.01 (1.00-1.02)	1.10 (1.07-1.14)	1.19 (1.11-1.28)	1.23 (1.10-1.38)

Model 1 is adjusted for sex, age, education, household income, urban/rural, smoking status, alcohol use, marital status, province of recruitment, time.

- Reference group for BMI is <30 kg/m^2, for WC is <88cm for females and <102 cm for males, for WHR is <0.85 for females and <0.90 for males, and for %BF is ≤35% for females and ≤25% for males.
- Acronyms: Body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), percent body fat (%BF), relative (RR), confidence interval (CI), general practitioner (GP), emergency department (ED).

Table S5. Sex stratified risk difference for the excess risk of HCU in those with obesity compared to those without obesity defined by BMI, WC, WHR, and %BF (n= 30 092). Risk per 100 people (Model 1).

		Contact with GP RD (95% CI)	**Contact with Specialist** RD (95% CI)	**Visit to ED** RD (95% CI)	**Overnight in Hospital** RD (95% CI)
BMI ≥30 kg/m^2	Females	1.6 (0.6-2.6)	5.1 (3.0-7.3)	5.0 (3.2-6.7)	3.5 (2.4-4.7)
	Males	2.0 (0.9-3.2)	4.6 (2.4-6.8)	3.4 (1.7-5.1)	2.0 (0.9-3.1)
	Both	1.9 (1.1-2.7)	4.6 (3.0-6.1)	2.5 (1.7-3.3)	2.6 (1.8-3.4)
WC females ≥88cm, males ≥102cm	Females	1.7 (0.7-2.7)	5.6 (3.6-7.6)	3.5 (1.9-5.0)	2.6 (1.7-3.6)
	Males	2.2 (1.0-3.4)	6.7 (4.7-8.8)	4.1 (2.5-5.7)	2.7 (1.7-3.7)
	Both	1.9 (1.1-2.7)	5.9 (4.5-7.4)	3.8 (2.7-4.9)	2.6 (1.9-3.3)
WHR females ≥0.85, males ≥0.90	Females	1.1 (0.1-2.1)	4.9 (2.8-6.9)	2.5 (0.9-4.1)	1.5 (0.5-2.5)
	Males	1.6 (-0.5-3.6)	7.1 (5.0-10.2)	4.2 (2.0-6.4)	2.2 (1.1-3.2)
	Both	1.2 (0.3-2.1)	5.1 (3.4-6.8)	3.0 (1.7-4.3)	1.7 (1.0-2.4)
%BF females >35%, males>25%	Females	1.6 (0.3-2.9)	3.0 (0.5-5.4)	3.8 (2.0-5.5)	1.7 (0.8-2.7)
	Males	2.1 (0.6-3.6)	3.1 (0.8-5.4)	3.0 (1.0-4.7)	1.4 (0.4-2.3)
	Both	1.8 (0.7-2.8)	2.9 (1.2-4.5)	3.3 (2.1-4.5)	1.3 (0.6-2.0)

Model 1 is adjusted for age, education, household income, urban/rural, smoking status, alcohol use, marital status, province of recruitment, time.
- Reference group for BMI is <30 kg/m^2, for WC is <88cm for females and <102 cm for males, for WHR is <0.85 for females and <0.90 for males, and for %BF is ≤35% for females and ≤25% for males.
- Acronyms: Body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), percent body fat (%BF), risk difference (RD), confidence interval (CI), general practitioner (GP), emergency department (ED).

Table S6. Age stratified risk difference for the excess risk of HCU in those with obesity compared to those without obesity defined by BMI, WC, WHR, and %BF (n= 30 092). Risk per 100 people (Model 1).

		Contact with GP RD (95% CI)	**Contact with Specialist** RD (95% CI)	**Visit to ED** RD (95% CI)	**Overnight Stay in ED** RD (95% CI)
BMI ≥30 kg/m^2	45-54	2.7 (0.9-4.5)	3.8 (1.0-6.7)	4.3 (2.2-6.5)	2.1 (0.8-3.3)
	55-64	1.7 (0.4-3.0)	7.2 (4.8-9.6)	4.2 (2.3-6.1)	3.3 (2.0-4.5)
	65-74	1.0 (-0.1-2.1)	6.2 (3.4-9.0)	4.1 (1.8-6.4)	4.4 (2.7-6.2)
	75+	1.4 (0.1-2.6)	-1.4 (-5.2-2.3)	3.6 (0.3-6.9)	0.7 (-1.8-3.2)
	All	1.9 (1.1-2.7)	4.6 (3.0-6.1)	2.5 (1.7-3.3)	2.6 (1.8-3.4)
WC females ≥88cm, males ≥102cm	45-54	2.7 (1.0-4.4)	6.8 (4.1-9.5)	3.5 (1.5-5.5)	2.2 (1.1-3.4)
	55-64	2.1 (0.9-3.4)	6.7 (4.4-0.9)	5.1 (3.4-6.8)	3.2 (2.0-4.3)
	65-74	1.8 (0.6-2.9)	6.7 (4.1-9.4)	3.5 (1.4-5.6)	4.0 (2.6-5.5)
	75+	1.3 (0.0-2.5)	0.7 (-2.5-3.9)	1.2 (-1.6-3.9)	0.5 (-1.6-2.7)
	All	1.9 (1.1-2.7)	5.9 (4.5-7.4)	3.8 (2.7-4.9)	2.6 (1.9-3.3)
WHR females ≥0.85, males ≥0.90	45-54	0.9 (-1.1-2.9)	7.5 (4.5-10.5)	3.9 (1.7-6.0)	2.0 (1.0-3.0)
	55-64	2.2 (0.7-3.7)	6.2 (3.4-8.9)	2.4 (0.3-4.4)	2.0 (0.8-3.3)
	65-74	1.0 (-0.2-2.2)	2.6 (-0.7-5.9)	3.1 (0.6-5.7)	1.5 (-0.1-3.2)
	75+	0.6 (-0.9-2.0)	-1.7 (-5.7-2.3)	0.4 (-3.1-3.9)	0.4 (-2.1-3.0)
	All	1.2 (0.3-2.1)	5.1 (3.4-6.8)	3.0 (1.7-4.3)	1.7 (1.0-2.4)
%BF females >35%, males>25%	45-54	2.1 (0.2-4.0)	3.7 (1.0-6.3)	3.6 (1.7-5.5)	1.3 (0.3-2.2)
	55-64	1.8 (0.1-3.4)	3.4 (0.7-6.1)	4.4 (2.5-6.4)	1.5 (0.4-2.7)
	65-74	1.5 (-0.2-3.2)	2.2 (-1.2-5.6)	1.3 (-1.4-3.9)	1.8 (0.6-3.0)
	75+	1.7 (-0.2-3.6)	-1.7 (-6.2-2.6)	-2.3 (-6.1-1.5)	-1.5 (-4.4-1.4)
	All	1.8 (0.7-2.8)	2.9 (1.2-4.5)	3.3 (2.1-4.5)	1.3 (0.6-2.0)

Model 1 is adjusted for sex, education, household income, urban/rural, smoking status, alcohol use, marital status, province of recruitment, time.
- Reference group for BMI is <30 kg/m^2, for WC is <88cm for females and <102 cm for males, for WHR is <0.85 for females and <0.90 for males, and for %BF is ≤35% for females and ≤25% for males.
- Acronyms: Body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), percent body fat (%BF), risk difference (RD), confidence interval (CI), general practitioner (GP), emergency department (ED).

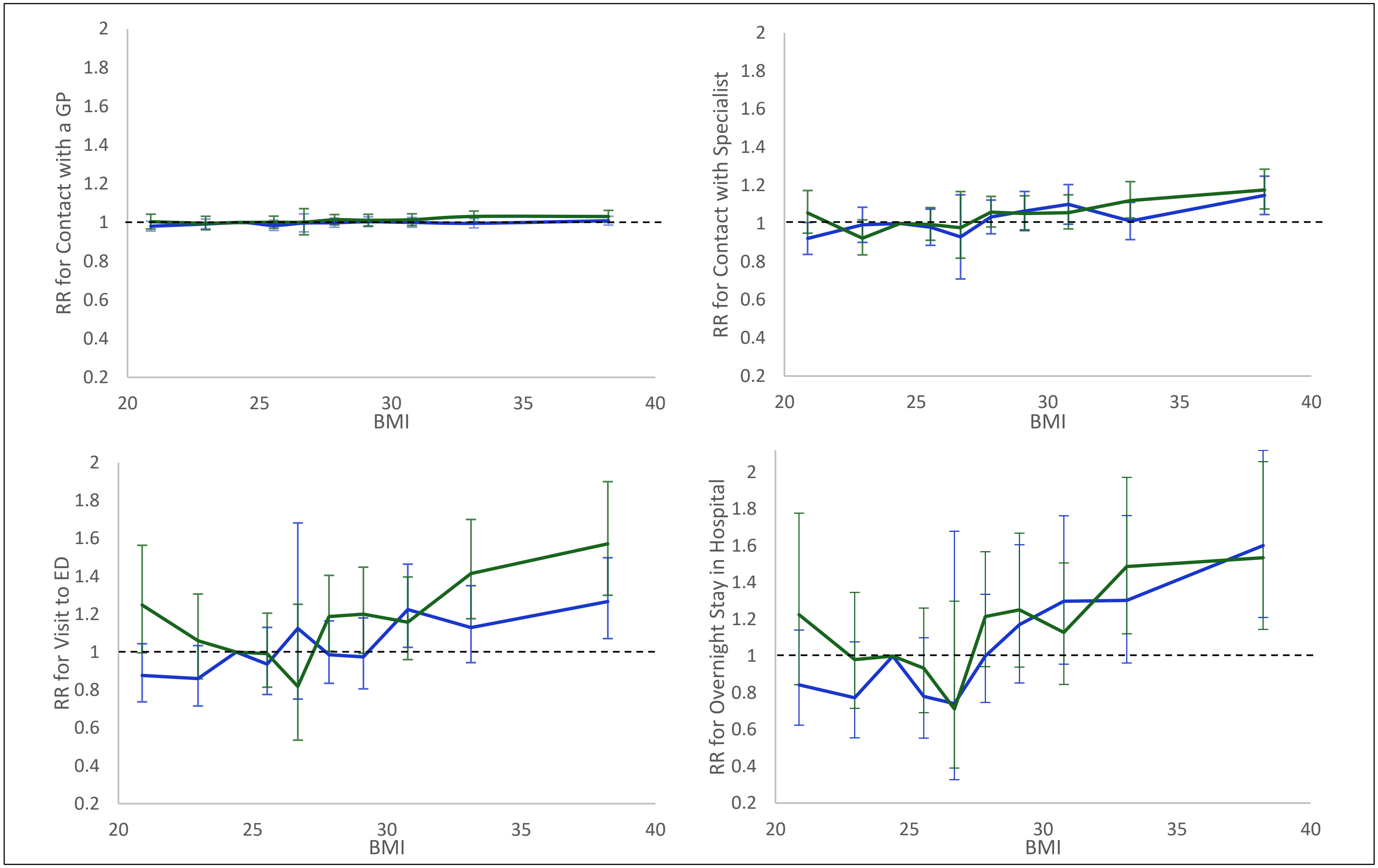

Figure S1. Plot of BMI against relative risk for each type of HCU for females (blue) and males (green) (n= 30 092). BMI was separated into deciles, with each decile group compared the reference decile with a median of 24.4 kg/m^2 (range: 23.7-25.0 kg/m^2). Figure 2a, 2b, 2c, and 2d depict the RRs for contact with a GP, contact with a specialist, visit to an ED, and overnight stay in the hospital, respectively

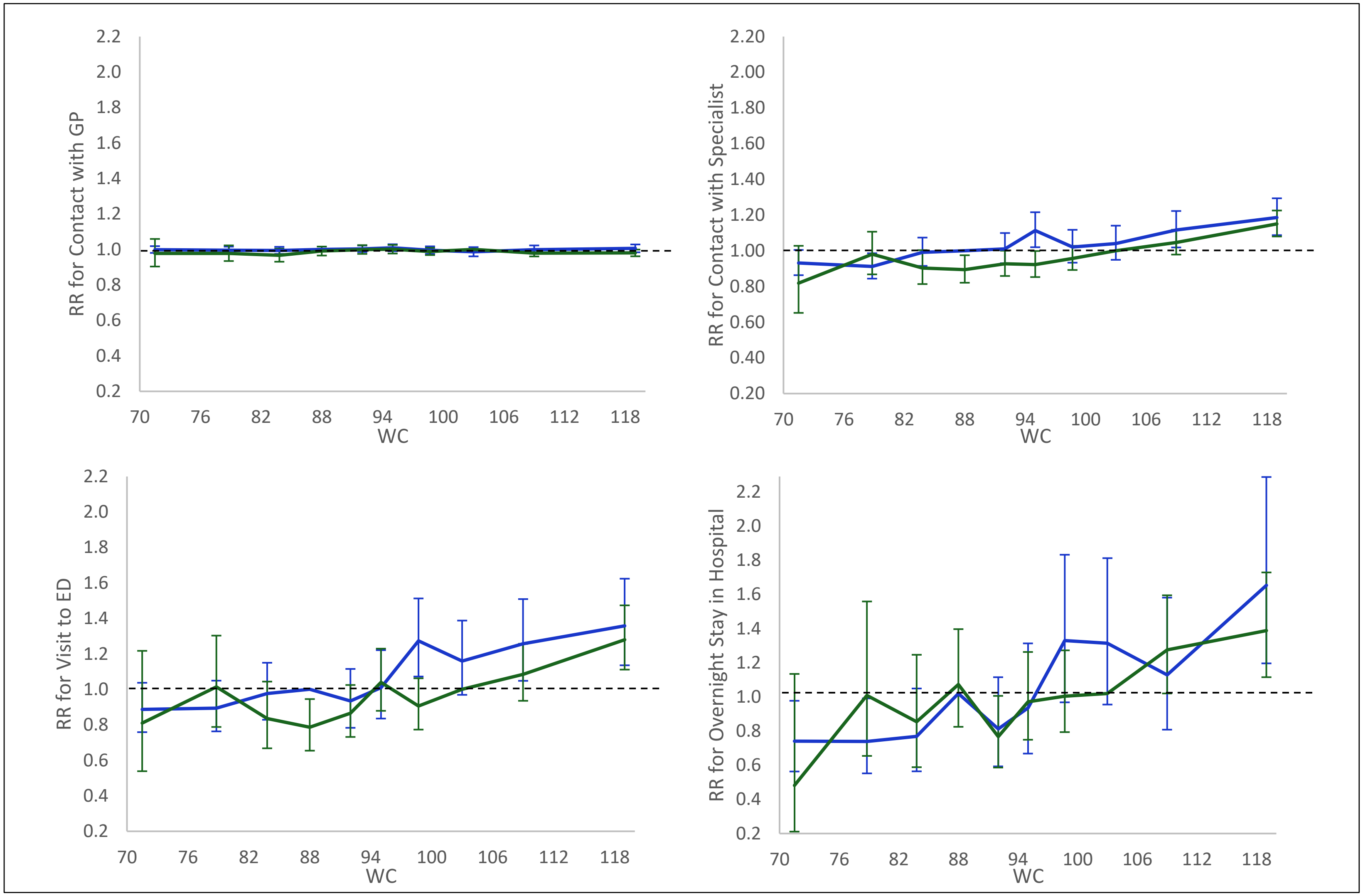

Figure S2. Plot of WC against RR for each type of HCU for females (blue) and males (green) (n= 30 902). WC was separated into deciles, with each decile group compared the reference decile with a median of 88cm for females and 103cm for males (female range: 86-90, male range: 101-106). Figure 3a, 3b, 3c, and 3d depict the RRs for contact with a GP, contact with a specialist, visit to an ED, and overnight stay in the hospital, respectively.

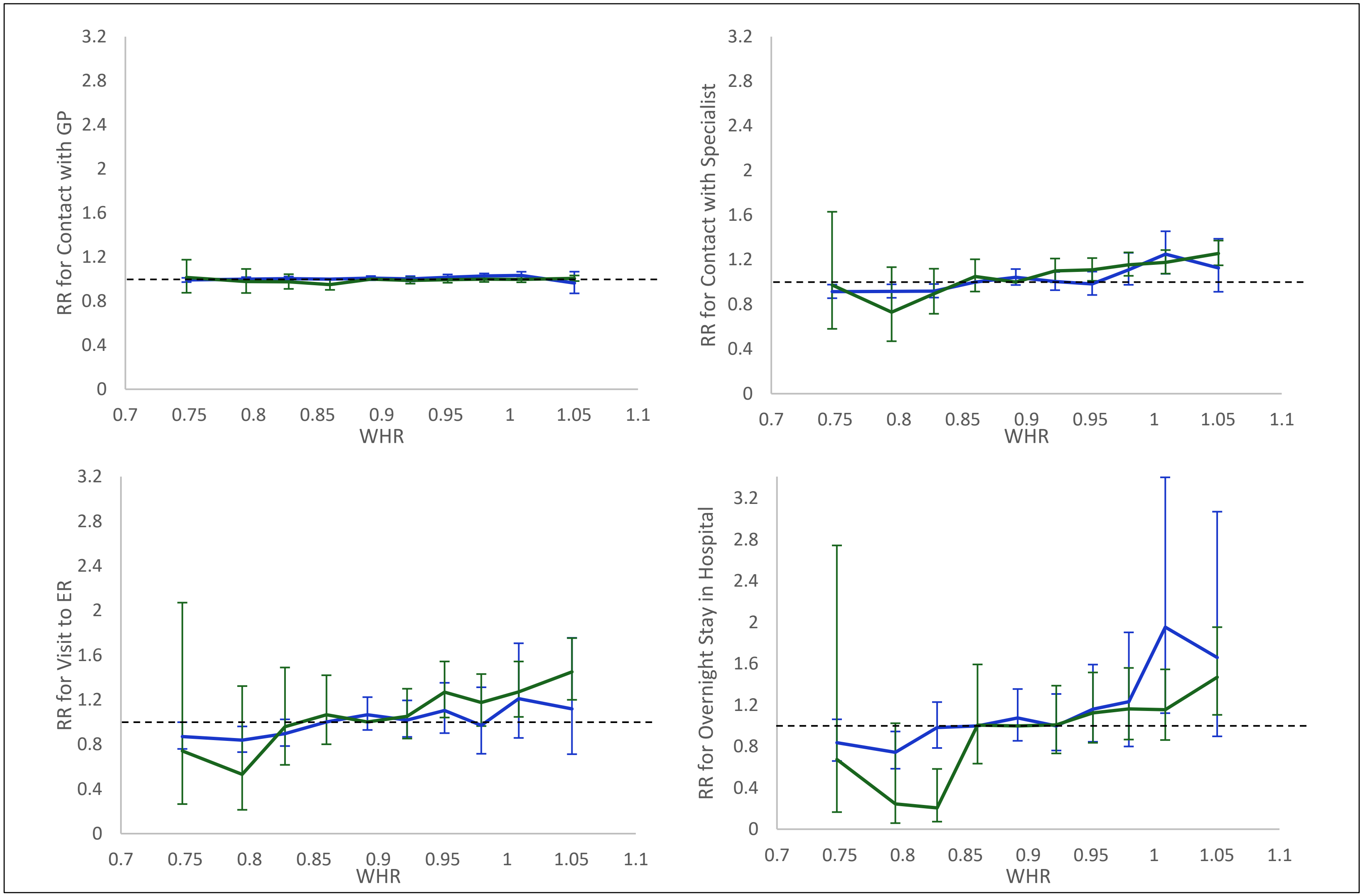

Figure S3. Plot of WHR against RR for each type of HCU for females (blue) and males (green) (n= 30 902). WHR was separated into deciles, with each decile group compared the reference decile with a median of 0.86 for females and 0.89 for males (female range: 0.84-0.88, male range: 0.88-0.91). Figure 4a, 4b, 4c, and 4d depict the RRs for contact with a GP, contact with a specialist, visit to an ED, and overnight stay in the hospital, respectively.

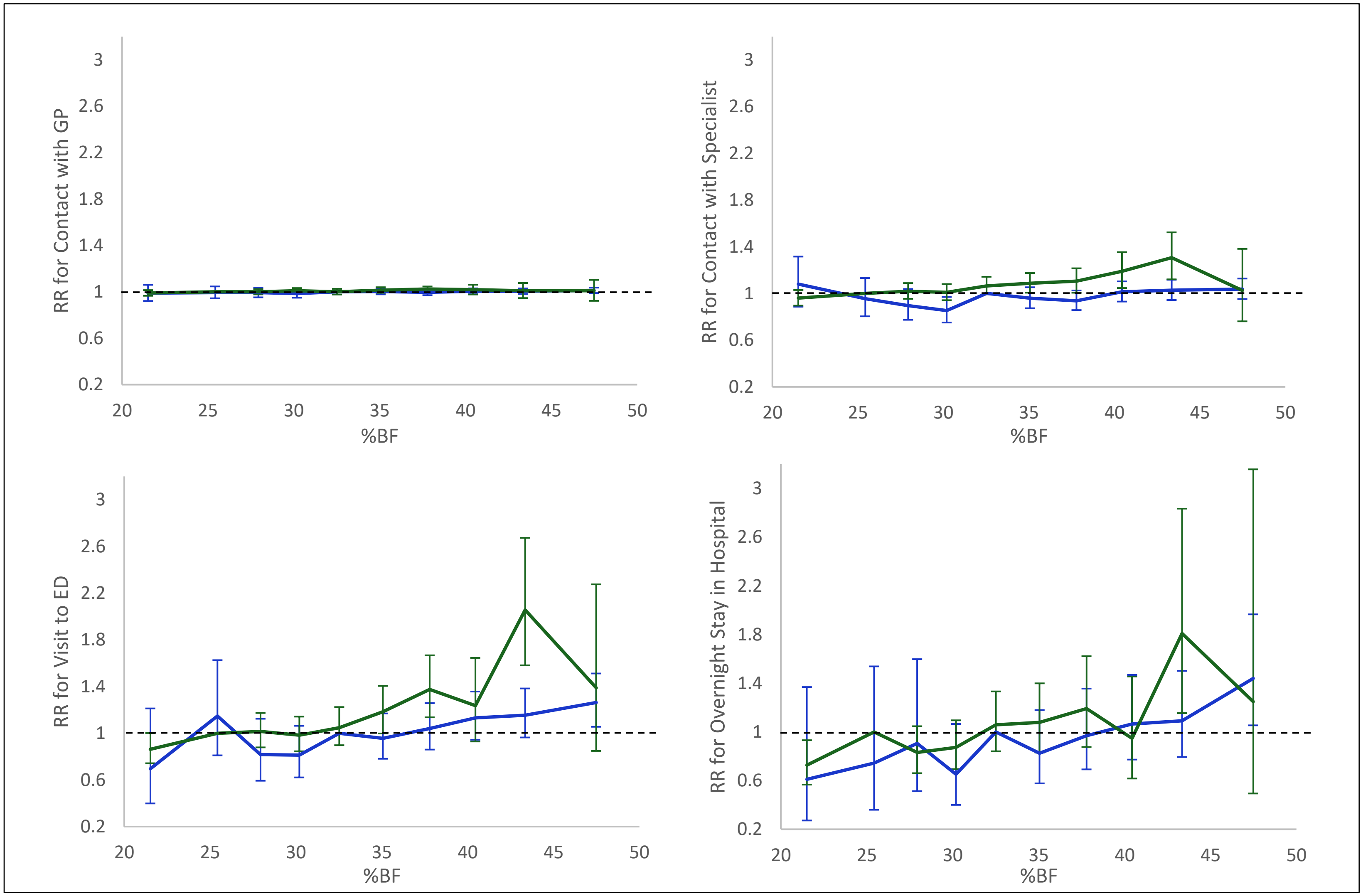

Figure S4. Plot of %BF against RR for each type of HCU for females (blue) and males (green) (n= 30 902). %BF was separated into deciles, with each decile group compared the reference decile with a median of 32.5% for females and 25.4% for males (female range: 31.4-33.7%, male range: 23.8-26.8%). Figure 4a, 4b, 4c, and 4d depict the RRs for contact with a GP, contact with a specialist, visit to an ED, and overnight stay in the hospital, respectively

Chapter 3: Additional Findings

In this short chapter, I present findings that were not included as primary or supplementary results of the manuscript in Chapter 2. Additional results are discussed in Section 3.1 and tables are presented in Section 3.2 to provide more comprehensive and transparent findings.

3.1 Additional Results

Table S7 contains the weighted means and standard deviations for each anthropometric measure, stratified by sex. Mean BMI was greater in males than females, although not significant. Mean WC and mean WHR were significantly greater in males than females. Mean %BF was significantly greater in females than males.

Table S8 contains weighted counts of BMI, WC, WHR and %BF using obesity cut points, stratified by age group. For WC, WHR and %BF, the prevalence of obesity generally increased as age group increased. For BMI, the prevalence of obesity was lowest in the oldest age group.

Table S9 contains weighted counts for each type of HCU, stratified by age group. Generally, older adult groups with any definition of obesity had greater proportions of HCU for both outpatient and inpatient indicators.

Table S10 and Table S11 contain sensitivity and specificity values comparing BMI, WC, and WHR cut points to %BF by age group in females and males, respectively.

3.2 Additional Tables

Table S7. Weighted means (standard deviation) for continuous anthropometric measures stratified by sex.

	Female	**Male**	**Total**
BMI, kg/m^2 (n=29,956)	27.7 (0.05)	28.4 (0.05)	28.02 (0.04)
WC, cm (n=29,857)	87.7 (0.1)	99.8 (0.1)	93.6 (0.1)
WHR, (n=29,857)	0.83 (0.0006)	0.97 (0.0006)	0.90 (0.0006)
%BF, % (n=28,782)	39.1 (0.06)	28.1 (0.06)	33.7 (0.05)

Table S8. Weighted counts (%) of categorical anthropometric measures stratified by age.

	45-54	55-64	65-74	75+	Total
BMI					
BMI <30 kg/m^2	9000 (72.8)	6174 (68.1)	3662 (69.1)	2466 (75.8)	21 302 (71.1)
BMI ≥30 kg/m^2	3357 (27.2)	2888 (31.9)	1641 (30.9)	789 (24.2)	8 675 (28.9)
WC					
females <88cm, males <102cm	7980 (64.6)	5017 (55.6)	2642 (50.1)	1722 (53.0)	17 312 (58.1)
females ≥88cm, males ≥102 cm	4369 (35.4)	4011 (44.4)	2637 (49.9)	1525 (47.0)	12 542 (41.9)
WHR					
females <0.85, males <0.90	5269 (42.7)	3190 (35.3)	1825 (34.6)	1052 (32.4)	11 336 (37.9)
females ≥0.85, males ≥0.90	7079 (57.3)	5838 (64.7)	3454 (65.4)	2196 (67.6)	18 567 (62.1)
%BF					
females ≤35%, males ≤25%	4671 (35.6)	2085 (23.8)	926 (18.2)	522 (16.9)	7802 (27.0)
females >35%, males>25%	7719 (64.4)	6680 (76.2)	4160 (81.8)	2557 (83.1)	21 115 (73.0)

Table S9. Weighted counts (%) for health care use in the past 12 months, stratified by age.

	45-54	55-64	65-74	75+	Total
Contact with a GP					
No	1 864 (15.8)	930 (10.6)	320 (6.2)	150 (4.9)	3 264 (11.4)
Yes	9 942 (84.2)	7 812 (89.4)	4 813 (93.8)	2 923 (95.1)	25 490 (88.6)
Contact with a specialist					
No	6 861 (58.1)	4 454 (50.9)	2 313 (45.1)	1 321 (43.1)	14 949 (52.0)
Yes	4 948 (41.9)	4 296 (49.1)	2 817 (54.9)	1 746 (56.9)	13 807 (48.0)
Seen in an ED					
No	9 828 (83.2)	7 197 (82.2)	4 109 (80.1)	2 342 (76.3)	23 477 (81.6)
Yes	1 992 (16.8)	1 553 (17.8)	1 018 (19.9)	728 (23.7)	5 498 (18.4)
Patient in a hospital overnight					
No	11 269 (95.3)	8 162 (93.2)	4 631 (90.2)	2 648 (86.2)	26 711 (92.8)
Yes	556 (4.7)	598 (6.8)	503 (9.8)	426 (13.8)	2 082 (7.2)

Table S10. Sensitivity and specificity values (95% confidence interval) for BMI, WC, and WHR compared to %BF by age group (45-54, 55-64, 65-74, 75+) in females.

	Reference Standard (%BF >35%)							
	45-54		**55-64**		**65-74**		**75+**	
	Sensitivity	**Specificity**	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**
BMI (≥30 kg/m^2)	37.6 (36.1-39.1)	98.8 (98.4-99.3)	38.5 (36.8-40.1)	98.8 (98.0-99.5)	37.4 (35.5-39.4)	99.0 (98.1-100.0)	31.1 (28.7-33.6)	99.5 (98.6-100)
WC (≥88cm)	54.0 (52.5-55.6)	93.6 (92.6-94.7)	57.6 (56.0-59.3)	92.0 (90.2-93-8)	62.3 (60.3-64.2)	91.5 (88.9-94.1)	59.5 (56.9-62.1)	92.5 (89.4-95.6)
WHR (≥0.85)	38.7 (37.1-40.2)	86.4 (84.9-87.9)	43.9 (42.2-45.5)	80.6 (77.9-83.2)	49.1 (47.1-51.1)	79.8 (76.0-83.6)	51.4 (48.7-54.0)	74.3 (69.2-79.5)

Table S11. Sensitivity and specificity values (95% confidence interval) for BMI, WC, and WHR compared to %BF by age group (45-54, 55-64, 65-74, 75+) in males.

	Reference Standard (%BF >25%)							
	45-54		**55-64**		**65-74**		**75+**	
	Sensitivity	**Specificity**	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**
BMI (≥30 kg/m^2)	43.1 (41.6-44.7)	94.6 (93.7-95.6)	43.6 (41.9-45.3)	94.7 (93.4-96.0)	37.9 (35.7-40.2)	97.6 (96.2-98.9)	26.0 (23.5-28.5)	99.0 (97.7-100)
WC (≥102)	49.4 (47.8-51.0)	94.8 (93.8-95.7)	54.5 (52.8-56.2)	93.1 (91.7-94.5)	55.8 (54.5-58.1)	92.4 (90.1-94.8)	49.6 (46.8-52.5)	93.7 (90.6-96.7)
WHR (≥0.90)	93.4 (92.6-94.2)	31.4 (29.5-33.4)	95.0 (94.2-95.7)	24.5 (22.1-26.9)	95.6 (94.6-96.5)	22.7 (19.0-26.4)	95.0 (93.8-96.3)	24.0 (18.6-29.2)

Chapter 4: Conclusion

4.1 Summary of Findings

Analysis of the Comprehensive cohort from the CLSA revealed that the prevalence of obesity in Canadian adults and older adults varied greatly depending on which anthropometric measure was used to define obesity. The most commonly used measure to assess obesity, BMI, largely underestimated the 'true' prevalence of obesity when using %BF. Comparisons of anthropometric measures revealed that BMI and WC were more highly correlated with %BF than WHR. Commonly accepted BMI and WC cut points had high specificity and lower sensitivity in estimating obesity defined by %BF in females and males, while the diagnostic accuracy of WHR in relation to %BF was quite variable between sexes. Finally, adults with any definition of obesity had greater relative and absolute risk of all types of outpatient and inpatient HCU. Relative and absolute risks of HCU did not differ between males and females although the oldest adult group generally demonstrated lower relative risks and smaller absolute risks than the youngest group, which may be indicative of selection bias within the CLSA cohort or that obesity is not as strong of a predictor of HCU in older adults.

4.2 Implications to Public Health and Areas for Future Research

This thesis work is important to public health as we have demonstrated differences among BMI, WC, WHR, and %BF in defining obesity and in predicting 'true' obesity status defined by %BF. Although BMI is the measure most commonly used in clinical settings, BMI, WC, WHR, and %BF may be evaluating different aspects of obesity that may be important to investigate further and consider when diagnosing individuals with obesity. Future research should aim to discern the best measure to evaluate obesity and if there are more appropriate sex and/or age specific cut points to define obesity.

Regardless of the anthropometric measure used, we found increased HCU for both outpatient and inpatient indicators, suggesting that we need to properly allocate healthcare resources and design prevention strategies to mitigate the effects of obesity on the Canadian economy. Additionally, we found that chronic conditions and self-rated general health were potential mediators on the causal pathway between obesity and HCU. Therefore, efforts to prevent and reduce the burden of obesity may have added benefits in also reducing chronic diseases and improving self-reported health. To better investigate which type of health service is used most by individuals with obesity, future research should investigate the association of obesity with the number of HCU visits or health care costs by linking anthropometric data to administrative health data.

Although our findings demonstrated lower relative risks and smaller absolute risks of HCU in older adults aged 75+ with obesity compared to adults aged 45-54 with obesity, we must consider that the CLSA is a predominately healthy and educated cohort of community-dwelling adults and may not be truly reflective of the whole Canadian population.[1] Since the proportion of adults aged 65 years and older is projected to increase from 15.6% in 2014 to 23% by 2030,[2] we need to focus future research on older adults and prepare for the aging population by allocating public health and healthcare resources effectively.

4.3 Final Remarks

This thesis work used data from the Comprehensive cohort of the CLSA and provided anthropometric measures recorded by trained staff, including %BF measured using DXA, on just over 30,000 Canadian adults. Our comparisons of BMI, WC, WHR, and %BF with such a large sample size was highly relevant to public health and health research as researchers and clinicians work towards discerning the best measure and appropriate cut points for obesity. These findings will inform future research on anthropometric measures and the utilization of healthcare resources by individuals with obesity so that we may work towards so improving the health of Canadians and diminish the burden on the Canadian health care system.

4.4 References

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2. Government of Canada. *Action for Seniors Report*.; 2014. https://www.canada.ca/en/employment-social-development/programs/seniors-action-report.html. Accessed July 4, 2019.