THE RELATIONSHIP BETWEEN BODY COMPOSITION AND LUNG FUNCTION, AND THE EFFECT OF PHYSICAL FITNESS

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Table of Contents

List of Tables

Abstract

Body composition is a potential modifiable risk factor for decreased lung function. It is therefore useful to understand this association. A single study examined this relationship while considering physical fitness/activity as possible confounders, but the results were not widely generalizable.

Cycles 1 and 2 of the Canadian Health Measures Survey were used to address the following objectives:

1. Examining the association between anthropometric measures and lung function in Canadians over age 40.
2. Determining if that association is influenced by physical fitness/activity.

Anthropometric measures were stronger predictors of FVC than FEV1. Physical fitness and physical activity were confounders of the relationship of interest. The results of the current study add support to the literature stating that BMI is not the best anthropometric predictor of lung function, as well as indicate that physical fitness and activity should be taken into consideration as potential confounders of the relationship of interest.

List of Symbols and Abbreviations Used

AFS	Aerobic Fitness Score
ARDC	Atlantic Research Data Center
ATC	Anatomical Therapeutic Chemical
BMC	Bone Mineral Content
BMI	Body Mass Index
CD	Compact Disc
CDC	Centre for Disease Control and Prevention
CHMS	Canadian Health Measures Survey
CI	Confidence Interval
cm	centimeter
COPD	Chronic Obstructive Pulmonary Disease
CV	Coefficient of Variation
DEXA	Dual Energy X-Ray Absorptiometry
FEV_1	Forced Expiratory Volume in the First Second
FM	Fat Mass
FSQ	Functional Status Questionnaire
FVC	Forced Vital Capacity
HALS1	Health and Lifestyle Survey 1
HR	Hazard Ratio
i^2	Percentage of Variability

kg	kilogram
kg/m^2	kilogram per squared meter
L	liter
L/min	liter per minute
LLN	Lower Limit of Normal
mCAFT	Modified Canadian Aerobic Fitness Test
MEC	Mobile Examination Center
METs	Metabolic Equivalent of Task
mm	millimeters
n	number
NHANES III	National Health and Nutrition Examination Survey III
PAEE	Physical Activity Energy Expenditure
PAI	Physical Activity Index
PPT	Physical Performance Test
R^2	Coefficient of Determination
RR	Risk Ratio
SD	Standard Deviation
SEM	Standard Error of the Mean
VO_2	Maximal Oxygen Consumption
%	Percentage
β	Regression Estimate

Chapter 1: Introduction

Respiratory diseases are increasingly some of the most prevalent conditions affecting the Canadian population. In a Public Health Agency of Canada publication from 2007, *Life and Breath*, they state that the problem of respiratory illness in Canada is increasing as the population ages and that the demand on the healthcare system due to this increase is creating a significant challenge to accommodate.(1) The most common lung diseases affecting the Canadian population include both Chronic Obstructive Pulmonary Disease (COPD) and asthma.(2) According to the Asthma Society of Canada there are currently (as of February 2014) approximately 3 million Canadians living with asthma.(3) The Public Health Agency of Canada reported that in 2010-2011, 772,200 Canadians over the age of 35 had reported a diagnosis of COPD.(4)

There is a significant economic burden that is directly related to respiratory disease. Many respiratory diseases, including COPD and asthma, are chronic conditions that people live with for many years. In 2007, respiratory diseases (not including lung cancer) were responsible 6.5% of total Canadian health care costs, a figure which will likely increase with the increasing prevalence of the disease in the aging Canadian population.(1) It was also estimated, that in 2007, $5.70 billion was spent on direct health care costs for respiratory disease, while another $6.72 billion was spent on less direct costs associated with lung disease such as disability and premature mortality.(1)

The burden of respiratory disease, however, is not solely economic. There is also a significant impact on the quality of life of those affected. In 2011, Canadians living with COPD identified an impact of disease on their overall health, mental health, limitations to mobility, activities of daily living, work and volunteer participation, social and recreational activities.(1)

Decreased lung function is a diagnostic indicator for lung disease. Decreased lung function however, is also a predictor of mortality independent of diagnosed lung disease.(5) This implies that even small changes in lung function that may be clinically insignificant (and would not result in the diagnosis of a respiratory disease) are still related to mortality. This is an important association and therefore it is useful to look at not only lung disease, but also general lung function and its predictors. Moreover it has been recommended that lung function be included as a tool when assessing general health.(5)

There are several known risk factors for lung disease and decreased lung function. Socioeconomic factors have been shown to be associated with decreased lung function such as low socioeconomic status, low level of education, and marital status.(6) There are several well-known physical risk factors for decreased lung function as well, including lack of physical activity (7), smoke exposure, environmental exposures, and obesity. Factors such as age, sex, height, ethnicity, and cigarette smoking are also known to affect lung function. It is important to understand how these factors inter-relate to affect lung function, especially those risk factors which are modifiable.

According to the Centre for Disease Control and Prevention (CDC), the definition of obesity is when an individual's weight is higher than would be considered healthy for their height.(8) The idea that obesity influences lung function is not new. In 360 BC an obese tyrant, Dionysius, was described as having "daily gluttony and intemperance, increased to an extraordinary degree of Corpulency and Fatness, by reason whereof he had much adoe to take breath."(9) While this is an old idea, and many studies have investigated various aspects of the association between obesity and lung function, some questions remain.

Obesity as a risk factor for decreased lung function is less understood than many of the common risk factors and is the topic of increasing research. Obesity has the potential to affect lung function through an excess of fat surrounding the rib cage and abdomen, reducing the available volume for the lungs to expand.(10) There are however, various indicators and measurements of obesity. There are those measures which distinguish fat mass from fat-free mass and those that do not. Body mass index (BMI) is the most commonly reported measure of obesity but does not distinguish between fat mass and fat-free mass. Due to the mechanism by which obesity is proposed to affect lung function, it is unclear whether BMI is the most appropriate measure of obesity to be used when studying lung function.

It is commonly found that obesity is inversely related to physical fitness, with the most obese being the least physically fit.(11) There is also a reported association between physical fitness and lung function.(12) Although it has been shown that physical fitness is associated with obesity and with lung function, there is little known about how physical fitness impacts the relationship between them.

Chapter 2: Objectives

The objectives of the current study are i) to investigate the association between anthropometric measures and lung function in a population-based sample of Canadians over the age of 40; and ii) to determine if the relationship between anthropometric measures and lung function is independent of both physical fitness and physical activity.

Chapter 3: Literature Review

In this literature review I describe the various implications of decreased lung function. I will describe the impact of obesity and its association with lung function, in those with and without lung disease. The pathophysiological explanations will be explored, as well as the impact of which measures of obesity are considered and the differences among them. I include in the later sections of the literature review, the effects of body composition and physical fitness on health outcomes and more specifically on lung function. Finally, I will conclude the literature review by describing a key study, which investigated the relationship between body composition and lung function while considering physical fitness and highlighting how the current research will complement the limited literature on this subject.

3.1 – Lung function is commonly evaluated using two spirometric measures: forced vital capacity (FVC) and forced expiratory volume in the first second (FEV_1)

A spirometer is a device that measures airflow from specific breath maneuvers in order to measure certain aspects of lung function, in a test called spirometry. Two of the most commonly used measurements from spirometry, and therefore of lung function, are forced vital capacity (FVC) and forced expiratory volume in the first second (FEV_1). These measurements are obtained from the same spirometric maneuver. FVC is the maximal volume of air that can be exhaled, following a maximal inspiration.(13) FEV_1 is the maximal volume of air that can be forcibly exhaled during the first second of exhalation, following maximal inspiration.(13) Together these two measures indicate how much air an individual can breathe out, and how quickly they can do so and thus give an indication of lung function.(2)

The interpretation of spirometry is most effective in diagnosis when the results can be considered along with the pre-test probability of disease and the post-test probability of disease.(14) The shape of the volume versus time curves obtained from spirometry would be the first place where less severe airflow obstruction would be reflected.(14) As obstruction to the airways becomes more advanced, it is also reflected in any timed measurements from spirometry, such as FEV_1.(14)

Often FVC and FEV_1 are reported as ‘percent predicted’ values. A predicted value is calculated by a formula. One example of a percent predicted equation is derived from the National Health and Nutrition Examination Survey III (NHANESIII) study.(14) The parameters of the equation to calculate predicted values are based on large samples of healthy individuals between the ages of 30-90 and take into consideration the age, sex, height and ethnicity of the individuals.(14) In 2011, prediction equations for individuals between ages 20-90 were created based on two population-based Canadian studies and the results from the prediction equation were not significantly different than those from the NHANESIII reference equation.(15)

Expected values and the defined range of normal spirometric values depend on an individual’s age, sex, height, and ethnicity. According to the Center for Disease Control and Prevention (CDC) “Reference Value Calculator” (16), estimations of the predicted spirometric values for white males and white females are presented in appendix A. A 50-year-old male who is 170 cm tall would have an expected FEV_1 of 3.29L and an expected FVC of 4.14L. A female of the same age and height would have an expected FEV_1 of 2.75L and an expected FVC of 3.42L. The expected values for females are lower than for males of the same age and height. The expected values decrease with age and increase with height for both males and females. The lower limit of normal (LLN), presented in the tables in Appendix A, is the lower end of the normal range for an individual of that age, sex, and height.

While the values in Appendix A are not suitably calculated for clinical use, they are approximations of the ranges of "normal" spirometric values for white males and white females.

3.2 – Lung function is associated with morbidity and mortality independent of the presence of diagnosable lung disease

Lung function is often studied in the context of various lung diseases such as chronic obstructive pulmonary disease (COPD) and asthma, however there is also value in investigating the range of lung function in the general population. A study by Beaty et al in 1982 concluded that not only was lung function associated with an increase in mortality from lung disease but it was also associated with an increase in all-cause mortality.(17) They examined the association between lung function impairment and the risk of mortality, in a "healthy" population of non-patients who were specifically ascertained through methods other than their own health status. This was a secondary analysis of a larger study, which included COPD patients, their family members, a non-respiratory patient group, and other non-patients. For the secondary analysis only healthy participants, family members and other non-patients were included. They concluded that after controlling for confounders associated with both impaired lung function and risk of mortality, such as smoking, age, race, and sex, the risk of mortality was 1.81 for those with impaired lung function over those who did not have impaired lung function, a value which is stated to be significant although it is not stated whether this is clinical or statistical significance.(17)

Due to this inverse association between lung function and all-cause mortality, Hole et al suggested in 1996 that FEV_1, a common measure of lung function, should be included as part of a general health assessment of middle-aged patients.(18) In their prospective cohort study with 15 years of follow-up, Hole et al found that for men and women who were lifelong non-smokers, there was an association between decreased lung function and mortality from all causes, with the exception of cancers.(19) This was shown through plotting the relative FEV_1 against the log of the decrease in risk of mortality for both smokers and non-smokers. While it appeared that the relationship between FEV_1 and risk of mortality is similar in both smokers and non-smokers, reflected in the shape of the curves, the overall risk was lower among the non-smokers.

More recently in 2000, Schunemann et al concluded that lung function was a long-term predictor of overall survival, supporting the previous findings with a 29-year follow-up study.(5) Schunemann et al studied a randomly selected population of individuals from Buffalo, New York. The measurement of lung function used in this study was FEV_1% predicted which was calculated from raw FEV_1 measurements and using separate equations for men and women which each include an age term and a height term.

All-cause mortality was calculated as the percentage of study subjects who were alive at each time interval. The hazard ratios for all-cause mortality for men and women were 0.985 (95%CI: 0.980-0.990) and 0.990 (95%CI: 0.985-0.995) respectively. From these results it was concluded that a 1-1.5% decrease in mortality risk was associated with a 1% increase in FEV_1 (% predicted). The mortality calculations took place 25 years after enrollment in the study and all data up to that point was included.

While Hole et al found an increased risk of all-cause mortality associated with decreased lung function, they also found that it was associated with an increase in mortality due to ischemic heart disease (trend for men and women showing no symptoms of ischemic heart disease -4.01, $p<0.001$, and -4.36, $p<0.001$, respectively), lung disease (trend for men and women showing no sign of respiratory disease, -2.21, $p<0.05$ and -3.06, $p<0.01$, respectively), for those even with moderately impaired lung function.(18) A longitudinal, population-based study of over 20,700 Americans and meta-analysis of the literature by Sin et al found that even modestly impaired lung function was associated with a fivefold increase in ischemic heart disease deaths.(20) The results from Sin et al were independent of other risk factors including age, gender, and Framingham risk scores.(20)

Sin et al discussed that while there was the possibility that the association between impaired lung function and increased risk of mortality was confounded by an unmeasured factor, there existed evidence to support that the association was causal.(20) In a previous paper they concluded that the increased cardiovascular mortality could be attributed to the systemic inflammation that was present in many of the subjects with impaired lung function.(21) In 2011, Lee et al concluded in a narrative review that lung function was an even better predictor of cardiovascular mortality than were previously known risk factors such as cholesterol.(22)

The link between diminished lung function and all-cause as well as cause-specific mortality supports the need for a greater understanding of lung function and the factors that affect it.

3.3 – Obesity is a modifiable risk factor for lung function and, more generally, body composition is related to lung function with a "U-Shaped" association

The majority of the literature, looking at some measure of body fat and health outcomes, is focused on the obesity end of the body weight spectrum. Obesity has been shown to be a risk factor for many health outcomes such as type II diabetes mellitus, heart disease, high blood pressure, stroke, and certain types of cancer.(23) It has also been shown to be a risk factor for lung disease including asthma.(24) A systematic review of prospective studies looking at adult asthma and obesity concluded that there was dose-dependent increase in incident asthma with increasing BMI.(24) Although obesity was found to be associated with a decreased risk of COPD, it was also associated with an increased severity of symptom expression.(25) While those individuals who were obese were found to have higher lung function values, they were also found to be experiencing greater levels of dyspnea and lower quality of life.(25)

Carey et al found that there was a relationship between lung function and obesity. They found that the relationship differed slightly by sex.(26) The study was a 7-year follow-up with participants in the Health and Lifestyle Survey (HALS1) in England, Scotland and Whales. 3391 of the original 9003 participants were enrolled in the follow-up study. Weight change was measured (in kg) from the initial measurement to the follow-up and forced expiratory volume, statistically adjusted for social class, region, pack-year history, and average weight, was used as the measure of lung function. They found the overall effect of obesity to be greater in males (-96, SEM=16, $p<0.001$) compared to females (-51, SEM=12, $p<0.001$). The size of the effect differed also by age group between the sexes. In men, the largest effect was seen for middle-aged subjects between 32 and 59 years of age (-88, $p<0.05$ between 31-45 years of age and -108, $p<0.001$ between 46-59 years of age). For females, the largest effect was seen in the youngest subjects between 18 and 31 years of age (-80, $p<0.01$).

Considerably less prevalent in the literature is the effect of being underweight on lung function. It has been shown, however, that underweight individuals also have poor health outcomes in a COPD population.(27) While the results of the study by Lan et al are generalizable only to a COPD population, it has been shown to be consistent for a non-COPD population also, by Carey et al. They concluded that maximal lung function (as measured by FEV_1 and FVC) was achieved at a near-ideal body weight.(26) Wise et al, in 1998, found that among both male and female former smokers, those who achieved the highest FEV_1 were between 90 and 100 percent of their ideal body weight.(28) Ideal body weight was calculated from "population norms" in the form of BMI and was compared to the BMI measured for each study subject. Those who achieved the highest FVC were between 90 to 95 percent of ideal body weight for both males and females. (28)

Carey et al stated that the demonstrated relationship between body composition and lung function was usually interpreted as having both a muscular effect component and an obesity effect component resulting in a "u-shaped" association.(26) This accounted for the diminished lung function of both the underweight and overweight subjects. The obesity effect described those who were overweight while the muscular effect described the diminished lung function of those who were underweight. Subhan et al, in 2012, stated that it has been previously shown upon autopsy that body weight was significantly correlated with diaphragm muscle mass, describing the muscular effect. (29)

3.4 – The association between lung function and body composition is different in those with and without diagnosed lung disease

Studies have investigated the association between body composition and lung diseases such as asthma and COPD.(24, 25) These studies used measures of lung function to determine the association with body composition in populations defined by their asthma and COPD status respectively. There are, however, studies that have investigated the relationship between body composition and lung function in healthy populations with no lung disease.

One such study, from Ochs-Balcom et al, which excluded those with diagnosed lung disease, did a sub-analysis which also excluded those with lung function values less that 90% predicted, to remove subjects with possible undiagnosed lung disease.(30) From this sub-analysis it was found that the association differed upon removal of the subjects with possible undiagnosed lung disease. In the sub-group with possible undiagnosed lung disease, Ochs-Balcom et al found that there was no longer an inverse relationship between any measure of body composition and lung function. From this result Ochs-Balcom et al concluded that body composition affects lung function differently in those with and without lung disease. Hence, it is important to take into account lung disease status when investigating the association.

3.5 – The associations between lung function and measures of body composition are inconsistent through the literature

The reported associations between lung function and body composition are not consistent throughout the literature, which could be for a variety of reasons. Studies do not consistently control for the same factors and the study populations also differ. As was previously discussed (section 3.3), lung disease status influenced the relationship between body composition and lung function, therefore whether or not the study populations include those with diagnosed or even undiagnosed lung disease could affect the consistency of results between studies. Carey et al also suggested that the association differs between men and women.(26) While some studies stratify their analysis by sex (31), others controlled for sex.(27) Some primary studies took into account potential confounders of the relationship such as physical activity, smoking status, and socioeconomic status (32) but this is not consistent through the literature. Perhaps the greatest cause for heterogeneity of the results is which measure of body composition was used.

There are wide ranges of associations reported in the literature, with the direction or existence of a significant association varying among primary studies. Chen et al found that there was a significant association between waist circumference and lung function, but that the same association did not exist with BMI.(33) This was a cross-sectional study, which targeted all residents aged 18-79 in Humboldt, Saskatchewan. In a model adjusted for standing height and body weight, Chen et al found that waist circumference was significantly associated with FVC (-0.013, $p<0.001$) and FEV_1 (-0.011, $p<0.001$). In this study FVC and FEV_1 were both measured in liters and waist circumference was measured in cm. The beta-coefficients presented, therefore, have units of L/cm. For BMI, while the association with both FVC and FEV_1 was significant in several categories. Chen et al concluded that it provided less consistent predictability for each measure than did waist circumference.

While Mohamed et al found that there was no linear association between body weight and any measure of lung function, they found that bone-free lean body mass was a significant predictor of FVC, and FEV_1.(31) Studying a population of healthy, non-smoking, Italians between the ages of 18 and 58 years, Mohamed et al included BMI, bone-free lean body mass, total bone mineral content, and total fat mass using DEXA total body scan. Using multiple linear regressions each of the body composition variables were tested for significance. Sex, age (years) and height (m) were each significant predictors of FEV_1 (-0.743, p<0.0001; -0.016, p<0.0001; and 3.543, p<0.0001 for sex, age, and height respectively) and FVC (-0.207, p=0.0051; -0.013, p=0.0046; and 4.522, p<0.0001 for sex, age, and height respectively). An interaction term between bone-free lean body mass and height was also found to be a significant predictor for both FEV_1 (0.103, p=0.0006) and FVC (0.124, p=0.0013). None of the other body composition variables, which included weight, bone mineral content (BMC), and fat mass (FM), were found to be significant predictors of FEV_1 measured in liters (-0.007, p=0.4542; 0.075, p=0.6022; 0.008, p=0.3797 for weight (kg), BMC (kg), and FM (kg) respectively) and FVC measured in liters (-0.012, p=0.348; 0.100, p=0.5894; and 0.007, p=0.5631 for weight (kg), BMC (kg), and FM (kg) respectively). From this analysis Mohamed et al concluded that neither weight nor its components, with the exception of bone-free lean body mass, were statistically significant predictors of lung function.

Conversely, Park et al did find a significant association between BMI (as well as other measures of body composition) and FVC but concluded that it was not enough to be able to predict lung function.(34) Park et al stated that in multiple linear regression models the adjusted coefficient of determination was not significantly better in the models including each measure of body composition than a similar model excluding body composition. This study included subjects from age 20-70 who had undergone spirometry at Yeungnam University Hospital Health Promotion Center over a 3-month period. Excluded were individuals who had a history of certain conditions and diagnosed respiratory diseases including COPD and asthma. Correlation coefficients were obtained and the statistical significance of each body composition variable was tested. Each of the variables age, height, body weight, sex, BMI, fat %, muscle, fat-free mass, fat-free mass index, and waist-hip ratio were all found to be significant predictors of FEV_1 ($p<0.05$). Conversely, only age measured in years (-0.104, $p=0.038$) and fat % (-0.12, $p=0.02$) were found to be statistically significant predictors of FVC. However, when the analysis was stratified by sex, for males, each variable was found to be a significant predictor with the exception of BMI, and fat % for FEV_1 and FVC. For females, each of the predictors were significant with the exception of body weight and fat-free mass index for FVC and body weight, BMI, fat %, and fat-free mass index for FEV_1. Chen et al concluded that, while some significance was found in univariate analysis, these variables did not add any significance to the current prediction formulas including variables for age, sex, and height.

Different still, Pekkarinen et al concluded that there was no significant association between body composition and lung function, except for an inverse relationship between abdominal diameter or waist circumference and the FEV_1/FVC ratio.(35) In a study aimed to create lung function reference equations for Finland, healthy subjects over the age of 18 were studied. For two of the outcome variables, FEV_1 and FVC, Pekkarinen et al found that none of the body composition variables had a statistically significant correlation coefficient. BMI measured in kg/cm^2 (0.16, p=0.007) and waist circumference measured in centimeters (0.16, p=0.006), were significantly correlated with FVC (% predicted) in the overall population but that significant relationship was not present when stratified by sex.

Sato et al conducted their analysis twice, once with lung function as the outcome and a second time with lung function decline over time as the outcome.(36) The study was completed as part of the Molecular and Epidemiological Study of Regional Characteristics of 21st century Centers of Excellence (COE) program. Initial spirometry and abdominal circumference measurements were taken upon enrollment in the study, beginning in 2006 and repeat measurements for the Sato et al study were taken in 2009 allowing for differences to be calculated. When single spirometry values were used in the analysis they were the measures at visit 2. From this analysis they concluded that there was no significant relationship between waist circumference and lung function, however, there was a significant relationship found between waist circumference and lung function decline (difference between first and second measurements).

Thus, it appears that while several studies have looked at the association between body composition and lung function, there is no consistent conclusion among them.

3.6 – There are various pathophysiological explanations for the relationship between body composition and lung function

While there is little agreement among studies as to which measure of body composition is most associated with lung function, it is commonly concluded in the literature that there does exist a relationship between some measure of body composition and spirometric lung function values. Several studies have offered possible explanations for the relationship between body composition and lung function. While some studies describe the overall effect of obesity in regard to lung function, it is important to differentiate between the measures of body composition as they may affect lung function through different pathophysiological mechanisms. Abdominal obesity effects lung function through a different mechanism than does height and weight body proportion as measured by BMI.(11, 30, 37) Abdominal obesity restricts the movement of the diaphragm and limits how much the lungs are able to expand (30, 37, 38) while overall obesity can compress the chest wall.(30, 37) The differences between the effect of abdominal adiposity and overall adiposity may also explain the difference observed between males and females. Males were generally found to be more likely to have excess weight around their waist (abdominal adiposity), while females generally tended to have more weight around their hips (non-abdominal adiposity).(26)

While many of the explanations of the mechanism by which body composition effects lung function focus on those who are overweight or obese, there is also a proposed explanation for the decreased lung function seen in underweight individuals. Much of the literature addressing an underweight population is looking at a population of individuals with COPD, and may not be generalizable to a healthy population. Subhan et al, however, with a population of healthy subjects showed that those who were underweight had significantly decreased FVC and FEV_1.(29) They discussed this association, claiming that diaphragm muscle mass is correlated with BMI and therefore those who were underweight also had decreased respiratory muscle function, explaining the observed decrease in each measure of lung function.(29)

3.7 – It is important to distinguish between measures of body composition that differentiate between fat mass and fat-free mass, and those that do not

There are various measures of obesity and more generally body composition. Certain measures of body composition such as BMI do not distinguish fat mass from fat-free mass (or lean muscle mass). Other measures of body composition, such as waist circumference, take into account how mass is distributed throughout the body. It is important to distinguish between fat mass and fat-free mass as they have different effects on lung function. Increased fat mass was shown to be associated with a decrease in lung function, while increased fat-free mass was shown to improve lung function.(39) Due to this difference, a measure of body composition that distinguishes between the two types of mass would likely provide stronger and more consistent associations with lung function. Wannamethee et al also concluded that total body fat and central adiposity, two measures that consider fat mass, are negatively associated with lung function, while fat-free mass is positively associated with lung function.(40) It is concluded that these results support claims from the previous studies regarding fat mass versus fat free mass and the associations with lung function.

3.8 – Waist circumference, as a measure of body composition, is more highly associated with lung function than is body mass index

Waist circumference has been demonstrated to be more highly associated with general health than body mass index. A study from Janssen et al determined that waist circumference and not BMI was associated with many obesity-related various health risks.(41) This study investigated "obesity related" health risks, specifically: hypertension, dyslipidemia, and metabolic syndrome. When waist circumference was added to the model as a continuous variable, the risks of the comorbidities of interest were similar across BMI categories. They concluded that people with the same waist circumference, regardless of BMI category (normal, overweight, or obese) had comparable health risks.(41)

Of all the measures of body composition or fat distribution, waist circumference is among the most commonly studied in regard to lung function. It is easy to measure and there is a physiological explanation for its impact on lung function, restricting diaphragm movement and expansion. While BMI and waist circumference are often highly correlated (40) there is a common theme in the literature that waist circumference is more predictive of lung function than is BMI.(30, 33, 39, 40) BMI was found not to be an ideal measure as a predictor of lung function as it does not distinguish muscle mass from fat mass and was correlated with overall body size, which was positively associated with lung size, and therefore lung volumes (reflected in FEV_1 and FVC).(33)

3.9 – The reported relationship between waist circumference and lung function is not consistent throughout the literature

While it is commonly reported in the literature that waist circumference is more predictive of lung function than is BMI, this is not always the case. As described in section 3.5, Sato et al stated that while they did not find a significant association between waist circumference and lung function, they did find a significant association between waist circumference and lung function decline.(36) Canoy et al used waist-to-hip ratio as a measure of central adiposity and also concluded a significant and consistent relationship with lung function.(32) Canoy suggested that when using waist circumference alone as a measure of central adiposity, that height needed to be included to put the values into the context of body size, and to obtain the association.(32) From their multivariate model, waist circumference was determined to be a predictor of FEV_1 (-23, 95% CI: -31.8 to -14.3), while adjusting for age. In a similar model, adjusting for both age and height, the estimate for waist circumference was -57.5 (95% CI: -65.8 to -49.1). When FVC was the outcome of the model, adjusting for age, the estimate for waist circumference was -32.1 (95% CI: -43.8 to -20.5) and when adjusting for age and height the estimate for waist circumference was -81.3 (95% CI: -92.2 to -70.3). The effect of waist circumference on both FEV_1 and FVC was increased upon adjusting for height in addition to age.

While the majority of studies concluded that the measure of body composition most strongly associated with lung function was a measure of central adiposity, this was not always the case. As described in section 3.5, Pekkarinen et al found that there was no significant univarate association between any measure of body composition and spirometry values.(35) Finally, Park et al concluded that BMI, fat %, muscle mass, fat-free mass, fat-free mass index, and waist-to-hip ratio were all significantly associated with lung function.(42) Park, however, also discussed that although significant associations were found for each of the measures; those indicating more fat distribution in the upper body (waist-to-hip ratio) were associated with lower lung function values.

3.10 – Further population-based studies are needed to confirm the association between waist circumference and lung function

A systematic review and meta-analysis, published in 2012 by Wehrmeister et al, investigated the relationship between waist circumference and lung function.(38) This systematic review confirmed that the relationship was different in men and women, existing more strongly in men. Sex was identified as the factor contributing most to the heterogeneity (i^2>90%) of the results from the included primary studies. Included in the meta-analysis were studies that had waist-circumference as a continuous variable and raw spirometry values. The included studies adjusted for different factors including various combinations of: age, height, BMI, weight, current occupation, caloric intake, smoking, sex, school, and skin color.

From this systematic review and meta-analysis it was recommended that more population-based studies be completed to confirm the result that waist circumference is negatively associated with lung function.

3.11 – Physical fitness and physical activity may confound the relationship between obesity and lung function

Studying the relationship between body composition and lung function, it is important to consider any potential confounders. Physical fitness is one such possible confounder of the relationship, as it could possibly be associated with both body composition and lung function. Body composition and physical fitness were found to be correlated with the most obese being the least physically fit.(11) Using an Ellestad treadmill stress test, Vranian et al, found that there was an inverse relationship between the fitness test results and BMI measured in kg/m^2 (-0.423 for men and -0.390 for women), waist size measured in centimeters (-0.503 for men and -0.401 for women), and obesity defined using BMI (-0.376 for men and -0.307 for women).

In response to obesity, the recommended interventions are often weight loss and/or physical activity to increase physical fitness. In the elderly, weight-loss alone may increase frailty by increasing the loss of muscle mass.(43) Villareal et al conducted a randomized controlled trial of obese adults who were randomized to control, weight loss, exercise, or weight loss and exercise groups.(43) The diet and exercise group had significantly greater improvements for each of the outcomes: physical performance test (PPT), VO2max (an objective measure of cardiorespiratory fitness), and functional status questionnaire (FSQ). It was determined from this study that a combination of both weight loss and increasing physical fitness resulted in the best outcomes for physical function in obese adults.(43)

Lakoski et al concluded in a prospective cohort study found that although physical activity was important for cardiorespiratory health, that obesity might decrease the benefits in healthy individuals.(44) Subjects were grouped by their physical activity index (PAI) and within group analysis was based on BMI categories ($<25kg/m^2$, $25-29.9kg/m^2$, and $\geq 30kg/m^2$). From this study, for individuals who participated in a similar amount of physical activity, those who were obese had consistently less favorable cardiorespiratory health benefits. Conversely, Vranian et al stated that obesity related mortality could be improved through physical activity.(11) Vranian et al found that in obese and overweight but otherwise healthy young adults, increasing fitness levels (evaluated by level of Ellestad fitness test achieved) was consistently and significantly ($p<0.001$ for each risk factor) associated with a decrease in each of the cardio metabolic risk factors that were measured. They further stated that those who were fit and obese had lower cardiovascular mortality than those who were normal weight yet unfit, relying on cardiovascular risk factors to estimate mortality.

A systematic review and meta-analysis was published in 2014, including studies that were prospective and included BMI as well as cardiorespiratory fitness measures and investigated their association with all-cause mortality.(45) Through comparison of individuals who were normal weight fit and unfit, overweight fit and unfit, and obese fit and unfit, Barry et al concluded that public health, and clinical interventions should be based on physical activity as opposed to weight-loss. From the ten studies that met the final inclusion criteria, the overall analysis found more than double the risk of all-cause mortality for unfit individuals versus their fit counterparts, within their BMI categories. They also concluded that there was no statistically significant difference in the risk of all-cause mortality between those individuals who were obese and fit versus those who were normal weight and fit (HR 1.21, 95%CI: 0.95-1.52).

For many years there has been interest in studying the relationship between lung function and physical fitness/activity. In 1988, a study by Hagberg et al investigated this association by comparing older athletes and non-athletes.(12) Although they concluded that lung function was greater in the athlete group, body composition was not considered and the non-athlete group was 33% heavier, which could have been a potential confounder of this relationship.(12) In a study from 1989, physical activity was concluded to be associated with lung function in a study investigating respiratory muscle function.(46) Chen et al concluded that the positive correlation between physical activity and lung function could be attributed to an increase in inspiratory muscle endurance.(46) They found that in men the pressure time-index (measure of inspiratory muscle endurance) was 14 648 (SEM=1 796) for those who were inactive and was 38 316 (SEM=3 480) for those who were active.

A 2014 study, conducted by Behrens et al investigated the relationship of body size, physical activity, and incidence of COPD.(47) This was a cohort study with ten years of follow-up. The initial cohort included 113 279 individuals with no reported history of COPD. Physical activity information was obtained based on validated self-reports. Incidence of COPD was self-reported during the ten-year follow-up period. It was concluded that based on BMI both underweight (<18.5) and severely obese (>35) were associated with increased risk of COPD but that after adjustment for waist circumference only underweight individuals maintained the elevated risk of COPD, with a relative risk of 1.56 (95%CI: 1.15-2.11). Waist circumference (RR 1.72, 95%CI: 1.37-2.16) and waist-hip ratio (RR 1.46, 95%CI: 1.23-1.73) were also each associated with increased risk of COPD. Physical fitness was inversely associated with incidence of COPD with a relative risk of 0.71 (95%CI: 0.63-0.79). Behrens et al concluded that both healthy body size as well as being physically fit decrease the risk of COPD.

More recent studies have also looked at the question of physical activity and lung function. Pelkonen et al concluded that physical activity, estimated as the number of kilometers walked, cycled, or skied daily, slowed the decline of spirometry measures in a 25 year follow-up study.(48) The lung function measurement used in this study was FEV0.75, which is the amount of air expelled in 75 hundredths of a second, a measure found to be more sensitive to obstruction than the commonly used FEV_1 in child asthmatics.(49) The mean annual decline of $FEV_{0.75}$ was -45.2 mL/year (reference value) for those in the lowest tertile of physical activity, -39.9, p=0.083 for those in the middle tertile, and -34.8, p=0.009 for those in the highest tertile. The trend by tertile was significant, with a p-value of 0.006. However, this study did not include a measure of body composition as a potential confounder. There was also no objective measure of physical fitness, but instead a more subjective measure of physical activity.

3.12 – The relationship between body composition and lung function is independent of physical fitness and physical activity in a specialized population

Few studies looking at the association between lung function and obesity, control for physical activity.(32, 33, 40, 50) These studies each concluded that the relationship between body composition and lung function is independent of physical activity. They do not, however, include an objective measure of physical fitness. Canoy et al discussed the possible relationship of both body composition and lung function with physical activity, but stated that the relationship is not well documented.(32) They also stated that the measurement error of physical activity may not permit proper adjustment.(32)

A single study specifically investigated the relationship between obesity and lung function and the impact of physical activity and physical fitness.(51) This study by Steele et al was a sub-study of the ProActive trial in the UK. The ProActive study included individuals with a history of parental type II diabetes who were targeted for lifestyle interventions. Study participants enrolled in the sub-study tended to have BMI (27.5, SD= 5.3 for women and 28.2, SD= 4.8 for men) and body fat % (26.2%, SD=10.4 for women and 23.3%, SD=8.5), which were slightly high. Various body composition measurements were taken, including: BMI, waist-to-hip ratio, fat mass, fat-free mass, and body fat percentage. Fat mass, fat-free mass, and body fat percentage were measured using an electrical impedance device. Aerobic fitness was assessed using a submaximal graded treadmill test to estimate VO_2max and the physical activity energy expenditure (measure of physical activity) was also calculated based on the Weir formula. To determine the association between each of the measures of body composition and lung function, a model was created for each outcome (FEV_1 and FVC)/body composition combination. Each of the models were adjusted for age, sex, height, and smoking with the exception of the model including BMI as the exposure where height was left out to avoid co-linearity. The analysis was conducted on the entire study sample and then again separating males and females.

In women, significant predictors of FEV_1 were BMI (-0.020, $p<0.01$), waist circumference (-0.004, $p<0.027$), fat mass (0.002, $p=0.003$), and body fat percent (-0.010, $p<0.01$). With FVC as the lung function outcome, BMI (-0.091, $p=0.023$), fat mass (-0.009, $p=0.006$), and body fat percent (-0.013, $p=0.003$) were each found to be significant predictors. Waist circumference was not found to be a significant predictor of FVC (-0.004, $p=0.099$) in women, contrary to the findings of previous studies (section 3.10). In men, each of the body mass composition measures was found to be significant predictors ($p<0.01$ for each) of both FEV_1 and FVC. Each of these models was adjusted for age, sex, height, and smoking status.

To investigate the effect of physical fitness/physical activity on the relationship between lung function and body composition VO2max and physical activity energy expenditure (PAEE) were added together to each of the models described above and a new beta-value for each measure of body composition was reported. Upon adjustment for PAEE and VO2max in women, the same measures of body composition were significant predictors of FEV_1 as with the model unadjusted for physical fitness or physical activity. Most had similar magnitude with the exception of fat mass for which the direction of the association changed (-0.007, $p<0.01$). With FVC as the outcome in women, upon adjusting for physical fitness and physical activity, the associations also remained unchanged. In men, after adjusting for physical fitness and physical activity for both FEV_1 and FVC, the associations were all similar to those from the previous models, unadjusted for physical fitness or activity, in both magnitude and significance. The difference between men and women being only that for women FEV_1 was influenced by the addition of physical fitness and activity terms.

Steele et al concluded that the relationship between body composition and lung function existed independent of physical fitness and physical activity. The strength of this study is that there was an objective measure of physical fitness as well as physical activity, and that the specific aim was to investigate this relationship of interest. The study population, however, due to the known link between obesity and diabetes, as well as the nature of the main study lifestyle intervention, greatly limits the generalizability of the results beyond the specific study population. A similarly conducted, population-based study, would lead to more broadly generalizable results.

3.13 – Literature Review Summary

In summary, forced expiratory volume in the first second (FEV_1) and forced vital capacity (FVC) are important spirometric values that are measures of lung function. These values have been shown to be associated with overall mortality, independent of the presence of diagnosable lung disease. It was suggested that these measures be included in general health assessments due to their association with overall mortality. It is therefore important to understand the factors that influence lung function. One such factor is obesity, which is often concluded to be associated with lung function and there are several physiological explanations for this association. While many conclude that general obesity is associated with lung function it is less consistent which measure of body composition is best for predicting lung function.

Measures of body composition that differentiate between fat mass and fat free mass, or measures that indicate abdominal versus overall fat, are often concluded to be more associated with lung function than those that do not. Consistent with this, in several studies waist circumference was found to be more associated with lung function than BMI. However, population-based studies are needed to confirm this relationship.

Physical fitness is a potential confounder of any relationship between measures of body composition and lung function, although it is rarely considered in studies on this topic. A single study looks at the association between lung function and measures of body composition and included objectively measured physical fitness and activity. A specialized population was studied, however, and therefore the findings have potentially limited generalizability. There is currently a gap in the literature. A population-based study investigating lung function and measures of body composition, including physical fitness as a potential confounder is needed.

Chapter 4: Methods

4.1 – Overview

This study is a secondary analysis of data from the Canadian Health Measures Survey (CHMS). Data for the CHMS is collected from a cross-sectional sample of Canadians biennially; the first and second cycles, released in 2009 and 2011, were utilized for the present study. The CHMS includes both questionnaire data as well as physical measurements. We pooled the two cycles of data to examine the relationship between body composition and lung function, and to determine the effect of physical fitness on this relationship.

All participants of the survey with lung function and anthropometric measurements and who were over the age of 40 were included ($n \approx 4000$). As part of the ageing process, the lungs change and become less efficient. Lung maturity is reached by age 20-25 after which time there is a natural, gradual but progressive decrease in lung function.(52) Including only those from ages 40-79 in the current study narrowed the range of expected lung functions and lead to a more homogeneous study population.

While inclusion in the current study was based on age and participation in the CHMS, other factors were also considered in the analysis. Data about participant's smoking history, ethnicity, income, education, use of certain medications, and self-reported diagnosis of lung disease were each taken into consideration as potential confounders of the relationship of interest.

To access the Statistics Canada data from the CHMS, a detailed application was submitted and approved by a Statistics Canada Subject Matter Expert. The data was accessed securely in the Atlantic Research Data Centre (ARDC) located at Dalhousie University. As the current study is a secondary analysis of statistics Canada data, research ethics approval was not necessary for this specific study. The application process, and procedures for accessing/analyzing and reporting of Statistics Canada data from the ARDC ensures the privacy and protection of the subjects who participated in the survey. The Health Canada Research Ethics board approved the survey prior to cycle 1. Internationally recognized standards for research involving humans were met and maintained throughout the completion of the survey.

4.2 – Data Source

4.2.1 – The Canadian Health Measures Survey

The CHMS is a cross-sectional, Canadian population-based data platform that is conducted by Statistics Canada. Each cycle of the CHMS is completed biennially. The first cycle began in March 2007 and was completed in March 2009; the second cycle was completed from August 2009 to November 2011. Data from each of these two cycles was included in the current study.

Data from CHMS is representative of people living in all ten provinces of Canada. Those living in the territories or on reservations in the provinces were excluded from the survey. Individuals between the ages of 6 and 79 years (Cycle 1) and between the ages of 3 and 79 (Cycle 2) were eligible to be selected to participate in CHMS. Physical measures for those between the ages of 6 and 79 were collected. There was a minimum requirement of 500 males and 500 females from each of the following age ranges: 6 to 11, 12 to 19, 20 to 39, 40 to 59, and 60 to 79. This age distribution requires at least 5,000 participants for each cycle of the survey. As with many surveys conducted by Statistics Canada, a complex survey design was used and was based on the age distribution of the Canadian population.

The CHMS is unique in that it encompasses both a home interview with questionnaires as well as a visit for each subject to a mobile examination center (MEC) for physical measurements. This lead to an additional consideration in sampling compared to other Statistics Canada surveys, since each subject was required to live within a defined geographic radius of a MEC in order to be eligible to participate. All measurements were completed in a single visit to the MEC.

In addition to the measurements taken at the MEC, each participant was given an accelerometer to wear for one week following the visit, to monitor their physical activity. There were also short questionnaires which were conducted at the MEC visit to complement the more extensive home-visit surveys.

The overall response rate for CHMS Cycle 1 was 51.7%. For Cycle 2 of the survey the overall Canadian response rate was 55.5%.

4.2.2 – Sampling

Sampling clusters were created based on metropolitan areas where the population was at least 10,000 and potential subjects would need to travel no more than 50 kilometers in urban areas and 100 kilometers in rural areas to access the

MEC. Individuals living in regions that did not fall within the maximum radius of a MEC were excluded from the survey. A total of 96.3% of the Canadian population between the ages of 6 and 79 lived within the survey catchment area, and were therefore included in the sampling frame for the survey.

The survey was conducted in five regions across Canada. Households were identified initially through census data in order to be included in the sample frame. The five Canadian regions were British Columbia, the Prairie Provinces, Ontario, Quebec, and the Atlantic provinces. Within these regions there were multiple study sites. In addition to those who were excluded based on geographic region, there were other groups of Canadians who were not included in the survey. Those Canadians living on reservations or aboriginal settlements were not included in the sampling frame. Canadians living in institutions as well as members of the Canadian forces were also excluded from the sample.

4.2.3 – Sample Size

The sample size for this study was predetermined by the available data. Statistics Canada based their sample size on the number subjects needed to obtain reliable population estimates of key health status. Sample size is based on age range of the Canadian population and is further specified by sex within each range. Although weighted data is used, approximately 4,662 of the approximately 11,000 total participants were over the age of 40 and are therefore included in the current study. 2254 of these participants were male and 2408 were female.

4.3 – Measurement

4.3.1 – Exposures

Body composition is the main exposure of interest. There are several anthropometric measures from the CHMS, each of which are obtained at the MEC following a specific procedure. Extensive details on the procedure for each of the measurements can be found in the Canadian Health Measures Survey Data User Guide.(53) Of the body composition measures including in CHMS, waist circumference, hip circumference, waist to hip ratio, waist to height ratio, and BMI had approximately 4% missing data, with each measure having n>2300.

Body Mass Index (BMI)

BMI is a derived variable that is calculated from two other measures, height in centimeters (cm), and weight in kilograms (kg). Body mass index is the ratio of weight to the square of standing height.

A Health Measurement Specialist was responsible for measuring height at the MEC using a fixed stadiometer. Height was recorded to the nearest 0.01 cm. For participants who were unable to stand unassisted, who had a chronic condition such as being confined to a wheelchair, or who refused to have their height measured; they were asked to self-report their height.

Weight was measured at the MEC using a Mettler Toledo digital scale (Mettler Toledo International Inc., Columbus, OH, USA). To measure weight, participants were instructed to stand on the scale while weight measurements were taken to the nearest 0.1 kg.

Although BMI was recorded as a continuous variable, there is also a categorical weight variable included in analysis, calculated based on the WHO cutoffs for BMI for adults over the age of 18.(54) The categories for BMI are underweight (<18.5 kg/m^2), normal weight (18.5-24.9kg/m^2), overweight (25.0-29.9 kg/m^2), and obese (>30 kg/m^2).

Waist Circumference

To measure waist circumference, participants were instructed to stand straight up with relaxed posture and their arms slightly out in front of them. Measurements were taken directly on the skin. The waist circumference was measured between the bottom of the rib cage (last floating rib) and the top of the iliac crest. Measurement was taken at the end of a normal expiration to the nearest 0.1 cm. Individuals who were pregnant, in a wheelchair, unable to stand unassisted, and have a colostomy bag were excluded from waist circumference measurements.

The waist circumference variable, is continuous and is in units of centimeters. This variable is included as both continuous and categorical. The categories for this variable are created based on the WHO recommended cut-off points for risk of metabolic complications.(55) For men, >94cm is the increased risk group, while >102 cm is the substantially increased group. For women >80 cm is the increased risk group, while >88 cm is the substantially increased risk group.

Hip Circumference

The procedure for measuring hip circumference was according to the Canadian Standardized Test of Fitness (edition 3).(56) The procedure was similar to that for measuring waist circumference. Hip circumference was measured over clothing, around the symphysis pubis and the greatest gluteal protuberance. This measurement was also to the nearest 0.1 cm. Individuals who were pregnant, in a wheelchair, and those who were unable to stand unassisted were also excluded from the hip circumference measurements. The variable of interest is continuous and is recorded in units of centimeters. This variable was grouped into tertiles as there were no accepted reference values.

Waist to Hip Ratio

Waist to hip ratio is a derived variable based on waist circumference and hip circumference measurements. This variable is used as both a continuous variable and categorical variable. The categories are based on the WHO recommendations for cut-off points, which are 0.9 for males and 0.85 for females.(55)

Waist to Height Ratio

Waist to height ratio is a variable that was created for the purposes of this analysis based on the waist circumference and height variables, which were previously described. It is a continuous variable, which is the ratio of waist circumference measured in cm to height also measured in cm. A categorical variable was also created for waist to height ratio, which is based on the cut-off of 0.5.(57) This cut-off is accepted for males and females and across all age groups.(57)

Skinfold Thickness

Skinfold measurements were performed at the MEC with a Harpenden skinfold caliper. This measure of body composition estimates the amount of subcutaneous fat, which is used as an indicator of overall body fat. There are five locations at which skinfold measurements are performed: triceps, biceps, subscapular, iliac crest, and medial calf. Each location is marked and the measurements are taken to the nearest 0.2 mm. The variable of interest for the measurement of skinfolds is a continuous variable for the sum all 5 skinfold measurements measured in millimeters. This variable was grouped into tertiles as there were no accepted reference values.

The skinfold thickness variable had approximately 33% missing values, higher than the other body composition measurements. The exclusion criteria for this measurement were having a BMI>30kg/m^2 as well as having missing limbs or refusal to complete the measurement upon demonstration of the technique.

4.3.2 – Outcomes

Each of the outcome measures of interest, Forced Expiratory Volume in the first second (FEV$_1$) and Forced Vital Capacity (FVC), were obtained through spirometry testing. A specially trained health measurement specialist performed spirometry at the MEC. All medications were taken as usual prior to testing in the MEC including respiratory medications. The only medications that were cause for exclusion from spirometry testing were those treating tuberculosis.

Koko spirometers (nSpire Health, Longmont, CO, USA) with disposable filtered mouthpieces, and disposable nose clips were used during the lung function measurements. The test was performed while participants were sitting in a chair, with good posture, and both feet flat on the floor. Participants were coached to first take a maximal inspiration and then immediately blast out all of the air as quickly as possible through the mouthpiece and to continue exhaling for as long as possible. Once a plateau on the time/volume curve was seen, the participant was instructed to inhale normally. As the results of spirometry are effort-dependent, encouragement was given to participants during the testing.

A minimum of three and maximum of eight trials were completed. The aim of repeated trials is to assess repeatability. From the three repeatable trials the best measurement was recorded. The best measurement was defined by having the highest sum of FEV_1 and FVC. If three repeatable trials could not be completed during the first eight attempts, then the best of the available attempts was saved. To determine whether a test was acceptable, standards from the 1994 Update of the Standardization of Spirometry by the American Thoracic Society were employed.

There are several possible reasons for missing spirometry data. Individuals with a stoma, pregnant women (past 27 weeks), heart attack within the last three months, major surgery on the chest or abdomen within three months of the testing date, heart attack within three months taking medication for tuberculosis, eye surgery within six weeks, an acute respiratory conditions (such as a cold or flu), individuals with a language barrier, difficulty breathing at rest, and individuals with a persistent cough were all contraindicated for spirometry.

There are two continuous outcome variables of interest, included in CHMS. The variable representing FEV_1 is defined as "the largest FEV_1 from acceptable trials" and is measured in liters. The variable representing FVC is defined similarly as “the largest FVC from acceptable trials” and is also measured in liters.

4.3.3 – Covariates

Aerobic Fitness Score (VO_2max)

Two components of physical fitness are captured in the CHMS. Musculoskeletal fitness is comprised of grip strength, sit and reach components, and partial curl-ups. The second component of physical fitness is measured through the Modified Canadian Aerobic Fitness Test (mCAFT) and was performed by participants from ages 6-69. Required for this test were a blood pressure cuff, the mCAFT step where the exercise is performed, an mCAFT CD, a stopwatch/timer, and a heart rate monitor.

The value obtained from the mCAFT is VO2max. This is the point where despite an increasing amount of work being done, oxygen intake becomes constant and is a measure of an individual’s aerobic fitness. The mCAFT was chosen as an indicator of physical fitness as it measures the “combined efficiency of the lungs, heart, vasculature, and exercising muscles” according to the CHMS data dictionary. The protocol for this test was extracted from the Canadian Physical Activity, Fitness & Lifestyle Approach edition 3.(58) The test involved the study participants stepping up and down from a double step (40.6 cm high) at a constant speed over a 3-minute interval. After every 3-minute interval heart rate was measured and if it was not at the maximum recommended for the individuals age then they completed another 3-minutes of stepping at a faster speed. Once the maximum had been reached, the test was complete. (59) From this test the Aerobic Fitness Score (AFS) can be calculated according to equation [1].(58) O_2 cost (L/min) is determined from the heart rate and the stepping rate at the last 3-minute stage completed, body mass is weight in kilograms, and age is the current age of the subject in years.

$$AFS = 10[17.2 + (1.29\ x\ O_2cost) - (0.09\ x\ Body\ Mass) - (0.18\ x\ age)] \qquad [1]$$

The aerobic fitness score was a continuous variable and was rounded to an integer value. This was a derived variable, which was calculated based on O_2 cost at the highest step achieved, body mass, and age of the participant. Estimates of VO2 max obtained via mCAFT were compared to VO2 max estimates from the typical cardiopulmonary exercise test and mCAFT was validated for this purpose.(60)

This variable had approximately 45% missing data for males and females over the age of 40. This missing data could be attributed to a few factors. Individuals over the age of 70 were automatically excluded from completing the fitness test. The exclusion criteria also included use of certain medications, chronic or acute medical conditions, and failure to adhere to pre-test instructions (such as wearing appropriate footwear and loose fitting clothing).

Musculoskeletal Fitness

Total handgrip strength was also included as a strength component of physical fitness. Grip strength measures the maximum force exerted by a certain muscle group. Handgrip strength is measured at the MEC using a handgrip dynamometer. The grip strength of each hand was measured twice, alternating hands between trials. The subjects were asked to exert maximum force, squeezing the dynamometer while exhaling. Each grip strength score was recorded to the nearest kilogram. Handgrip strength is represented by a continuous variable. The handgrip strength variable had approximately 5% missing values.

Physical Activity Index

Participants in CHMS were asked, through the questionnaires, how often they participated in certain physical activities. They were then asked: "about how much time did you spend on each occasion?" From these two values daily energy expenditure was calculated using equation [2]. In the equation, N is the number of times in 12 months the participant engaged in the activity, D is the average duration of engagement in the activity, and MET value is energy cost of the activity in kilocalories/kg of body weight/hour.

$$EE = \frac{(N \times D \times METvalue)}{365} \qquad [2]$$

Once the energy expenditure for each activity was calculated they were added together and the total daily energy expenditure was determined. These values were then categorized into inactive, moderately active, and active based on the total energy expenditure value/day. Inactive was defined as 0-1.5 kcal/kg/day, while moderately active was 1.5-3.0 kcal/kg/day, and active was greater than 3.0 kcal/kg/day.

Activity Monitor

As part of CHMS activity monitors were given to all eligible participants to be worn for seven days. Participants between the ages of 6 and 79 were eligible. Only those participants confined to a wheelchair were excluded from activity monitor data. Each participant was given an Actical activity monitor (Phillips, The

Netherlands) and adjustable belt. They were instructed to wear the monitor for seven days and then to mail it back. The activity monitor used an omnidirectional accelerometer to monitor all activity during the wear-time over the seven days.

Steps/day were calculated for each of the seven days. For the current study the average number of steps/day were calculated and used in the analysis.

Time spent moderately-vigorously active per day was also calculated based on activity monitor data. Moderate-vigorous activity is determined by metabolic equivalents (METs) of greater than 3. A MET is defined as energy cost as a multiple of resting energy expenditure. Therefore moderate-vigorous physical activity was activity such that at least 3 times the energy was required compared to being at rest. The total number of minutes/day spent at this level of activity was summed over the seven days and the resulting total number of minutes/week was used in analysis.

Total number of inactive minutes/day was also derived from activity monitor data. Inactive minutes were those where the individual was either not wearing the activity monitor or where the individual was completely still. Periods of stillness (or not wearing the monitor) were summed to obtain the total number of minutes/day for each of the seven days. The mean of these values was calculated for use in the current study as average number of inactive minutes/day.

Only a subset of the total sample was given activity monitors to wear following the study visit. From this data was available for 43% of males and 44% of females included in the current study.

Potential Confounding Variables

There are several other possible confounding variables that were collected via home questionnaire as part of the CHMS. Smoking history is an important, possibly confounding, variable to be considered. Smoking history is a categorical variable which has 8 levels including daily smoker, occasional smoker (former daily smoker), always an occasional smoker, former daily smoker, former occasional smoker, never smoked, not applicable, and not stated. For the purposes of the analysis categories were collapsed into 'Never Smoker', 'Former Smoker', and 'Current Smoker'.

The use of certain medications is known to effect lung function and was included in the analysis as potential confounders. Using Anatomical Therapeutic Chemical (ATC) drug classification there are two categories of respiratory drugs included. The first level of classification is for the anatomical main group and all those medications in group-R describe drugs affecting the respiratory system. The second level of classification, which consists of two digits, represents the therapeutic main group and all medications in group-03 are those that treat obstructive airway diseases. In addition to each of the respiratory medications those under the first classification of C (cardiovascular system) and the second classification of 07, describing the therapeutic main group of beta-blocking agents were included. These medications were combined into a single categorical variable, which is "yes" if the individual is currently taking any of the drugs from the above categories and "no" if they were taking none of the drugs of interest.

Data regarding chronic conditions was collected via the home questionnaires. Questions such as: “Do you have Chronic Obstructive Pulmonary Disease?” were asked about a wide range of conditions. Chronic conditions included in the analysis as potential confounders were those for which there is a plausible association between either the outcome (lung function) and the exposure (body composition measures) of interest. The respiratory conditions included in the CHMS were asthma, chronic bronchitis, emphysema, and Chronic Obstructive Pulmonary Disease and were included in the current analysis. Due to very low numbers, Emphysema, COPD, and Chronic Bronchitis were combined in a single variable, “yes” if the individual had any of the three conditions, and “no” if the individual had none of the three conditions. Other conditions included in the analysis as potential confounders were diabetes and heart disease.

Other potential confounders, included in the home questionnaires, were the determinants of health such as racial origin, socioeconomic status, and education. Racial origin was included as a potential confounder as there may be differences between the shape and size of the bodies, including their lungs and consequently lung volumes. Race is sometimes taken into consideration when conducting spirometry and interpreting results. The racial origin variable was used in the analysis but due to small sample sizes; the categories were collapsed into “white” and “other”.

Income and education are derived variables that were included in the analysis. The income variable of interest was total household income adequacy, based on the total household income and the number of people living in the household. The categories for this variable were lowest, lower middle, upper middle, and highest income adequacy grouping. For use in the analysis, the first two categories were collapsed to a single “Low Income” category. The education variable of interest was the highest level of education in the household. This variable was recoded into three categories: high school graduation or less, college, and university.

4.4 – Statistical Analysis

All analyses were stratified by sex. The descriptive statistics, crude associations, and finally the linear regression models, which directly address the objectives, were all completed separately for males and females. Bootstrap and population weights were applied to the data for each component of the analysis.

4.4.1 – Descriptive Statistics

Means and standard deviations or proportions were reported for each of the descriptive variables as applicable. The coefficient of variation (CV) was calculated as a measure of sampling error. As per Statistics Canada guidelines, a CV between 16.6 and 33.3% indicates marginal sampling variability and was identified in the results (marked in table with footnote description), while results with a CV > 33.3% are considered unacceptable and were suppressed.

4.4.2 – Linear Regression Models

The crude relationship between each of the variables and the outcomes was investigated using linear regression models. These base models were adjusted for age and height, which are the main factors taken into consideration for spirometry results.

Linear regression models were created to address objectives 1 and 2. As a first step, scatter and lowess plots were created to examine whether the relationship between the continuous exposure variables and the outcomes was linear. Since several exposure/outcome relationships were not linear, it was decided to categorize all body composition exposure variables to enable comparability amongst models. Where established cut-off values were available (BMI, waist circumference, waist to hip ratio, and waist to height ratio), categories were based on these cut-offs. For exposure variables with no established cut-off values (hip circumference and sum of 5 skinfolds), sex-specific tertiles were created based on the weighted study sample.

4.4.3 – Addressing Objective 1

Firstly, a backwards model building process was completed for each of the outcome (FEV_1 and FVC)/exposure (anthropometric measures) pairs, stratified by sex. Covariates that were not statistically significant ($p < 0.05$) were removed stepwise. If the removal of a covariate resulted in a change in the coefficient of the main effect of >15%, the removed covariate was considered a confounder of the relationship of interest and was added back into model. The F test was used to assess the overall significance of categorical variables in the models. From this process, any covariates that were confounders for any of the models were included in the final set of covariates so that models would be comparable while still including all relevant confounders.

This full set of covariates was then categorized into three blocks to be added to each of the final models addressing this objective. Block 1 consisted of demographic variables including: race, income, and education. Block 2 consisted of health variables including: diagnosis of asthma, diagnosis of diabetes, diagnosis of heart disease, and diagnosis of other lung disease (COPD, Chronic Bronchitis, or Emphysema). Finally, Block 3 consisted of other confounders, which included: smoking status and respiratory medication or beta-blockers. The fully adjusted models used to assess the relationships of interest were all adjusted for the consistent full set of covariates from Blocks 1, 2, and 3.

To create the final models addressing the first objective, each outcome (FEV_1 and FVC) was treated separately and separate models were created for males and females. Base models were controlled for age and height as those are known to effect FEV_1 and FVC. Where the anthropometric measure of interest included a height measurement (BMI and waist to height ratio), height was not included as a separate covariate to avoid co-linearity.

From the fully adjusted models for each outcome/exposure pair, the R^2 values were compared to determine the best anthropometric measure for the prediction of lung function. The R^2 value is the coefficient of determination and demonstrates how well the data fits a given model; in this case a linear model. The R^2 value is between 0 and 1 and represents the proportion of the variation in the outcome, which can be explained by the model.

F-tests were also conducted on the categorical anthropometric variables to determine their significance in each model.

4.4.4 – Addressing Objective 2

The physical fitness variables were added to the previously described models one at a time. The models with and without a physical fitness term were compared to assess whether the relationship between body composition and lung function was independent of physical fitness. To determine whether physical fitness was a confounder of the relationship, the estimates for the anthropometric measure were compared between the initial fully adjusted model and the fully adjusted model also including a physical fitness term. A physical fitness measure was judged to be a confounder when the estimate for the exposure variable changed by >15% upon its addition to the model. The % change was calculated in the following way, where the unadjusted estimate was the coefficient for waist circumference in the model without a physical fitness or activity term, and the adjusted estimate was the coefficient for waist circumference in the model with a physical fitness or activity term.

$$\%change = \frac{|\beta_{unadjusted} - \beta_{adjusted}|}{|\beta_{unadjusted}|} x100$$

To address whether or not physical activity or physical fitness were effect modifiers of the relationship between waist circumference and both FEV_1 and FVC, additional analyses were completed. The median aerobic fitness scores for males and females were calculated and a variable was created with two values: low fitness (below the median value for that sex) and high fitness (above the median value for that sex). Each of the four models for FEV_1/FVC and males/females were then stratified based on aerobic fitness score and the estimates for waist circumference were compared between corresponding high fitness and low fitness models to assess for the presence of effect modification. Additionally, a categorical Steps/Day variable was created with two values: low steps (less than 10,000 per day) and high steps (greater than 10,000 per day). The same procedure was then repeated, stratifying based on high/low number of steps per day and comparing corresponding estimates for waist circumference.

Chapter 5: Results

5.1 – Descriptive Statistics

Bootstrap and population weighted data is presented in the following descriptive statistics. This data, weighted to the Canadian population over age 40, was explored to examine select characteristics for males and females.

5.1.1 – Demographic Characteristics

Several demographic characteristics were examined and are presented in Table 1. Means and proportions, along with associated P-values and standard deviations, where appropriate, are reported. Variables for which the coefficient of variation is greater than 16.6% were specified.

There was no difference in mean age between males and females, 55.1 years (10.4 years) and 55.8 years (10.2 years) respectively. A larger proportion of males had a university education (36.2% versus 29.4% for females), higher income adequacy (52.5% versus 46.1% for females), and were current or former smokers (60.7% versus 50.8% for females) compared to their female counterparts.

5.1.2 – Health Characteristics

Select health characteristics were also examined and are presented in Table 2. Data from home-administered questionnaires were collected in each cycle of CHMS on health status, diagnoses of various diseases, and medications.

The mean FEV_1 for males was 3.34 L (0.73 L) while for females it was 2.41 L (0.55 L). The mean FVC for males was 4.43 L (0.90 L) while for females it was 3.17 L (0.66 L). A higher proportion of males had heart disease and diabetes, and reported taking either respiratory medication or beta-blockers, while a higher proportion of females reported diagnoses of asthma, or other lung diseases.

5.1.3 – Anthropometric Characteristics

Descriptive statistics for the anthropometric measures are presented in Table 3. Mean BMI was 28.3 kg/m^2 (4.7 kg/m^2) for males and 27.8 kg/m^2 (6.2 kg/m^2) for females. The mean BMI for both males and females were in the overweight category. Mean waist circumference was 99.8 cm (13.5 cm) and 90.2 cm (15.3 cm) for males and females respectively. For males this mean value was in the increased risk category while the mean waist circumference for females was in the substantially increased risk category. The sum of 5 measures of skinfold thickness had mean values of 63.2 mm (20.6 mm) and 90.6 mm (26.8 mm) for males and females respectively.

Mean height, weight, waist circumference, BMI, waist to hip ratio, and waist to height ratio were all slightly higher for males, compared to females. Mean hip circumference and sum of 5 skinfolds was greater for females.

5.1.4 – Physical Activity Characteristics

Descriptive statistics for the physical activity/physical fitness measures are shown in Table 4. Grip strength was the fitness variable which differed the most between males and females. Males had average grip strength of 86 kg (17.4 kg) while females had average grip strength of 50.6 kg (10.7 kg). Aerobic fitness score was 342.8 (71.3) on average for males and was 293.1 (55.7) for females.

On average, males in the study were slightly more fit/active than females, had higher mean values of grip strength, aerobic fitness score, steps/day, and minutes/week of moderate-vigorous physical activity. Females conversely, had higher average number of inactive minutes/day than males.

Table 1 - Demographic characteristics for individuals over 40 from Cycles 1 and 2 of the Canadian Health Measures Survey, using both population and bootstrap weights

Demographic Characteristic		Males	Females	P-value
		Mean (Standard Deviation) or Proportion	Mean (Standard Deviation) or Proportion	
Age (years) – Mean (SD)		55.1 (10.4)	55.8 (10.2)	
Education (%)	Secondary	20.8	21.7	0.0092
	College	43.0	48.9	
	University	36.2	29.4	
Racial Origin[1] (%)	White (vs. non-white)	84.4	85.5	0.5848
Household Income Adequacy (%)	Low	18.0	21.2	0.0094
	Middle	29.5	32.8	
	High	52.5	46.1	
Smoking Status (%)	Current Smoker	21.1	17.8	0.0012
	Former Smoker	39.6	33.0	
	Never Smoker	39.4	49.2	

[1] Coefficient of variation > 16% (23.1% and 20.4%, respectively, for males and females in the “non-white” category)

Table 2 - Health characteristics for individuals over 40 from Cycles 1 and 2 of the Canadian Health Measures Survey, using both population and bootstrap weights

Health Characteristic	Males	Females	P-value
	Mean (SD) or Proportion	Mean (SD) or Proportion	
FEV$_1$ (L) – Mean (SD)	3.34 (0.73)	2.41 (0.55)	
FVC (L) – Mean (SD)	4.43 (0.90)	3.17 (0.66)	
Diagnosis of Asthma (%)	7.6	8.6	0.4542
Diagnosis of other Lung Disease (%) – COPD, Emphysema, Chronic Bronchitis	2.6	5.2	0.0023
Diagnosis of Heart Disease (%)	8.9	5.1	0.0001
Diagnosis of Diabetes (%)	10.0	7.2	0.0136
Respiratory Medication and Beta-Blockers (%)	7.0	5.6	0.1502

Table 3 - Anthropometric measures for individuals over 40 from Cycles 1 and 2 of the Canadian Health Measures Survey, using both population and bootstrap weights

Anthropometric Characteristic	Males	Females
	Mean (SD)	Mean (SD)
Height (cm)	174.1 (7.0)	161.0 (6.6)
Weight (kg)	86.0(16.1)	72.0 (16.9)
Waist Circumference (cm)	99.8 (13.5)	90.2 (15.3)
Hip Circumference (cm)	103.3 (8.9)	105.9 (12.8)
Body Mass Index (kg/m^2)	28.3 (4.7)	27.8 (6.2)
Waist to Hip Ratio	0.97 (0.08)	0.86 (0.07)
Waist to Height Ratio	0.57 (0.08)	0.56 (0.10)
Skinfold Thickness (sum of 5 measurements – mm)	63.2 (20.6)	90.6 (26.8)

Table 4 - Physical fitness/activity measures for individuals over 40 from Cycles 1 and 2 of the Canadian Health Measures Survey, using both population and bootstrap weights

Demographic Characteristic		Males	Females	P-value
		Mean (Standard Deviation) or Proportion	Mean (Standard Deviation) or Proportion	
Physical Activity (%)	Active	24.2	19.0	0.0109
	Moderately Active	23.8	25.2	
	Inactive	52.0	55.8	
Grip Strength (kg) – Mean (SD)		86.0 (17.4)	50.6 (10.7)	
Aerobic Fitness Score – Mean (SD)		342.8 (71.3)	293.1 (55.7)	
Average Number of Steps/day – Mean (SD)		8297.2 (4268.8)	7194.1 (3781.4)	
Average Number of Inactive minutes/day –Mean (SD)		1012.1 (131.5)	1014.8 (131.3)	
Average number of minutes/day of moderate or vigorous activity – Mean (SD)		145.4 (161.6)	111.8 (122.0)	

5.2 – Crude Associations with Lung Function

To determine the crude associations between each of the variables with the outcomes of interest, linear regression models were created. Each model was adjusted for age and height except where height was included in the variable (i.e. BMI, waist to height ratio), in which case the model was adjusted only for age.

5.2.1 – Crude Associations with FEV_1

The crude associations for the demographic variables are presented in Table 5. For both males and females, identifying a racial origin other than "white" was significantly associated with a decrease in FEV_1, -0.31 (95% CI: -0.43; -0.20) and -0.12 (95%CI: -0.20; -0.05) respectively. A higher income adequacy level was associated with a larger FEV_1.

Crude associations of the disease/medication variables with FEV_1 are presented in Table 6. Each variable was significantly associated with FEV_1 with the exception of diabetes for men and heart disease for women. In each case the associations were negative in direction, therefore having the disease or being on medication was associated with lower FEV_1.

The crude associations between the anthropometric measures and FEV_1 are presented in Table 7. Waist circumference was significant for males (-0.12, 95%CI: -0.22; -0.02) and females (-0.08, 95%CI: -0.15; -0.01) at the substantially increased risk but not for the increased risk category. BMI was significant for males in the overweight category and the association with FEV_1 was 0.20 (95%CI: 0.07; 0.32). Waist to hip ratio was significant for females but not for males and waist to height ratio was not significant for males or females. Skinfold thickness, when categorized in tertiles, was significant for males but not for females. For males in the middle tertile the estimate for skinfold thickness was -0.119 (95%CI: -0.21;-0.02) and in the highest tertile the estimate was -0.167 (95%CI: -0.26;-0.07).

The crude associations between the physical fitness and physical activity variables with FEV_1 are presented in Table 8. Lower levels of self-reported physical activity were significantly associated with lower FEV_1, except for men in the moderately active category where the association was non-significant. The number of steps/day was significantly positively associated with higher FEV_1 for both males (0.22, 95%CI: 0.04; 0.40) and females (0.17, 95%CI: 0.05; 0.30). The number of inactive minutes/day was significantly associated with lower FEV_1 in females but the association was non-significant for males.

Table 5 - Crude associations with FEV_1 and demographic variables from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted using both population and bootstrap weights

Variable	Males		Females	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Education (referent – secondary)				
College	-0.01	-0.14 ; 0.11	0.04	-0.02 ; 0.09
University	0.09	-0.04 ; 0.21	0.12	0.04 ; 0.20
Smoking Status (referent – never smoker)				
Current Smoker	-0.30	-0.43 ; -0.17	-0.26	-0.36 ; -0.17
Former Smoker	-0.12	-0.22 ; -0.03	-0.04	-0.10 ; 0.03
Racial Origin (referent – white)				
Other	-0.31	-0.43 ; -0.20	-0.12	-0.20 ; -0.05
Income Adequacy (referent – low)				
Middle	0.09	-0.001 ; 0.18	0.11	0.03 ; 0.19
High	0.19	0.11 ; 0.27	0.18	0.10 ; 0.26

Table 6 - Crude associations with FEV_1 and related disease/medication measures from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted using both population and bootstrap weights

Variable	Males		Females	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Diagnosis of Asthma (referent – no diagnosis of asthma)				
Yes	-0.33	-0.49; -0.16	-0.27	-0.38; -0.17
Diagnosis of Chronic Bronchitis (referent – no diagnosis of chronic bronchitis)				
Yes	-0.42	-0.67; -0.16	-0.36	-0.47; -0.25
Diagnosis of COPD (referent – no diagnosis of COPD)				
Yes	-0.69	-0.96; -0.42	-0.60	-0.86; -0.34
Diagnosis of Emphysema (referent – no diagnosis of emphysema)				
Yes	-0.47	-0.84; -0.10	-0.94	-1.22; -0.66
Diagnosis of COPD, Emphysema, or Chronic Bronchitis (referent – no diagnosis of COPD, Emphysema, or Chronic Bronchitis)				
Yes	-0.47	-0.66; -0.28	-0.49	-0.60; -0.38
Diagnosis of Heart Disease (referent – no diagnosis of heart disease)				
Yes	-0.14	-0.26; -0.01	-0.08	-0.20; 0.03
Diagnosis of Diabetes (referent – no diagnosis of diabetes)				
Yes	-0.11	-0.25; 0.02	-0.17	-0.27; -0.07
Respiratory Medication or Beta-Blockers (referent – not taking respiratory medication or beta-blockers)				
Yes	-0.38	-0.55; -0.22	-0.28	-0.40; -0.17

Table 7 - Crude associations with FEV$_1$ and anthropometric measures from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted using both population and bootstrap weights

Variable	**Males**		**Females**	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Waist Circumference (referent – normal)				
Increased Risk	0.06	-0.04; 0.15	0.02	-0.06; 0.10
Substantially Increased Risk	-0.12	-0.22; -0.02	-0.08	-0.15; -0.01
Hip Circumference (referent – lowest tertile)				
Middle	0.051	-0.07; 0.17	-0.004	-0.07; 0.06
Highest	-0.019	-0.13; 0.09	-0.043	-0.12; 0.03
BMI (referent – non-overweight/non-obese)				
Overweight	0.20	0.07; 0.32	0.001	-0.08; 0.08
Obese	0.02	-0.14; 0.18	-0.07	-0.17; 0.02
Waist to Hip Ratio (referent – normal)				
Substantially Increased Risk	-0.09	-0.19; 0.02	-0.09	-0.14; -0.03
Waist to Height Ratio (referent – normal)				
At Risk	-0.09	-0.20; 0.01	-0.06	-0.17; 0.04
Skinfold Thickness (referent – lowest tertile)				
Middle	-0.119	-0.21; -0.02	0.002	-0.07; 0.07
Highest	-0.167	-0.26; -0.07	-0.080	-0.17; 0.01

Table 8 - Crude associations with FEV$_1$ and physical fitness/activity from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted using both population and bootstrap weights

Variable	**Males**		**Females**	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Aerobic Fitness Score	0.002	0.002; 0.003	0.001	0.0004; 0.002
Grip Strength (kg)	0.006	0.003; 0.008	0.009	0.006; 0.011
Steps (10^4/day)	0.22	0.04; 0.40	0.17	0.05; 0.30
Inactivity (min/day)	-0.0006	-0.001; 0.0002	-0.0006	-0.001; 0.0003
Moderate-Vigorous Physical Activity (min/week)	0.0005	0.0003; 0.0008	0.0004	-0.00004; 0.0009
Activity (referent – active)				
Moderate Activity	0.01	-0.10; 0.12	-0.09	-0.16; -0.03
Inactive	-0.17	-0.24; -0.09	-0.17	-0.25; -0.09

5.2.2 – Crude Associations with FVC

The crude associations with FVC for the demographic variables are presented in Table 9. For males, identifying as having a racial origin other than white was associated with a 0.50 decrease in FVC (95%CI: -0.65; -0.036) while in females it was associated with a 0.27 decrease in FVC (95%CI: -0.39; -0.14).

Crude associations of the disease/medication variables with FVC are presented in Table 10. Each of the disease/medication variables was negatively associated with the outcome and the associations were statistically significant with the exception of asthma and emphysema for males, and heart disease for females.

The crude associations between FVC and the anthropometric measures are presented in Table 11. The categorical anthropometric measures were inversely associated with the outcome but only statistically significant at the highest level of each variable.

The crude associations between FVC and physical fitness/activity are presented in Table 12. Physical fitness/activity was consistently and significantly associated with higher FVC while inactivity was significantly associated with lower FVC with the exception of the moderate category of self-identified physical activity for males.

Table 9 - Crude associations with FVC and demographic variables from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

Variable	**Males**		**Females**	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Education (referent – secondary)				
College	-0.027	-0.158; 0.103	0.019	-0.056; 0.095
University	-0.003	-0.128; 0.121	0.086	-0.006; 0.177
Smoking Status (referent – never smoker)				
Current Smoker	-0.10	-0.23; 0.03	-0.10	-0.20; 0.01
Former Smoker	-0.05	-0.16; 0.06	0.02	-0.05; 0.10
Racial Origin (referent – white)				
Other	-0.50	-0.65; -0.036	-0.27	-0.39; -0.14
Income Adequacy (referent – low)				
Middle	0.13	0.03; 0.23	0.09	-0.01; 0.19
High	0.18	0.08; 0.28	0.14	0.04; 0.24

Table 10 - Crude associations with FVC and related disease/medication variables from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

Variable	**Males**		**Females**	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Diagnosis of Asthma (referent – no diagnosis of asthma)				
Yes	-0.13	-0.27; 0.01	-0.19	-0.29; -0.08
Diagnosis of Chronic Bronchitis (referent – no diagnosis of chronic bronchitis)				
Yes	-0.39	-0.67; -0.10	-0.39	-0.48; -0.29
Diagnosis of Emphysema (referent – no diagnosis of emphysema)				
Yes	-0.18	-0.60; 0.24	-0.67	-1.03; -0.31
Diagnosis of COPD (referent – no diagnosis of COPD)				
Yes	-0.36	-0.68; -0.04	-0.47	-0.71; -0.24
Diagnosis of COPD, Emphysema, or Chronic Bronchitis (referent – no diagnosis of COPD, Emphysema, or Chronic Bronchitis)				
Yes	-0.31	-0.54; -0.09	-0.43	-0.55; -0.31
Diagnosis of Heart Disease (referent – no diagnosis of heart disease)				
Yes	-0.22	-0.37; -0.07	-0.10	-0.24; 0.03
Diagnosis of Diabetes (referent – no diagnosis of diabetes)				
Yes	-0.30	-0.50; -0.09	-0.28	-0.41; -0.15
Respiratory Medication or Beta-Blockers (referent – not taking respiratory medication or beta-blockers)				
Yes	-0.30	-0.44; -0.17	-0.24	-0.33; -0.15

Table 11 - Crude associations with FVC and anthropometric measures from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

Variable	Males		Females	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Waist Circumference (referent – normal)				
Increased Risk	-0.005	-0.127; 0.117	-0.011	-0.104; 0.082
Substantially Increased Risk	-0.320	-0.452; -0.187	-0.181	-0.267; -0.095
Hip Circumference (referent – lowest tertile)				
Middle	-0.075	-0.227; -0.078	-0.046	-0.119; 0.028
Highest	-0.198	-0.328; -0.068	-0.140	-0.223; -0.057
BMI (referent – non-overweight/non-obese)				
Overweight	0.13	-0.04; 0.30	-0.06	-0.17; 0.06
Obese	-0.15	-0.35; 0.05	-0.19	-0.31; -0.07
Waist to Hip Ratio (referent – normal)				
Substantially Increased Risk	-0.23	-0.34; -0.12	-0.14	-0.20; -0.08
Waist to Height Ratio (referent – normal)				
At Risk	-0.29	-0.46; -0.12	-0.16	-0.29; -0.03
Skinfold Thickness (referent – lowest tertile)				
Middle	-0.241	-0.369; -0.112	-0.079	-0.153; -0.005
Highest	-0.381	-0.489; -0.273	-0.225	-0.324; -0.125

Table 12 - Crude associations with FVC and physical fitness/activity from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

Variable	**Males**		**Females**	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Aerobic Fitness Score	0.003	0.002; 0.004	0.002	0.0008; 0.002
Grip Strength (kg)	0.008	0.004; 0.012	0.011	0.007; 0.015
Steps (10^4/day)	0.321	0.107; 0.535	0.203	0.068; 0.339
Inactivity (min/day)	-0.0009	-0.0016; -0.0002	-0.0007	-0.0011; -0.0002
Moderate-Vigorous Physical Activity (min/week)	0.0008	0.0004; 0.0012	0.0005	0.0001; 0.0009
Activity (referent – active)				
Moderate Activity	0.004	-0.123; 0.131	-0.139	-0.125; -0.063
Inactive	-0.179	-0.290; -0.069	-0.199	-0.290; -0.108

5.3 – Objective 1

The first objective, to determine the measure of body composition most associated with lung function was investigated using linear regression models. The results of this analysis are presented in the current section.

The results from each of the fully adjusted models are presented in Tables 13-16, along with the R^2 values as well as the p-value for the main effect.

Overall the models predicting FVC had higher R^2 values than the models predicting FEV_1 for each of the anthropometric measures. For both sexes and outcomes, models with skinfold thickness as the body composition measure had the highest R^2 values. For males the R^2 values for the fully adjusted models with skinfold thickness were 0.599 and 0.623 for FEV_1 and FVC respectively. For females the R^2 values for the fully adjusted models with skinfold thickness were 0.588 and 0.623 for FEV_1 and FVC respectively. The models containing waist circumference had consistently higher R^2 values than did the models containing BMI. The R^2 values for the models containing waist circumference were for males 0.564 and 0.604, and for females 0.569 and 0.602, each for FEV_1 and FVC respectively. Models with BMI and waist to height ratio consistently had the lowest R^2 values. The models for FEV_1, containing a BMI term had R^2 values of 0.456 and 0.446 for males and females respectively. The R^2 values for FVC models containing a BMI term were 0.408 and 0.434 for males and females respectively.

The changes in R^2 values with the addition of the covariates by anthropometric measure are summarized in Graphs 1-4, Appendix B. R^2 values consistently increased with the addition of covariates. There was a pattern in the relative R^2 values. For males and both FEV_1 and FVC each of the measures seemed to follow the same pattern of increase in R^2 with the addition of covariate blocks. For females (graphs 2 and 4), the pattern was less clear with skinfold thickness and waist to hip ratio changing by greater amounts. BMI and waist to height ratio models had similar R^2 values for FEV_1 and FVC in both men and women and R^2 values were consistently lower than for each of the other anthropometric measures.

The models with anthropometric measures that had the highest R^2 values were those that included skinfold thickness, waist circumference, waist to hip circumference, and hip circumference. The R^2 values for these measures were extremely close.

While skinfold thickness is consistently the highest, there was not much difference in the predictive value of more clinically useful measures such as waist circumference. Models with waist circumference as the anthropometric measure had the second highest R^2 values for both sexes and outcomes. Given its clinical utility, the ease of measurement, having a single measurement site and less variability in the measurement waist circumference was therefore chosen as the anthropometric measure to address Objective 2.

Table 13 - Linear regression models for an anthropometric measure and FEV$_1$ in males from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

Anthropometric Measures	Unadjusted Model[1]		Fully Adjusted Model[2]	
	Coefficient	P-Value	Coefficient	P-Value
Skinfold Thickness	**R^2=0.502** P=0.0046		**R^2=0.599** P=<0.0001	
Lowest	0.000		0.000	
Middle	-0.119	0.017	-0.153	0.002
Highest	-0.167	0.001	-0.198	<0.001
BMI	**R^2= 0.324** P=0.0005		**R^2=0.456** P=0.0035	
Underweight/ Normal Weight	0.000		0.000	
Overweight	0.196	0.004	0.053	0.307
Obese	0.020	0.796	-0.071	0.286
Waist Circumference	**R^2= 0.483** P=0.0001		**R^2=0.564** P=0.0002	
Normal	0.000		0.000	
Increased Risk	0.059	0.214	-0.020	0.627
Substantially Increased Risk	-0.124	0.018	-0.158	<0.001
Hip Circumference	**R^2=0.476** P=0.4087		**R^2=0.558** P=0.2566	
Lowest	0.000		0.000	
Middle	0.051	0.390	-0.002	0.958
Highest	-0.019	0.712	-0.074	0.141
Waist to Hip Ratio	**R^2= 0.476** P=0.0949		**R^2= 0.559** P=0.0360	
Normal	0.000		0.000	
Substantially Increased Risk	-0.089	0.095	-0.102	0.036
Waist to Height Ratio	**R^2=0.307** P=0.0803		**R^2=0.454** P=0.0697	
Normal	0.000		0.000	
At Risk	-0.094	0.080	-0.102	0.070

[1] Adjusted for height and age

[2] Adjusted for demographic variables (race, income, education), health variables (asthma, other lung disease, heart disease, diabetes), and other factors (respiratory medication/beta-blockers, smoking history)

Table 14 - Linear regression models for an anthropometric measure and FEV_1 in females from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

Anthropometric Measures	Unadjusted Model[1]		Fully Adjusted Model[2]	
	Coefficient	P-Value	Coefficient	P-Value
Skinfold Thickness	**R^2=0.469** P=0.1602		**R^2=0.588** P=0.0438	
Lowest	0.000		0.000	
Middle	0.002	0.959	-0.034	0.325
Highest	-0.080	0.079	-0.122	0.012
BMI	**R^2= 0.299** P=0.0755		**R^2= 0.446** P=0.0752	
Underweight/ Normal Weight	0.000		0.000	
Overweight	0.001	0.001	-0.024	-0.024
Obese	-0.073	-0.073	-0.092	-0.092
Waist Circumference	**R^2= 0.477** P=0.0029		**R^2= 0.569** P=0.0347	
Normal	0.000		0.000	
Increased Risk	0.001	0.972	-0.024	0.562
Substantially Increased Risk	-0.073	0.166	-0.092	0.043
Hip Circumference	**R^2=0.472** P=0.2509		**R^2=0.566** P=0.3674	
Lowest	0.000		0.000	
Middle	-0.004	0.894	-0.050	0.157
Highest	-0.043	0.250	-0.052	0.206
Waist to Hip Ratio	**R^2= 0.475** P=0.0031		**R^2= 0.566** P=0.0287	
Normal	0.000		0.000	
Substantially Increased Risk	-0.086	0.003	-0.063	0.029
Waist to Height Ratio	**R^2=0.298** P=0.2270		**R^2=0.444** P=0.1792	
Normal	0.000		0.000	
At Risk	-0.062	0.227	-0.065	0.179

[1] Adjusted for height and age

[2] Adjusted for demographic variables (race, income, education), health variables (asthma, other lung disease, heart disease, diabetes), and other factors (respiratory medication/beta-blockers, smoking history)

Table 15 - Linear regression models for an anthropometric measure and FVC in males from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

Anthropometric Measures	Unadjusted Model[1]		Fully Adjusted Model[2]	
	Coefficient	P-Value	Coefficient	P-Value
Skinfold Thickness	**R^2=0.555** P=<0.0001		**R^2=0.623** P=<0.0001	
Lowest	0.000		0.000	
Middle	-0.241	0.001	-0.246	<0.001
Highest	-0.381	<0.001	-0.361	<0.001
BMI	**R^2= 0.258** P=0.0001		**R^2=0.408** P=0.0006	
Underweight/ Normal Weight	0.000		0.000	
Overweight	0.129	0.121	-0.033	0.653
Obese	-0.154	0.128	-0.251	0.008
Waist Circumference	**R^2= 0.532** P=0.0000		**R^2=0.604** P=0.0000	
Normal	0.000		0.000	
Increased Risk	-0.005	0.935	-0.097	0.079
Substantially Increased Risk	-0.320	0.000	-0.353	0.000
Hip Circumference	**R^2=0.513** P=0.0062		**R^2=0.588** P=0.0023	
Lowest	0.000		0.000	
Middle	-0.075	0.321	-0.098	0.102
Highest	-0.198	0.004	-0.235	0.001
Waist to Hip Ratio	**R^2= 0.516** P=0.0004		**R^2= 0.588** P=0.0002	
Normal	0.000		0.000	
Substantially Increased Risk	-0.230	0.000	-0.227	0.000
Waist to Height Ratio	**R^2=0.250** P=0.0015		**R^2=0.406** P=0.0055	
Normal	0.000		0.000	
At Risk	-0.291	0.002	-0.271	0.005

[1] Adjusted for height and age

[2] Adjusted for demographic variables (race, income, education), health variables (asthma, other lung disease, heart disease, diabetes), and other factors (respiratory medication/beta-blockers, smoking history)

Table 16 - Linear regression models for an anthropometric measure and FVC in females from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

Anthropometric Measures	Unadjusted Model[1]		Fully Adjusted Model[2]	
	Coefficient	P-Value	Coefficient	P-Value
Skinfold Thickness	**R^2=0.562** P=0.0005		**R^2=0.623** P=0.0003	
Lowest	0.000		0.000	
Middle	-0.079	0.038	-0.104	0.006
Highest	-0.225	<0.001	-0.244	<0.001
BMI	**R^2= 0.294** P=0.0024		**R^2=0.434** P=0.0003	
Underweight/ Normal Weight	0.000		0.000	
Overweight	-0.055	0.331	-0.094	0.100
Obese	-0.188	0.003	-0.221	0.000
Waist Circumference	**R^2= 0.548** P=0.0000		**R^2=0.603** P=0.0001	
Normal	0.000		0.000	
Increased Risk	-0.011	0.810	-0.043	0.310
Substantially Increased Risk	-0.181	0.000	-0.192	0.000
Hip Circumference	**R^2=0.540** P=0.0012		**R^2=0.597** P=0.0120	
Lowest	0.000		0.000	
Middle	-0.046	0.211	-0.100	0.017
Highest	-0.140	0.002	-0.155	0.003
Waist to Hip Ratio	**R^2= 0.542** P=0.0001		**R^2= 0.595** P=0.0007	
Normal	0.000		0.000	
Substantially Increased Risk	-0.137	0.000	-0.117	0.001
Waist to Height Ratio	**R^2=0.292** P=0.018		**R^2=0.429** P=0.0063	
Normal	0.000		0.000	
At Risk	-0.163	0.018	-0.167	0.006

[1] Adjusted for height and age

[2] Adjusted for demographic variables (race, income, education), health variables (asthma, other lung disease, heart disease, diabetes), and other factors (respiratory medication/beta-blockers, smoking history)

5.4 – Objective 2

Objective 2 aimed to determine the effect of physical fitness and physical activity on the relationship between anthropometric measures and lung function. From the previous results, waist circumference was found to be a better measure than BMI and was in each model among the best predictors of both FEV_1 and FVC. Additionally, the coefficient of variation (CV) was calculated for both skinfold thickness and waist circumference. The CV was higher for skinfold thickness and therefore it was determined to be a less reliable measurement than was waist circumference. We therefore used waist circumference as the anthropometric measure to address Objective 2.

Upon addition of each of the physical fitness/activity measures confounding was assessed. Confounding was assumed to be present whenever the difference in the coefficient for waist circumference was greater than 10% between models. The results from these analyses are presented in Tables 17-20. There was evidence of confounding by each of the physical fitness/activity variables, with the exception of the categorical self-reported physical activity variable for FEV_1 and waist circumference in females. Overall, the effect of adding physical fitness or activity terms was much greater in FEV_1 than it was for similar models predicting FVC.

In addition to the changes in the magnitude of the effect of waist circumference on FEV_1 and FVC, other changes in the main effects were observed upon addition of a physical fitness term. When FEV_1 was the outcome, the addition of select physical fitness/activity terms also changed the significance of waist circumference in the model. For men, after addition of the aerobic fitness measure to the FEV_1 model, waist circumference was no longer a significant independent predictor of the outcome. Similar results were seen for females; following the addition of inactivity, steps/day, or minutes of moderate-vigorous physical activity measures, waist circumference was no longer a significant predictor of FEV_1. Waist circumference remained significant in each of the FVC models after the addition of the physical fitness/activity measures.

Additionally, to determine whether physical fitness or activity was a possible effect modifier of the relationship between waist circumference and lung function, analyses stratified based on steps/day and median aerobic fitness score were completed. None of the estimates for waist circumference from this analysis were statistically different as they had overlapping 95% confidence intervals. Hence, effect modification was not observed. Data from this analysis is presented in Appendix C.

Table 17 - Fully adjusted linear regression models for males waist circumference and FEV$_1$ with and without physical fitness/activity terms from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

	Waist Circumference Coefficients	P-Value for Waist Circumference in Model	% Change from Unadjusted Model
Fully Adjusted Model – no physical fitness/activity term			
Normal	0.000	0.0002	
Increased Risk	-0.020		
Substantially Increased Risk	-0.158		
Fully Adjusted Model – with Grip Strength term			
Normal	0.000	0.0001	
Increased Risk	-0.038		90%
Substantially Increased Risk	-0.175		11%
Fully Adjusted Model – with Aerobic Fitness Score term			
Normal	0.000	0.4927	
Increased Risk	0.036		280%
Substantially Increased Risk	-0.025		84%
Fully Adjusted Model – with inactivity term			
Normal	0.000	0.0316	
Increased Risk	-0.070		250%
Substantially Increased Risk	-0.140		11%
Fully Adjusted Model – with steps/day term			
Normal	0.000	0.0468	
Increased Risk	-0.068		240%
Substantially Increased Risk	-0.145		8%
Fully Adjusted Model – with moderate-vigorous physical activity term			
Normal	0.000	0.0839	
Increased Risk	-0.055		175%
Substantially Increased Risk	-0.120		24%
Fully Adjusted Model - with categorical self-reported activity term			
Normal	0.000	0.0007	
Increased Risk	-0.019		5%
Substantially Increased Risk	-0.148		6%

Table 18 - Fully adjusted linear regression models for females waist circumference and FEV_1 with and without physical fitness/activity terms from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

	Waist Circumference Coefficients	P-Value for Waist Circumference in Model	% Change from Unadjusted Model
Fully Adjusted Model – no physical fitness/activity term			
Normal	0.000	0.0347	
Increased Risk	-0.012		
Substantially Increased Risk	-0.082		
Fully Adjusted Model – with Grip Strength term			
Normal	0.000	0.0072	
Increased Risk	-0.021		75%
Substantially Increased Risk	-0.103		26%
Fully Adjusted Model – with Aerobic Fitness Score term			
Normal	0.000	0.0146	
Increased Risk	-0.047		292%
Substantially Increased Risk	-0.127		55%
Fully Adjusted Model – with inactivity term			
Normal	0.000	0.3104	
Increased Risk	0.002		117%
Substantially Increased Risk	-0.040		51%
Fully Adjusted Model – with steps/day term			
Normal	0.000	0.2987	
Increased Risk	-0.003		75%
Substantially Increased Risk	-0.045		45%
Fully Adjusted Model – with moderate-vigorous physical activity term			
Normal	0.000	0.2547	
Increased Risk	-0.003		75%
Substantially Increased Risk	-0.048		41%
Fully Adjusted Model - with categorical self-reported activity term			
Normal	0.000	0.0562	
Increased Risk	-0.010		17%
Substantially Increased Risk	-0.073		11%

Table 19 - Fully adjusted linear regression models for males waist circumference and FVC with and without physical fitness/activity terms from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

	Waist Circumference Coefficients	P-Value for Waist Circumference in Model	% Change from Unadjusted Model
Fully Adjusted Model – no physical fitness/activity term			
Normal	0.000	<0.0001	
Increased Risk	-0.097		
Substantially Increased Risk	-0.353		
Fully Adjusted Model – with Grip Strength term			
Normal	0.000	<0.0001	
Increased Risk	-0.119		23%
Substantially Increased Risk	-0.375		6%
Fully Adjusted Model – with Aerobic Fitness Score term			
Normal	0.000	0.0061	
Increased Risk	-0.029		70%
Substantially Increased Risk	-0.208		41%
Fully Adjusted Model – with inactivity term			
Normal	0.000	0.0015	
Increased Risk	-0.140		44%
Substantially Increased Risk	-0.364		3%
Fully Adjusted Model – with steps/day term			
Normal	0.000	0.0015	
Increased Risk	-0.135		39%
Substantially Increased Risk	-0.361		2%
Fully Adjusted Model – with moderate-vigorous physical activity term			
Normal	0.000	0.0016	
Increased Risk	-0.126		30%
Substantially Increased Risk	-0.351		1%
Fully Adjusted Model - with categorical self-reported activity term			
Normal	0.000	<0.0001	
Increased Risk	-0.096		1%
Substantially Increased Risk	-0.345		2%

Table 20 - Fully adjusted linear regression models for females waist circumference and FVC with and without physical fitness/activity terms from Cycles 1 and 2 of CHMS for individuals over 40 and data weighted with bootstrap and population weights

	Waist Circumference Coefficients	P-Value for Waist Circumference in Model	% Change from Unadjusted Model
Fully Adjusted Model – no physical fitness/activity term			
Normal	0.000	0.0001	
Increased Risk	-0.043		
Substantially Increased Risk	-0.192		
Fully Adjusted Model – with Grip Strength term			
Normal	0.000	<0.0001	
Increased Risk	-0.047		9%
Substantially Increased Risk	-0.218		14%
Fully Adjusted Model – with Aerobic Fitness Score term			
Normal	0.000	0.0003	
Increased Risk	-0.075		74%
Substantially Increased Risk	-0.234		22%
Fully Adjusted Model – with inactivity term			
Normal	0.000	<0.0001	
Increased Risk	-0.010		77%
Substantially Increased Risk	-0.157		18%
Fully Adjusted Model – with steps/day term			
Normal	0.000	<0.0001	
Increased Risk	-0.015		65%
Substantially Increased Risk	-0.162		16%
Fully Adjusted Model – with moderate-vigorous physical activity term			
Normal	0.000	<0.0001	
Increased Risk	-0.015		65%
Substantially Increased Risk	-0.167		13%
Fully Adjusted Model - with categorical self-reported activity term			
Normal	0.000	0.0001	
Increased Risk	-0.040		7%
Substantially Increased Risk	-0.181		6%

Chapter 6: Discussion

This study examined the association between several measures of body composition and their association with lung function. It also examined the impact of physical fitness/activity on the relationship between the body composition and lung function. There were several key findings based on the previously stated objectives, which are summarized and discussed in the following subsections.

6.1 – Summary of Study Findings

We found that overall, the anthropometric measures were inversely related to lung function in the Canadian study population over the age of 40; as measures of body fat increased, lung function decreased. The models containing anthropometric measures predicting FVC led to larger R^2 values than did similar models predicting FEV_1. Skinfold thickness was the anthropometric measure, of those included in the CHMS, which was the best predictor of both FEV_1 and FVC for males and females. Additionally, we found that waist circumference, hip circumference, and waist to height ratio were each better predictors of both FEV_1 and FVC than BMI and waist to height ratio measures.

When adjusted for the full set of confounders, waist circumference models had the second highest R^2 values, following skinfold thickness to predict FEV_1 and FVC for both males and females. Whereas skinfold thickness models were 3-6% better than waist circumference models in terms of R^2 for predicting both FEV_1 and FVC, waist circumference models were consistently 20-34% better than BMI in predicting both FEV_1 and FVC.

Based on these analyses, waist circumference was chosen as the anthropometric measure to address Objective 2. We found that physical fitness and physical activity measures were confounders of the relationship between waist circumference and both FEV_1 and FVC. However, the addition of physical fitness/activity terms had a much larger effect in the models predicting FEV_1 than it did in the models predicting FVC. Aerobic fitness score, grip strength, inactivity, number of steps/day, and moderate to vigorous physical activity each individually affected the relationship between waist circumference and lung function. Self-reported physical activity had the least impact on the relationship of interest and was only a confounder of the relationship between waist circumference and FEV_1 in females.

With the addition of physical fitness/activity terms, waist circumference remained a statistically significant independent predictor of FVC in both men and women. However, when moderate-vigorous physical activity, inactivity, steps/day, or categorical self-reported physical activity was added to the otherwise fully adjusted model for women, not only did the magnitude of the main effect change but waist circumference was also no longer a statistically significant predictor of FEV_1. For men, upon addition of aerobic fitness score or moderate-vigorous physical activity, waist circumference was no longer a statistically significant predictor of FEV_1.

6.2 – Discussion of Study Findings

The characteristics of the weighted sample were generally as expected. Males tended to have higher education and income adequacy as well as a higher proportion of former or current smokers than their female counterparts. The majority of anthropometric measurements were greater for males than for females. However, differences in the shape and body composition of females were reflected with higher skinfold thickness and higher hip circumference mean values compared to males.

The crude associations between the variables included in the study and the outcomes were also generally as expected with lung disease, smoking, and higher anthropometric measure values being negatively associated, while education and fitness (aerobic fitness score and grip strength measures) were positively associated with lung function. Identifying as a racial origin other than "white" was consistently and significantly associated with lower lung function values. This is consistent with literature on the subject stating that white individuals have larger chest cavities and an increased number of alveoli compared to individuals of other racial origins (in the cited study, those of Chinese and Indian decent).(61) To explain the differences between black and white participants, a study from 2001 suggested that sitting height accounted for 35-39% of the differences in lung function between racial groups. Black participants had shorter upper body segments proportionate to their height accounting for the observed lower lung function values.(62)

Skinfold thickness was found to be the best predictor of FEV_1 and FVC, based on R^2 values, for both men and women. However, there exist few studies in the literature that consider skinfold thickness in relation to lung function. In 1997 it was suggested that skinfold thickness, a measure of subcutaneous adiposity, would likely be significantly associated with lung function when also controlled for overall adiposity, in the form of BMI.(37) In the existing literature, skinfold thickness measures are sometimes used as separate measures at the individual measurement sites.(63) In CHMS, the variable used was the continuous sum of 5 skinfold measurements and in the current study was categorized into tertiles based on the study sample. In the literature, however, skinfold thickness measurements have also been used to calculate other body composition measures such as fat free mass index, or fat %.(39, 64)

Waist circumference was consistently the anthropometric measure that was the next-best predictor of lung function (both FEV_1 and FVC) following skinfold thickness. This is a significant result in several ways. Skinfold thickness is a more difficult measurement to take than is waist circumference. For skinfold thickness there are 5 specific measurement sites each introducing measurement challenges, compared to one easily identifiable waist circumference measurement site. Additionally any measurement error would be compounded with multiple measurements. Taking skinfold thickness measurements is a more involved procedure than measuring waist circumference and takes more specialized equipment and training. Skinfold thickness had a higher coefficient of variation (based on the mean and standard deviation values) than did waist circumference in the study population. In the literature, it is stated that the constancy of fat compressibility and skin thickness add to the variability of the skinfold thickness measurement.(65)

Additionally, skinfold thickness had 37% missing values while waist circumference had only 4% missing values for males and females. There were more exclusion criteria for the skinfold measurement than for waist circumference including those with BMI>30kg/m^2 and those with missing limbs. However, this could lead to some selection bias for the models containing the skinfold measurement.

In terms of prediction it is also useful that waist circumference has widely accepted cut-off points to classify measurements into normal, increased risk, or substantially increased risks.(55) No such cut-off points exist for skinfold thickness so the categorization in the current study was based on within-sample tertiles and may have limited usefulness in a broader clinical setting.

While BMI is the measure that is currently used in clinical settings accompanying lung function results, in the literature addressing anthropometric measures, waist circumference was generally found to be superior in terms of predicting the outcomes.(31, 33, 39, 40) The results of the current study support this. It is also in keeping with the existing literature stating the importance of body composition measures, which distinguish fat mass from fat-free mass when studying lung function. The literature states that increasing fat-free mass (or lean muscle mass) was shown to be associated with an increase in lung function.(39, 40) A higher BMI therefore does not always mean an increase in adiposity, which would negatively affect lung function and therefore is not the most reliable measure to consider.

The relationship between waist circumference and lung function is also supported by the literature. According to a recent systematic review and meta-analysis there is an inverse relationship between waist circumference and both FEV_1 and FVC though the effect was found to be greater in men than in women.(38) Each individual study looking at FEV_1 and waist circumference found an inverse relationship although it was not always statistically significant. The pooled data from the ten studies, however, indicates significant associations between waist circumference and lung function. The pooled estimates for FEV_1, for males and females were -15.9 mL/cm (95% CI: -23.2; -8.5) and -5.6 mL/cm (95%CI: -9.1; -2.1) respectively. With FVC as the outcome, the pooled estimates were -16.6mL/cm (95%CI: -21.0; -12.2) and -7.0 mL/cm (95%CI: -9.1'-4.8) for males and females respectively. In the current study we used waist circumference as a categorical variable based on level of risk (normal, increase risk, and substantially increased risk) so the coefficients are not directly comparable to those from the meta-analysis. The coefficients are generally larger in magnitude than those found in the meta-analysis, which is in keeping with categorical exposure variables.

The anthropometric measures included in the analysis for Objective 1 measure different aspects of obesity. Skinfold thickness is a measure of subcutaneous fat or fat that lies just beneath the skin at each of the five measurement sites. This measures only fat mass and not fat-free mass. Waist circumference, however, measures both subcutaneous and visceral (which lies inside the abdominal wall among the organs), abdominal fat.(66) Waist circumference may be affected by abdominal muscle mass. Hip circumference is similar to waist circumference in that it takes into account both subcutaneous and visceral fat at a different measurement site. Waist to hip ratio is a measure, not of the absolute size of the waist or hip circumference, but rather the relative size of one to the other. Waist to height ratio is the waist circumference put into the context of standing height. BMI, different still, takes into account subcutaneous and visceral fat as well as muscle mass and does not differentiate among them.

Based on the proposed physiological mechanism for the effect of body composition on lung function, that fat impedes the space for lung expansion and therefore limits the volume, it could be suggested that visceral fat may have a greater impact on lung function than does subcutaneous fat. (63, 67) From the current study, however, we cannot fully address this question of which type of fat is most detrimental to lung function because there are only slight differences in R^2 among several of the anthropometric variables. BMI and waist to height ratio consistently led to lower R^2 values, with the remaining four measurements leading to R^2 values differed by approximately 0.04 or less. Although from the current study we are unable to address which type of fat is most detrimental to lung function, the physiological mechanism by which fat affects lung function adds support to the choice of waist circumference as the measure of interest for the analysis for Objective 2.

Addressing the second objective, physical fitness/activity were found to be confounders of the relationship between waist circumference and both FEV_1 and FVC in the current study. Very few of the studies addressing the relationship between anthropometric measures and lung function considered physical fitness/activity as a potential confounder. The few that did consider activity or fitness often used potentially unreliable measures such as self-reported physical activity. There is a single study by Steele et al from 2009 that investigated the relationship between anthropometric measures and lung function, while taking into account objectively measured physical fitness as well as physical activity. The results of the current study, however, differ from the results of the previous study, which found that the relationship between anthropometric measures and lung function was independent of physical fitness/activity. They found that physical fitness/activity were not confounders of the relationship between anthropometric measures and lung function, as the coefficients remained the same upon addition of the fitness terms.

Steele et al conducted the analysis in a similar fashion to the current study, creating models for each anthropometric measure/lung function outcome pair, then comparing the coefficient for the main effect after the addition of physical fitness terms.(51) The sample sizes of the two studies differed greatly with the current study having over ten times the number of participants compared to Steele et al (n=398). Steele et al also state in their limitations that due to the specialized population, the offspring of diabetics, that the results may have limited generalizability. There were slight differences also in the population characteristics.

The most significant difference between the two studies, which could potentially account for the discordant results, was in the methodology. The two main differences between the studies are in the adjustment of models for other factors (i.e. demographic factors, medication, disease diagnosis) and the addition of two physical fitness terms. Steele et al. adjusted each of their models for age, sex, height, and smoking status whereas the current study included various other adjustments as well. Additionally, Steele et al added two physical fitness/activity terms to each model to obtain their main conclusion: VO_2 max (fitness) and physical activity energy expenditure (activity). VO_2 max is the measurement from which the aerobic fitness score was calculated in the current study. Physical activity energy expenditure is a measure of physical activity, which is calculated based on heart rate monitor readings over four days. The current study adds each of the physical activity/fitness variables separately with no model containing more than one variable. This has the potential to account for the differences between the observed results from the two studies.

Steele et al conclude that body fat measures are associated with lung function independent of physical fitness so reduction in body fat measures through dietary means may be sufficient to improve lung function without altering physical fitness or activity.(51) The current study results differ and indicate that physical fitness should be considered as a confounder when studying the association between anthropometric measures and lung function. While physical fitness and physical activity were found to be confounders of the relationship of interest in the current study, this does not mean that in a different study they would necessarily be confounders. Physical activity and fitness were confounders in the current study as there were imbalances between fitness/activity groups. In another study should physical fitness or activity be consistent among the population then it would not be necessary to control for it as a confounder. Therefore, although it may not be necessary in every study population to control for physical fitness or activity, it may be beneficial to consider them as they were shown in the current study to alter the relationship of interest. The disagreement in the results between the current study and the previous study from Steele et. al. points to the need for further population-based studies to add to the literature on this topic.

VO_2 max is a commonly accepted measure of aerobic fitness and represents the maximal oxygen uptake during exercise. VO_2 max depends on both cardiac function and lung function to a certain degree. While cardiac output, delivering the oxygen to the muscles involved in exercise was found to be the limiting factor for VO_2 max, it is unclear in the literature whether there is also a causal relationship between lung function and VO_2 max.(68) Cardiac output (amount of blood pumped/unit time) increases with exercise training, and since it is the limiting factor, therefore makes VO_2 max a good objective measure of physical fitness. Lung function, however, does have a role in the process supplying the oxygen upon inhalation, which is then distributed to the muscles through the cardiac output. While it is unclear how lung function affects VO_2 max, should there be some contribution of either FEV_1 or FVC in the measurement this has the potential to impact the results of the current analysis. To address this possibility, multiple measures of physical fitness (aerobic fitness score and grip strength) as well as multiple measures of physical activity were also used and the same conclusions were reached.

The outcome variables considered in the current study, FEV_1 and FVC, are often collectively referred to as lung function values. FEV_1 and FVC, however, measure different aspects of lung function. FVC is the total volume that can be inspired following a maximal exhalation and is a value measured in liters or milliliters. FEV_1 is the total volume which can be forcefully expired in the first second following a maximal inhalation and although it is also a volume measured in liters or milliliters, the time component makes it a rate measurement for the airflow. Based on the proposed physiological mechanism for the effect of body composition on lung function, FVC is the measure which would be most affected by increasing values of anthropometric measures as impeding the space for lung to expand would affect the total volume. The results of the current study support this idea, with the coefficients of the anthropometric measures being consistently larger when predicting FVC than FEV_1. Interestingly, the R^2 values for the models predicting FEV_1 are slightly lower than the R^2 values for the models predicting FVC, except in the case of BMI and waist to height ratio for which the opposite is true.

The differences between FEV_1 and FVC may also help to explain the results addressing Objective 2. After addition of the physical fitness and activity variables the relationship between waist circumference and FVC was still significant in each model. However, in the models predicting FEV_1 after the addition of certain fitness or activity terms, waist circumference was no longer significant. It is reasonable that

FVC would remain significant; as that is the outcome we would expect to be most related to body composition. Muscular strength and physical fitness is proposed to affect lung function through improvement of the respiratory muscles. While more studies are needed, looking at the mechanism and nature of the relationship between muscular strength and FEV_1 and FVC (69) it is reasonable to hypothesize that fitness/ muscular strength would have a greater impact on FEV_1 than FVC. Physical fitness may affect the strength of the respiratory muscles to forcibly expel the maximal amount of air in the first second and therefore impact the flow rate as measured by FEV_1.

6.3 – Limitations, Strengths, and Implications

6.3.1 – Limitations

The main limitation in the study current study is the cross-sectional survey design. Cross-sectional data does not allow for temporal inferences on causality or direction of association. Although it is possible to say that anthropometric measures are significantly associated with lung function, it is not possible to go so far as to say that a change in anthropometric measures causes or leads to a change in lung function. Additionally, it is not possible to draw any conclusions as to the reversibility of the impact of anthropometric measures on lung function. This is also an important aspect when considering the potential implications of this study. A prospective, longitudinal study design would be necessary to answer these questions.

Several of the anthropometric exposure variables are based on clinically significant cut-points, while skinfold thickness and hip circumference are based on tertiles within the study population. The variables that are categorized in tertiles have consistent numbers of observations in each of the categories while the variables using known cut-points may be unevenly distributed. Also, waist to hip ratio and waist to height ratio, which have only two categories, may be at a slight statistical disadvantage in terms of R^2. However, the cut-points were chosen based on clinically significant values so there is also the possibility that they are more suitable than those cut-points that are chosen based on the distribution of the sample.

In order to directly compare a large number of models, we obtained a consistent set of covariates including any potential confounders from each of the outcome/exposure pairs. Due to this approach, it is unlikely that the most parsimonious models were used in each case. However, this was necessary to be able to compare directly across models and also to ensure that none of the potential confounders considered were missed in any of the models.

Another limitation is the difficulty in drawing broad conclusions based on the results of this study. Skinfold thickness models consistently had the best R^2 value predicting each of the outcomes. Skinfold thickness, however, is likely the least reliable of the anthropometric measures contained in CHMS. There are five sites where measurements are taken, each one introducing a greater chance for measurement error. This was reflected in the CV, which was larger for skinfold thickness than for waist circumference. Although skinfold thickness was the best measure in terms of R^2 values, the top four measures were very close in the fully adjusted models and waist circumference was chosen as the main exposure to address Objective 2.

CHMS contains a wealth of information including both physical measures and questionnaire data. This is a strength of the current study but also introduces the potential for bias as the group willing to participate in this survey may be systematically different in certain key ways from the general population. The response rate for CHMS is 51.7% and 55.5% for cycles 1 and 2 respectively. For another large health survey from Statistics Canada, the Canadian Community Health Survey (CCHS), the response rate was 71.5% (for the 2010 cycle). The lower response rate for CHMS may be due to the additional component of travelling to a mobile examination center for physical measures. In addition to the need for travel to participate in the survey, there is also the potential that individuals would be less likely to participate in a study with physical measures and invasive tests than one consisting only of questionnaires. As part of CHMS, blood is drawn, an exercise test is completed, and physical measurements are taken which may each decrease the likelihood of participation. This could lead to a potential bias as it may be the people with the worst lung function, and/or the largest anthropometric values who are the least likely to agree to participate in the study.

The amount of missing data was not consistent among all of the variables. Skinfold thickness and aerobic fitness score had by far the highest percentage of missing data (~33% and ~45% respectively) compared to ~4% for the other variables included in the analysis. This leads to the potential for selection bias as it may be the people with highest skinfold measurements (nobody with a BMI>30kg/m^2 was included in this measurement) and the worst physical fitness that were excluded from this part of the analysis.

6.3.2 – Strengths

This study has several strengths. The large Statistics Canada survey and its complex sampling design and non-response weighting allow the results to be generalizable to the Canadian population. This is an advantage of the current study as the past study on this topic was generalizable only to a unique subset of the population. The large sample size also allows for stratification by sex while still having large enough numbers to describe each of the important characteristics of the population.

The survey also includes a wide range of variables, both physical measures and questionnaire data. Due to the wealth of variables available for use in the CHMS, objectively measured physical activity and physical fitness were both able to be included in the analysis in addition to the commonly used self-reported physical activity variable. It was possible to look at both aerobic fitness as well as peripheral muscular strength as both VO2 max (aerobic fitness score) and grip strength were included in the survey. Lung function and anthropometric measures were included and there are detailed guidelines as to how each measurement is completed to ensure quality of the data.

Included in the survey were also a large number of other variables to be considered as potential confounders. There is detailed information on smoking history, income, racial origins, health conditions, and medications, which were able to be included in the analysis.

6.3.3 – Implications

There are several implications arising from the results from the current study. The results are in keeping with the previous literature stating that BMI is not the best measure to consider in regard to lung function. Body mass index is what is currently reported on spirometry results and therefore taken into consideration during interpretation. Should future studies in the literature continue to support the findings of this study, waist circumference should be included on spirometry reports as it is more predictive of both FEV_1 and FVC than is BMI.

While there are additional studies needed to address these questions, there are potential public health implications of these results. With the ever-increasing prevalence of obesity in Canada, there are public health initiatives addressing both fitness and weight-loss. If future studies support these results, this would add to the list of benefits for both weight-loss and becoming more physically fit/active.

6.3.4 – Future Directions

The relationship between anthropometric measures, lung function, and physical fitness is worthy of further investigation. Future studies would ideally be longitudinal and population based to make inferences of causality and conclusions regarding the direction of associations possible. It may be interesting to try different analytical approaches as well, to test how the results may vary. It may be useful to try a statistical model-building procedure with each of the anthropometric measures included to see if there would be any effect on the outcome. There may also be some value in completing a stratified analysis based on lung disease diagnosis to obtain information about how the effect may be different in those with diagnosed lung disease.

Chapter 7: Conclusion

The current study looked at the relationship between body composition measures and lung function. Several measures of body composition were included in the study, one of which was BMI, which is currently used for clinical purposes in the interpretation of spirometric results.

This project added to the existing evidence that there is an inverse association between body fatness and lung function. It also added support to the finding that BMI is not the best anthropometric measure in the prediction of lung function values. Skinfold thickness, waist circumference, waist to hip ratio, and hip circumference were each consistently better predictors of FEV_1 and FVC than were BMI. This is consistent with several studies in the literature and could have clinical implications. Additionally, each of the anthropometric measures was a stronger predictor of FVC than FEV_1.

Additionally, in the current study physical fitness and physical activity were found to be confounders of the relationship of interest, between body composition and lung function. This study therefore points to the need to consider a measure of fitness and/or activity when investigating the relationship of body composition with lung function. While the physical fitness/activity variables confounded the relationship with each of the outcome measures, FEV_1 and FVC, they had a much larger effect in those models where FEV_1 was the outcome.

While this study adds to the literature on this subject, more population based, ideally longitudinal studies, are needed to fully address these questions.

Appendix A – Estimations of predicted lung function values for males and females by age and height

Table 1 *– Estimations of the predicted FVC values and lower limit of normal (LLN) for white males calculated using the CDC "reference value calculator"*

Height (cm)		Age (years)			
		40	50	60	70
160	Predicted	3.78 L	3.49 L	3.20 L	2.91 L
	LLN	2.82 L	2.60 L	2.38 L	2.17 L
165	Predicted	4.11 L	3.82 L	3.53 L	3.24 L
	LLN	3.06 L	2.84 L	2.63 L	2.41 L
170	Predicted	4.43 L	4.14 L	3.85 L	3.56 L
	LLN	3.30 L	3.08 L	2.87 L	2.65 L
175	Predicted	4.76 L	4.47 L	4.18 L	3.89 L
	LLN	3.54 L	3.33 L	3.11 L	2.89 L
180	Predicted	5.08 L	4.79 L	4.50 L	4.21 L
	LLN	3.78 L	3.57 L	3.35 L	3.14 L
185	Predicted	5.41 L	5.12 L	4.83 L	4.54 L
	LLN	4.03 L	3.81 L	3.59 L	3.38 L
190	Predicted	5.73 L	5.44 L	5.15 L	4.86 L
	LLN	4.27 L	4.05 L	3.84 L	3.62 L

***Table 2** – Estimations of the predicted FEV_1 values and lower limit of normal for white males calculated using the CDC “reference value calculator”*

Height (cm)		Age (years)			
		40	50	60	70
160	Predicted	3.04 L	2.77 L	2.50 L	2.23 L
	LLN	2.21 L	2.02 L	1.82 L	1.62 L
165	Predicted	3.30 L	3.03 L	2.76 L	2.49 L
	LLN	2.40 L	2.21 L	2.01 L	1.81 L
170	Predicted	3.56 L	3.29 L	3.02 L	2.75 L
	LLN	2.59 L	2.40 L	2.20 L	2.00 L
175	Predicted	3.82 L	3.55 L	3.28 L	3.01 L
	LLN	2.78 L	2.59 L	2.39 L	2.19 L
180	Predicted	4.08 L	3.81 L	3.54 L	3.27 L
	LLN	2.97 L	2.78 L	2.58 L	2.38 L
185	Predicted	4.34 L	4.07 L	3.80 L	3.53 L
	LLN	3.16 L	2.97 L	2.77 L	3.38 L
190	Predicted	4.60 L	4.33 L	4.06 L	3.79 L
	LLN	3.35 L	3.16 L	2.96 L	2.76 L

Table 3 *– Estimations of the predicted FVC values and lower limit of normal (LLN) for white females calculated using the CDC "reference value calculator"*

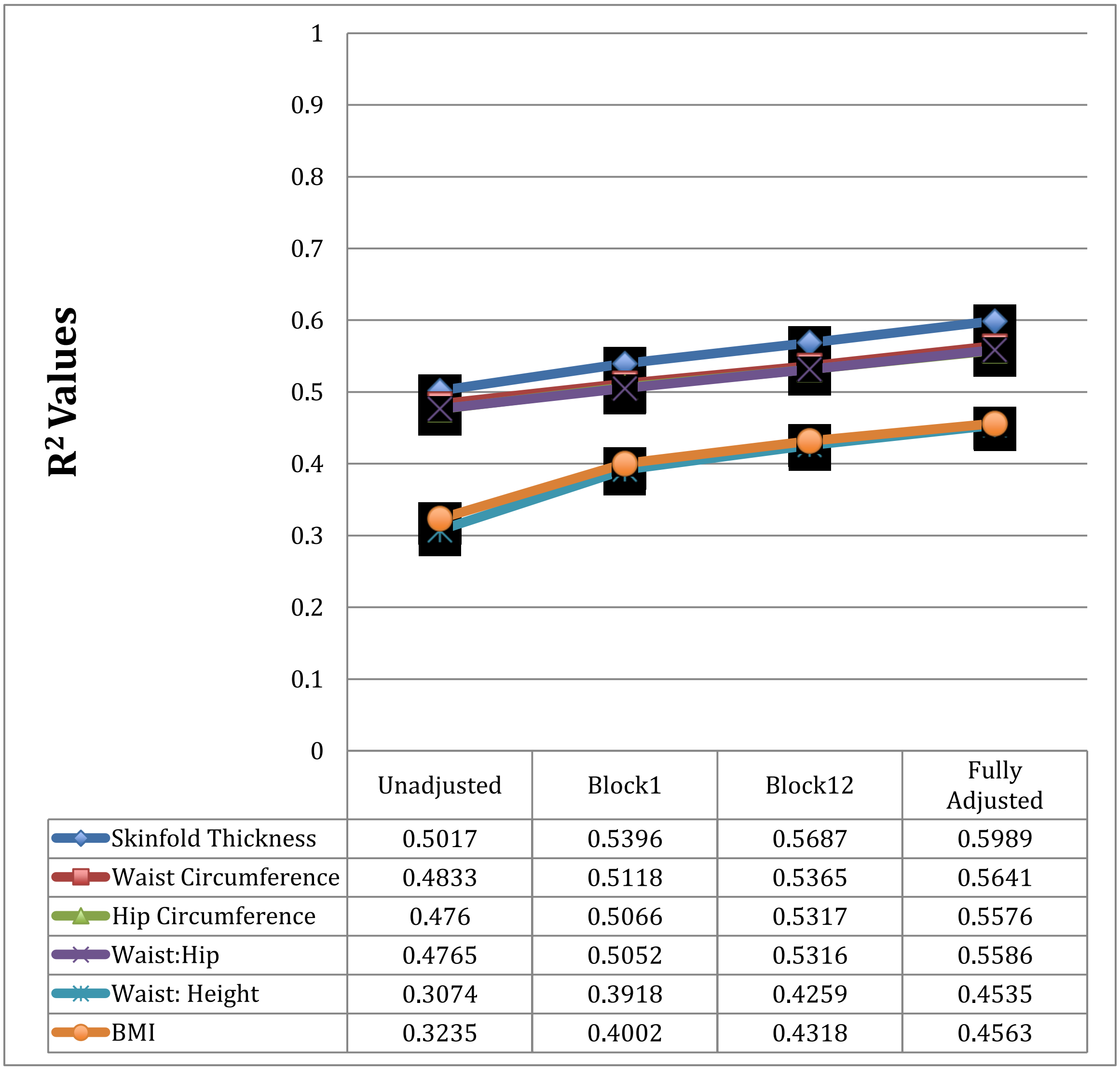
Height (cm)		Age (years)			
		40	50	60	70
160	Predicted	3.27 L	3.05 L	2.83 L	2.61 L
	LLN	2.17 L	2.02 L	1.88 L	1.73 L
165	Predicted	3.45 L	3.23 L	3.01 L	2.79 L
	LLN	2.29 L	2.15 L	2.00 L	1.85 L
170	Predicted	3.64 L	3.42 L	3.20 L	2.98 L
	LLN	2.42 L	2.27 L	2.12 L	1.98 L
175	Predicted	3.82 L	3.60 L	3.38 L	3.16 L
	LLN	2.54 L	2.39 L	2.25 L	2.10 L
180	Predicted	4.01 L	3.79 L	3.57 L	3.35 L
	LLN	2.66 L	2.52 L	2.37 L	2.22 L
185	Predicted	4.19 L	3.97 L	3.75 L	3.53 L
	LLN	2.79 L	2.64 L	2.49 L	2.35 L
190	Predicted	4.38 L	4.16 L	3.94 L	3.72 L
	LLN	2.91 L	2.76 L	2.62 L	2.47 L

Table 4 *– Estimations of the predicted FEV$_1$ values and lower limit of normal for white females calculated using the CDC "reference value calculator"*

Height (cm)		Age (years)			
		40	50	60	70
160	Predicted	2.69 L	2.48 L	2.27 L	2.06 L
	LLN	1.86 L	1.72 L	1.57 L	1.43 L
165	Predicted	2.82 L	2.61 L	2.40 L	2.19 L
	LLN	1.96 L	1.81 L	1.67 L	1.52 L
170	Predicted	2.96 L	2.75 L	2.54 L	2.33 L
	LLN	2.05 L	1.91 L	1.76 L	1.61 L
175	Predicted	3.09 L	2.88 L	2.67 L	2.46 L
	LLN	2.15 L	2.00 L	1.85 L	1.71 L
180	Predicted	3.23 L	3.02 L	2.81 L	2.60 L
	LLN	2.24 L	2.09 L	1.95 L	1.80 L
185	Predicted	3.36 L	3.15 L	2.94 L	2.73 L
	LLN	2.33 L	2.19 L	2.04 L	1.90 L
190	Predicted	3.50 L	3.29 L	3.08 L	2.87 L
	LLN	2.43 L	2.28 L	2.13 L	1.99 L

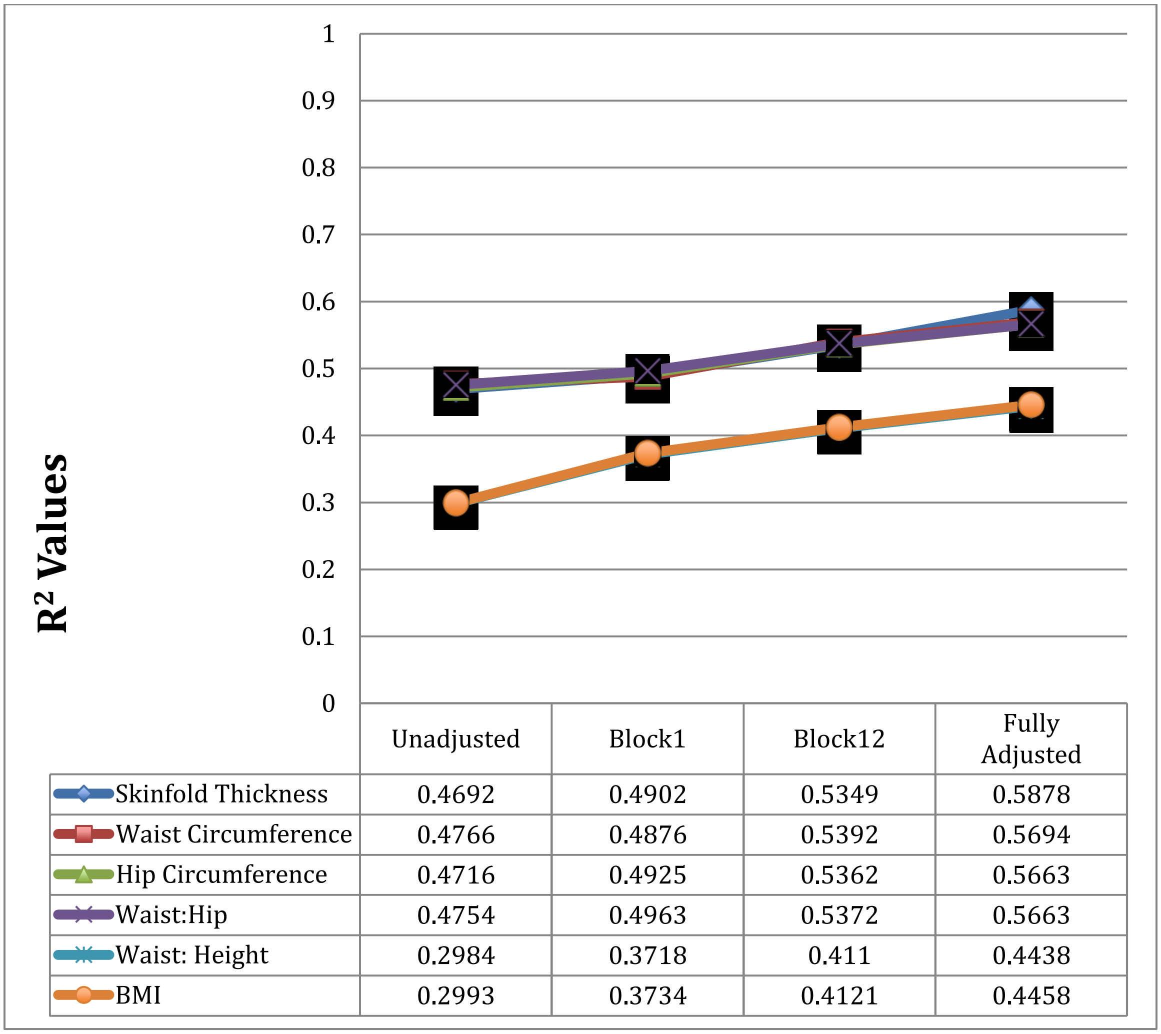
Appendix B – Graphs of changes in R^2 values for lung function and anthropometric measure models upon addition of covariates

Graph 1 – Change in R^2 values for FEV_1 and anthropometric measure models in males upon addition of covariates with data from Cycle 1 and Cycle 2 of CHMS for individuals over the age of 40, weighted using both bootstrap and population weights



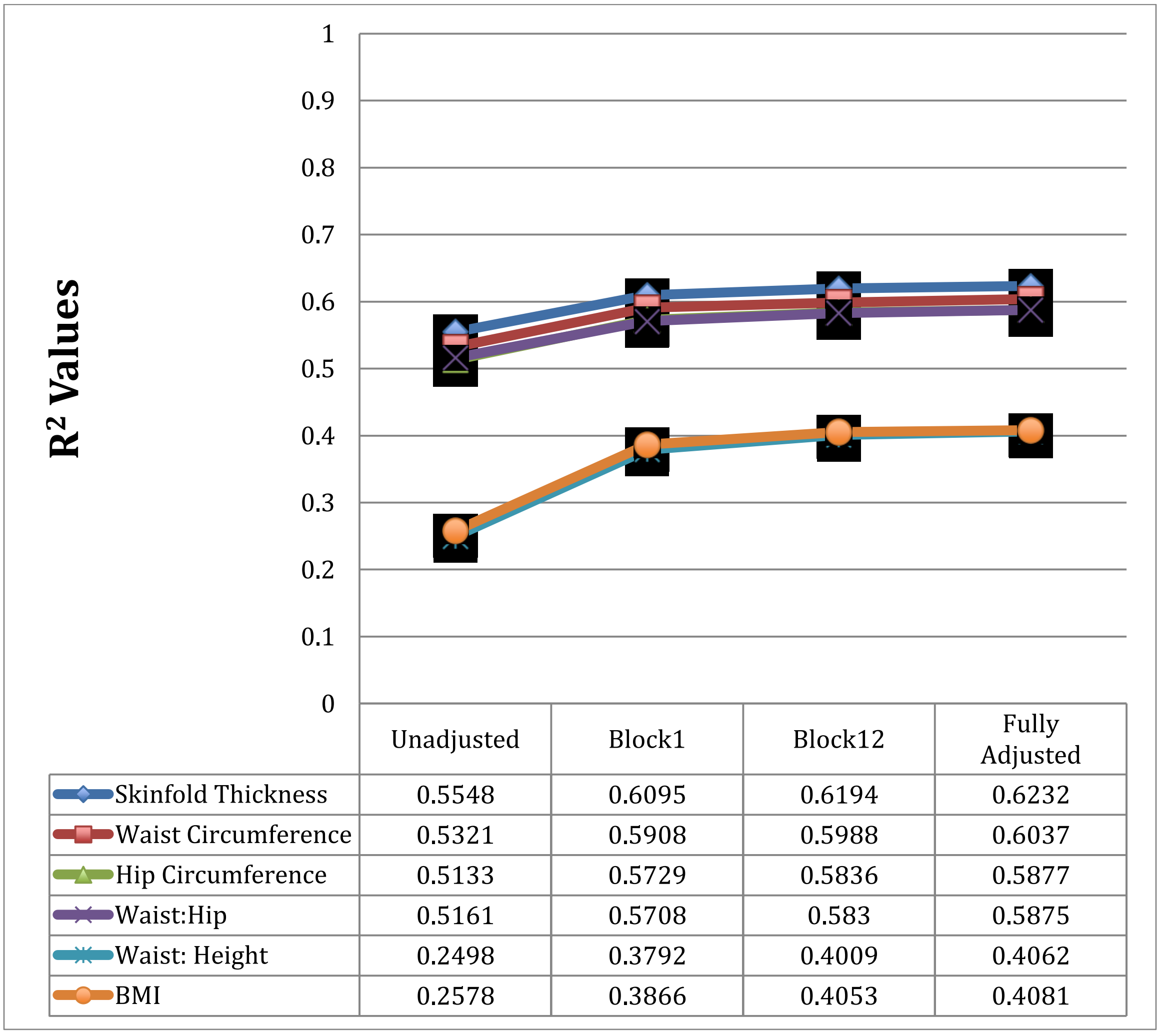
	Unadjusted	Block1	Block12	Fully Adjusted
Skinfold Thickness	0.5017	0.5396	0.5687	0.5989
Waist Circumference	0.4833	0.5118	0.5365	0.5641
Hip Circumference	0.476	0.5066	0.5317	0.5576
Waist:Hip	0.4765	0.5052	0.5316	0.5586
Waist: Height	0.3074	0.3918	0.4259	0.4535
BMI	0.3235	0.4002	0.4318	0.4563

Graph 2 – Change in R^2 values for FEV_1 and anthropometric measure models in females upon addition of covariates with data from Cycle 1 and Cycle 2 of CHMS for individuals over the age of 40, weighted using both bootstrap and population weights



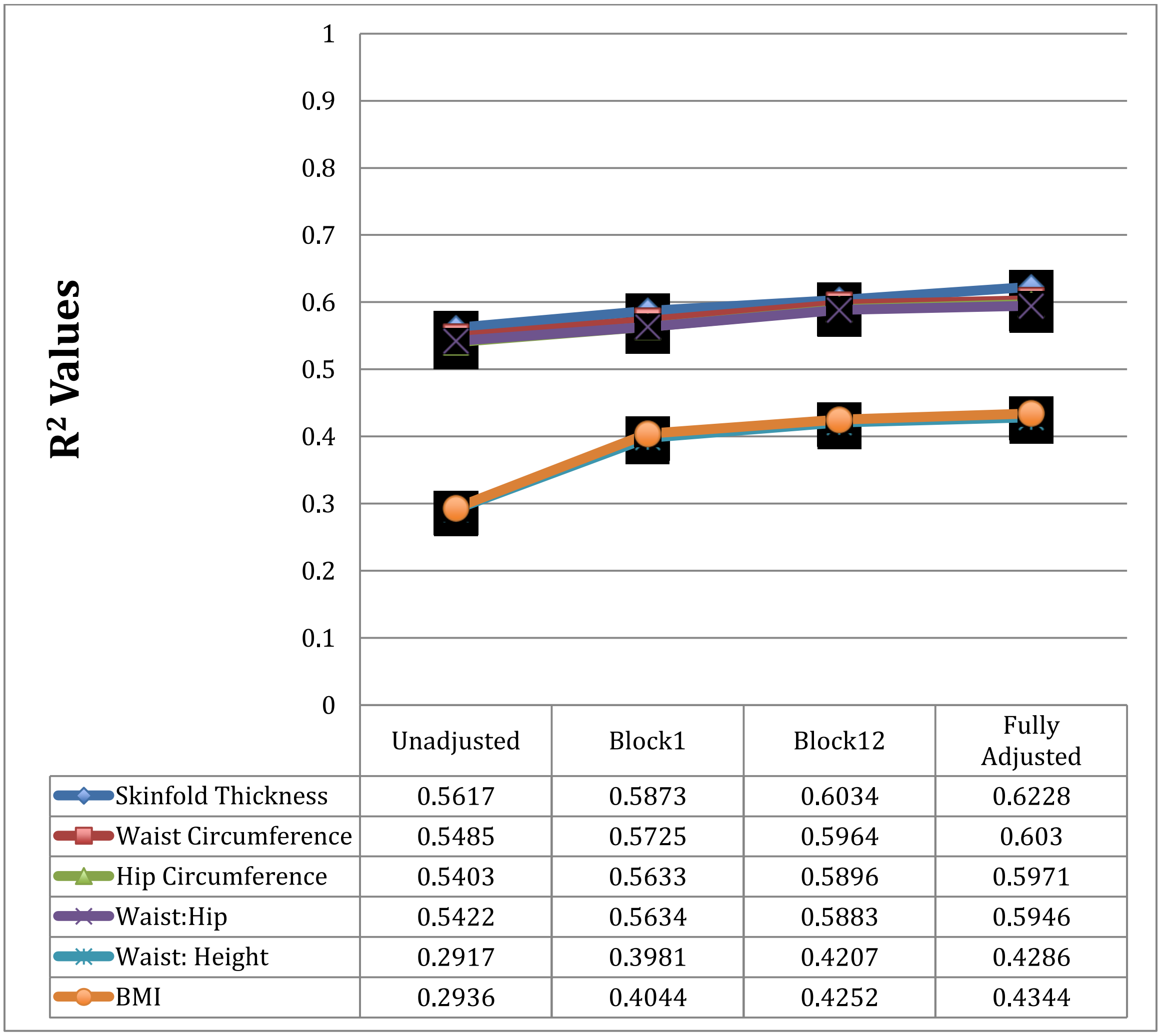
	Unadjusted	Block1	Block12	Fully Adjusted
Skinfold Thickness	0.4692	0.4902	0.5349	0.5878
Waist Circumference	0.4766	0.4876	0.5392	0.5694
Hip Circumference	0.4716	0.4925	0.5362	0.5663
Waist:Hip	0.4754	0.4963	0.5372	0.5663
Waist: Height	0.2984	0.3718	0.411	0.4438
BMI	0.2993	0.3734	0.4121	0.4458

Graph 3 – Change in R^2 values for FVC and anthropometric measure models in males upon addition of covariates with data from Cycle 1 and Cycle 2 of CHMS for individuals over the age of 40, weighted using both bootstrap and population weights



	Unadjusted	Block1	Block12	Fully Adjusted
Skinfold Thickness	0.5548	0.6095	0.6194	0.6232
Waist Circumference	0.5321	0.5908	0.5988	0.6037
Hip Circumference	0.5133	0.5729	0.5836	0.5877
Waist:Hip	0.5161	0.5708	0.583	0.5875
Waist: Height	0.2498	0.3792	0.4009	0.4062
BMI	0.2578	0.3866	0.4053	0.4081

Graph 4 – Change in R^2 values for FVC and anthropometric measure models in females upon addition of covariates with data from Cycle 1 and Cycle 2 of CHMS for individuals over the age of 40, weighted using both bootstrap and population weights



	Unadjusted	Block1	Block12	Fully Adjusted
Skinfold Thickness	0.5617	0.5873	0.6034	0.6228
Waist Circumference	0.5485	0.5725	0.5964	0.603
Hip Circumference	0.5403	0.5633	0.5896	0.5971
Waist:Hip	0.5422	0.5634	0.5883	0.5946
Waist: Height	0.2917	0.3981	0.4207	0.4286
BMI	0.2936	0.4044	0.4252	0.4344

Appendix C – The Association Between Waist Circumference and Lung Function Stratified by Level of Physical Fitness or Physical Activity

***Table 1** – The association between Waist Circumference and FEV_1 in males, stratified based on level of fitness or level of physical activity*

Model	Waist Circumference – Increased Risk Category	95% Confidence Interval	Waist Circumference – Significantly Increased Risk Category	95% Confidence Interval
Low Aerobic Fitness Score	0.009	-0.176; 0.195	-0.037	-0.196; 0.122
High Aerobic Fitness Score	-0.038	-0.119; 0.194	-0.108	-0.119; 0.194
Low Steps/Day	0.020	-0.059; 0.098	-0.106	-0.225; 0.014
High Steps/Day	-0.188	-0.488; 0.113	-0.180	-0.427; 0.068

***Table 2** – The association between Waist Circumference and FEV_1 in females, stratified based on level of fitness or level of physical activity*

Model	Waist Circumference – Increased Risk Category	95% Confidence Interval	Waist Circumference – Significantly Increased Risk Category	95% Confidence Interval
Low Aerobic Fitness Score	0.008	-0.112; 0.127	-0.159	-0.291; 0.028
High Aerobic Fitness Score	-0.092	-0.219; 0.035	-0.083	-0.201; 0.035
Low Steps/Day	-0.046	-0.184; 0.092	-0.071	-0.222; 0.081
High Steps/Day	0.177	0.085; 0.268	0.046	-0.080; 0.171

Table 3 *– The association between Waist Circumference and FVC in males, stratified based on level of fitness or level of physical activity*

Model	Waist Circumference – Increased Risk Category	95% Confidence Interval	Waist Circumference – Significantly Increased Risk Category	95% Confidence Interval
Low Aerobic Fitness Score	-0.009	-0.214; 0.197	-0.241	-0.427; -0.054
High Aerobic Fitness Score	-0.064	-0.236; 0.108	-0.241	-0.465; -0.018
Low Steps/Day	-0.068	-0.240; 0.105	-0.368	-0.556; -0.181
High Steps/Day	-0.237	-0.515; 0.042	-0.303	-0.671; 0.066

Table 4 *– The association between Waist Circumference and FVC in females, stratified based on level of fitness or level of physical activity*

Model	Waist Circumference – Increased Risk Category	95% Confidence Interval	Waist Circumference – Significantly Increased Risk Category	95% Confidence Interval
Low Aerobic Fitness Score	-0.044	-0.172; 0.084	-0.294	-0.435; 0.152
High Aerobic Fitness Score	-0.105	-0.271; 0.060	-0.141	-0.287; 0.004
Low Steps/Day	-0.047	-0.175; 0.090	-0.167	-0.295; 0.038
High Steps/Day	0.120	-0.007; 0.247	-0.142	-0.267; 0.017

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