Adiposity and Pulmonary Function: Analysis of the Canadian Health Measures Survey (CHMS)

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ABSTRACT

Adiposity has been linked to impaired respiratory function in adults but whether the distribution of adipose tissue has a differential effect on pulmonary function is still uncertain. Moreover, in children, the relationship between adiposity and lung dysfunction is not clearly understood. A two-stage multivariate analysis was conducted using data from 5604 Canadians aged 6 to 79 years who participated in the Canadian Health Measures Survey (CHMS). The associations of various anthropometric and skinfold measures with lung function were examined separately in adults and children. After adjustment of covariates, waist circumference and subscapular skinfold thickness showed the strongest inverse associations with FVC and FEV_1 in men. In women, BMI and sum of five skinfolds had the largest impact on pulmonary function. FVC and FEV_1 in boys were most affected by waist-to-hip ratio and triceps skinfold. In girls, adiposity was not linked to the lung function testing variables. Adiposity measures have differing effects on respiratory function depending on age and sex group.

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TABLE OF CONTENTS

LIST OF TABLES

SECTION 2 LITERATURE REVIEW

SECTION 7 RESULTS

LIST OF ACRONYMS

BMI	*Body Mass Index*
WC	*Waist Circumference*
WHR	*Waist-to-hip ratio*
SAD	*Sagittal Abdominal Diameter (abdominal height)*
FM	*Fat Mass*
FFM	*Fat Free Mass*
LBM	*Lean Body Mass*
%BF	*Body Fat Percentage*
BIA	*Bioelectrical Impedance Analysis*
DXA	*Dual Energy X-ray Absorptiometry*
CHMS	*Canadian Health Measures Survey*
CPAFLA	*Canadian Physical Activity, Fitness and Lifestyle Approach*
CAPI	*Computer-Assisted Personal Interviewing*
ERV	*Expiratory Reserve Volume*
FVC	*Functional Residual Capacity*
MVV	*Maximal Voluntary Ventilation*
PEF	*Peak Expiratory Flow*
TLC	*Total Lung Capacity*
RV	*Residual Volume*
FVC	*Forced Vital Capacity*
SVC	*Slow Vital Capacity*
VC	*Vital Capacity*
FEV_1	*Forced Expiratory Volume in one second*
$FEF_{25–75\%}$	*Forced Expiratory Flow between 25–75% of FVC*
$FEV_{0.75}$	*Forced Expiratory Volume at 0.75 seconds*
MMEF	*Maximal Mid-Expiratory Flow*

1. INTRODUCTION

Obesity is a growing epidemic worldwide, especially in developed countries. Its link to human disease continues to be a focus of extensive research. In recent times, it has "emerged as an important risk factor"[1] for chronic respiratory disorders, which are responsible for about 7% of all fatalities worldwide and represent 4% of the global burden of disease.[2] Moreover, impaired respiratory function has been linked to increased risks of cardiovascular and cerebrovascular disease, insulin resistance, diabetes[3] and overall mortality and morbidity.[4, 5] Obesity has been consistently shown to be associated with obstructive sleep apnea, obesity hypoventilation syndrome, asthma, and chronic obstructive pulmonary disease (COPD).[1] However, the effect of fat mass on pulmonary function is less clearly defined[3] although there has been a growing body of literature surrounding the topic of obesity and ventilatory function.[6] In previous studies researchers have mainly used body mass index, waist circumference and/or waist-to-hip ratio as indicators of fat mass. These measures are closely related to body size, which predicts lung function. An alternative approach for estimating adiposity is through skinfold measurements at various sites on the body and examining their association with pulmonary function. The present study used both anthropometric and skinfold measures to evaluate the association between adiposity and pulmonary function in adults and children separately.

2. LITERATURE REVIEW

2.1 Epidemiology of Respiratory Diseases

Chronic respiratory diseases are a serious global health concern. According to a World Health Organization (WHO) report, as of 2008 over a billion people worldwide suffer from this set of diseases, and it is estimated that these diseases result in 4 million deaths per year.[7] The most common chronic respiratory disorder is asthma, which affects approximately 300 million people, followed by chronic obstructive pulmonary disease (COPD), which affects 210 million.[7] The other 490 million people cope with sleep apnea syndrome, occupational lung diseases and pulmonary hypertension.[7] About a quarter of a million global deaths occurred due to asthma and 3 million due to COPD in the year of 2005.[7] Indeed, COPD is projected to become the third leading cause of mortality worldwide by 2030.[7]

In Canada, approximately 3.5 million people suffer from asthma and COPD.[8] These two respiratory diseases exert a huge economic burden on the Canadian health-care system with a total cost of about 5.63 billion Canadian dollars per year, according to the Economic Burden of Illness in Canada, 2000, preliminary estimates.[8]

2.2 Risk Factors for Respiratory Disease

The most significant risk factor for impaired lung function and chronic respiratory disease is tobacco smoke. There are two different routes of exposure to tobacco smoke: direct or indirect.[9] Direct exposure occurs through active smoking of cigarettes, cigars, pipes, sheesha; indirect exposure, known as environmental tobacco smoke (ETS) or passive smoking, occurs when people are in environments in which others are engaged in active smoking, including fetuses whose mothers smoke actively during pregnancy.[9] Both routes of exposure lead towards increased risks of asthma, COPD and lung cancer among adults and asthma, bronchitis and other respiratory complications among children.[9] Smoking cessation significantly lowers the risk of developing respiratory disease in comparison to those who continue to smoke.[9] According to the 2011 Canadian Tobacco Use Monitoring Survey, 17.3% (about 4.9 million) of the Canadian adults, aged 15 years or more, were current smokers. The vast majority of these smokers were daily smokers (13.7%), while 3.6% were non-daily smokers, also known as occasional smokers.[10] The same survey also showed that approximately 5.1% of children ages 17 and under were exposed either daily or almost daily to environmental tobacco smoke at home[11]. Thus, reduction in tobacco exposure is a crucial step towards respiratory disease prevention.

Another important, yet modifiable risk factor is indoor (i.e. homes, schools, workplace, etc.) and outdoor air quality. "The relationship between air quality and health is difficult to understand, however, because of the complex interplay of numerous factors such as personal exposures, genetics, underlying diseases, behaviour, dietary patterns, home environment, geographic location, and weather patterns." [9] Respiratory health research has shown that existing levels of pollutants in the air are associated with increased rates of hospitalization and premature deaths.[9] The major concern is that air pollutants, even at relatively low levels, can cause serious health outcomes for those already affected with respiratory disease.[9] In Canada, estimates show that air pollution is linked with about 16,000 premature deaths per year.[12]

Vitamin D deficiency has also been linked to chronic lung diseases with the strongest evidence for asthma and COPD.[13] Low levels of vitamin D have also been associated with significantly reduced lung function, however, a causal relationship has not yet been established.[13, 14]

Besides the aforementioned risk factors that are associated with respiratory diseases and impaired lung function, there are other well-established determinants of lung function including age, sex, height, ethnicity, and physical activity. Lung function increases with age until about age 20, at which point new alveoli are no longer made.[15] Afterwards, lungs start to lose their tissue as part of the normal aging process, which is associated with lung function decline.[15] Sex is also a determinant of pulmonary function. Females tend to have smaller airways, lung volumes and capacities as compared to their height- and age-matched male counterparts.[16] Another crucial factor for respiratory function is height. Individuals who are taller tend to have larger lung volumes. Ethnic background is also associated with pulmonary function. People of European origin tend to have larger lung volumes and capacities as compared to people of African descent and Asians. This difference is attributable to various genetic, environmental, and socioeconomic factors including the fact that people belonging to these ethnic groups tend to have a smaller trunk:leg ratio than people of European descent.[17] Physical activity has been associated with lower ventilatory function decline.[18-21]

Obesity has been shown to be a significant predictor in the development of respiratory diseases including obstructive sleep apnea, obesity hypoventilation syndrome, asthma, and COPD.[1] Many studies have revealed that obesity is also associated with impaired lung function, but whether the distribution of adiposity differentially affects the possible association between obesity and pulmonary function remains unclear.[22] One of the reasons is that it is difficult to disentangle the effects of various adiposity measures and body size measures due to high correlations between them.

2.3 Assessment of Overall Adiposity

2.3.1 Body mass index (BMI)

The body mass index or BMI, an overall adiposity marker, is the ratio of weight (in kg) divided by height^2 (in m^2). Although, not a direct measure of body fat, it is the most widely used indicator.[6]

2.4 Measures of Central Adiposity

2.4.1 Waist circumference

The waist circumference (see Figure 1(a) in Appendix I), measured at the midpoint between the lowest rib and the iliac crest, is an index of abdominal obesity. Accumulation of visceral fat around the abdomen area leads to an increase in waist size.

2.4.2 Waist-to-hip ratio

Waist-to-hip ratio (WHR) is also used as a surrogate measure of central obesity. It is defined as the ratio of the circumference of the waist (defined in 2.4.1) to that of the hips. Hip circumference (see Figure 1.1(a) in Appendix I) is determined at the point of maximum circumference over the buttocks.

2.4.3 Abdominal height or sagittal abdominal diameter (SAD)

Abdominal height (see Figure 1.1(a) in Appendix I), another measure of central obesity, is defined as the sagittal diameter of the abdomen at the iliac crest measured in the supine position.

2.5 Measures of Body Composition

There are several indicators of body composition, which include measures such as fat mass (FM), fat free mass (FFM), lean body mass (LBM), and body fat percentage (%BF). In order to estimate these parameters, numerous methods are available. Some of the most common ones are discussed below.

2.5.1 Bioelectrical impedance analysis

Bioelectrical impedance is an indicator of the amount of fat mass and fat free mass (two-component model) in the body. It is determined by passing an electrical current through the body from one extremity to the other (e.g., from the foot to the hand). The amount of resistance to the current flow is inversely related to the amount of fat-free or lean mass, since lean mass is a good conductor of electricity while fat mass is a relatively poor conductor. This method is relatively inexpensive and simple and when combined with other relevant data (i.e., sex, height, weight, age), bioelectrical impedance gives a reasonable estimate of the amount of lean and adipose tissue in comparison to other, more rigorous methods of determining body composition. [23, 24]

2.5.2 Dual energy X-ray absorptiometry

Dual energy X-ray absorptiometry (DXA) is a more direct method of determining body composition, specifically regional body fat distribution, total lean and fat mass, visceral fat than BIA and anthropometric measures.[24] It is based on a three-component model, in which the body is divided into fat-free and bone-free tissue, fat tissue and total body mineral.[24] The procedure uses two X-ray beams at different energies (one high and one low) to distinguish between the various tissue types[25]. The essential principle behind the technology is that the level of photon absorption varies depending on the tissue type[26]. The low intensity beam is only absorbed by soft tissue (muscle and fat), while both soft tissue and bones absorb the higher energy beam[25]. The differences in absorption are used to resolve body mineral and soft tissue[25]. Appropriate calibration is done to distinguish between lean and fat portions of the bone-free regions and then these proportions are extrapolated to the soft tissue covering bone to determine total fat and lean tissue content[26]. DXA is a reference method ("gold" standard) for determining bone mineral content and density, and also enables assessment of aortic calcification.[27]

2.5.3 Magnetic resonance imaging (MRI) and computed tomography (CT)

Magnetic resonance imaging (MRI) and computed tomography (CT) can estimate body composition through cross-sectional imaging. They are the reference methods for determining regional body composition.[24]

2.5.4 Skinfold measurement

Skinfold measurement is an anthropometric method, which can be used to estimate body composition. Like BIA, it is also based on the two-component model of body composition dividing the body into fat mass and fat-free mass. In this method, thicknesses of skinfolds at numerous sites of the body are obtained (see Figure 1.1(b) in Appendix I). These thicknesses represent the fat under the skin, or subcutaneous adipose tissue, which is proportional to the total amount of body fat. Some common parts of the body where these measurements are taken include the biceps, triceps, subscapular, suprailiac, and thigh.

2.6 Measures of Lung Function

There are two main types of pulmonary function measurements, which are commonly used for respiratory diagnosis. Spirometry is the most widely used method in determining these measurements. The first type called static includes those that quantify the volume of air contained in the lungs under a certain set of conditions, while the second type of measurements determine the rate at which air can be inhaled and exhaled from the lungs. Since the latter are time-based, they are referred to as dynamic. Some frequently used parameters of lung volume are (see Figure 1.2(a) in Appendix I): Total lung capacity (TLC) - the volume of air in the lungs after maximal inspiration, and residual volume (RV) – the volume of air in the lungs after maximum expiration.[28] Vital capacity is the quantity of air that is expelled from the lungs in going from TLC to RV during either a forced (FVC) or a slow (SVC) maneuver.[28] Functional residual capacity (FRC) is the volume of air in the lungs after a normal exhalation while expiratory reserve volume (ERV) is the maximum amount of additional air that can be exhaled after a normal expiration.[28]

Some of the most common parameters for measuring the flow of air are (see Figure

1.2(b) in Appendix I) forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), FEV_1/FVC ratio, forced expiratory flow between 25–75% of FVC ($FEF_{25–75\%}$), and peak expiratory flow (PEF). FVC is the total volume of air that can forcibly be exhaled after a maximum inspiration.[28] In other words, FVC is vital capacity (VC) exhaled forcefully and rapidly thus in healthy individuals VC and FVC should be nearly the same.[29] However in people with obstructive lung disease, vital capacity obtained in a forced maneuver (FVC) may be smaller than in a slow maneuver (SVC) because the narrowed airways tend to collapse during a forceful expiration, preventing all the air from being expelled.[29] FEV_1 is the volume of air expelled in the first second of a forced expiration after a maximal inspiration.[28] FEV_1/FVC ratio (or FEV_1%) is FEV_1 stated as a percentage of FVC (or VC if that is larger).[7] $FEF_{25–75\%}$, also known as the maximal mid-expiratory flow (MMEF) is the average expired airflow rate during the middle interval of the FVC maneuver.[28] PEF is the maximal exhaled flow rate achieved during a forced expiration.[28] Lung function testing is used to determine airflow obstruction. A decreased lung volume but a normal or elevated FEV_1/FVC ratio indicates restrictive lung disease. Obstructive airway disease that includes asthma and chronic obstructive pulmonary disease (COPD, including bronchitis and emphysema) is characterized by reduced FEV_1 and FEV_1/FVC ratio.

2.7 Body Weight or Body Mass Index and Ventilatory Function

The most common measures of adiposity used in epidemiological studies examining the relationship between adiposity and respiratory function have been body mass index (BMI) and body weight. Tables 2.1 and 2.2 present summaries of previous findings for BMI, body weight or weight change associated with lung function. Population-based longitudinal studies in adults have reported that increases in weight or BMI over time was associated with accelerated pulmonary function decline independent of age, smoking status and occupational exposure.[4, 30, 31, 32, 33, 34] The studies have also shown that the detrimental impact of increases in BMI on respiratory function was more prominent in individuals who were overweight or obese at baseline,[4, 30, 31, 35] which are consistent with the observations from cross-sectional studies.[3, 36, 27] In general, the effect of BMI or weight gain on pulmonary function loss has been stronger in men as compared to women.[30, 31, 32, 35] In addition, epidemiological investigations have shown that the detrimental effects of weight gain can be reversed through weight-loss.[30, 34, 38, 39, 40]

In children, there are a limited number of studies looking at the association between adiposity and lung function and the findings are controversial.[41] Some studies have shown no significant difference in lung function parameters between mildly obese and normal weight children.[42, 43, 44] Others have shown that higher BMI is associated with increased FVC and FEV_1 in both sexes[45, 46, 47] whereas FEV_1/FVC declined with increased BMI in both boys and girls.[45, 41] Moreover, a few investigations have demonstrated that lung function measures were significantly reduced in overweight or obese children as compared to normal weight children.[41, 48]

Although measured BMI is a relatively simple and reliable indicator that has been correlated with adult lung function decline, it is a gross measure of obesity.[34] It lacks information regarding body fat distribution and it cannot distinguish between different types of body tissue.[46] Thus, the opposing effects of fat and muscle tissue on pulmonary function cannot be determined using this parameter.[46] BMI may indicate the strength of respiratory muscles hence explaining the positive relationship in normal weight individuals.[49] However, in overweight or obese individuals, BMI represents body fat more closely.[49] In fact, the relationship between weight or BMI and lung function is "u-shaped" in that pulmonary function initially improves with increasing weight or BMI referred to as the 'muscularity effect' and then declines with further weight gain representing the 'obesity effect'.[31, 50]

Table 2.1 Summary of cross-sectional studies examining the association between BMI or weight and pulmonary function

Study	Type	Number of participants	Age range	Findings
Boran P, *et al.* 2007[42]	Cross-sectional controlled study	130	7-15	- No significant difference in lung function (FVC, FEV_1) parameters between mildly obese and normal weight children
Chen Y, *et al.* 2007[36]	Cross-sectional	1 674	18+	-BMI was positively associated with lung function in normal weight patients and an inverse correlation was observed in the overweight and obese groups. - No significant association was seen between BMI and FEV_1/FVC
Chu YT, *et al.* 2009[45]	Population-based cross-sectional	14 654	13-16	Increases in BMI was associated with an increase in FVC and FEV_1 in both genders, whereas FEV_1/FVC declined with increasing BMI in both males and female children.
Costa D, *et al.* 2008[114]	Cross-sectional	40	20-35	- No significant difference between the obese and the non-obese group for tidal volume (VT), VC, FVC and FEV_1. However the obese participants had a higher IRV and lower ERV and MVV in contrast to the non-obese participants. - There was positive relationship between IRV and BMI, while BMI and ERV and MVV showed an inverse relationship.
Cotes JE, *et al.* 2001[64]	Cross-sectional study of healthy volunteers	Men (383 ship yard workers) women (97)	25+	BMI, after adjusting for age and sex, increased the explained variance for all the main pulmonary function parameters in women and for some in men.
De Lorenzo A, *et al.* 2001[39]	Cross-sectional, observational	30 obese participants (7 men and 23 women)	42±12	- Mediterranean hypo-caloric diet resulted in a significant decrease in anthropometric parameters (Body Weight and BMI) - Significant increases were seen in the mean VC, FEV_1, FEF_{50}, FEF_{25-75}, ERV, and MVV.
De Lorenzo A, *et al.* 1999[40]	Volunteer sample; cross-sectional	16 obese participants	36±11	- After the diet program, a decrease in body weight and BMI was observed - In terms of the lung function parameters, VC, ERV, MVV, FEV_1, PEF were all significantly increased
Fung KP, *et al.* 1990[49]	Cross-sectional	1 586 (705 boys and 881 girls)	6.5-20	- In normal and overweight girls, there was a positive partial correlation between BMI and lung function. A similar positive correlation was observed in normal weight boys but not in the overweight group
He Q, *et al.* 2009[46]	Cross-sectional survey	2179	10.04±0.85	- Lung function measure, forced vital capacity (FVC), increased with BMI in all children. - Overweight boys and obese girls also showed a significantly higher forced expiratory volume in 1sec (FEV_1) as compared to their normal weight counterparts. - No significant difference in FEF_{25}, FEF_{75} and FEF_{25-75} were seen between different BMI groups.

Jenkins SC, *et al.* 1991[37]	Cross-sectional	144 men waiting for coronary artery surgery	38-77	FRC and ERV were decreased in the overweight participants as compared to the normal weight and an even greater reduction was observed in the obese participants.
Joshi AR, *et al.* 2008[65]	Cross-sectional study of student volunteers	132 (68 males and 64 females)	18-21	ERV, FVC and MVV all decreased significantly in the male and female overweight groups as compared to the normal weight groups.
Kalhoff H, *et al.* 2009[43]	Cross-sectional	518 children (241 boys and 277 girls)	6.0±0.3	- No significant correlation between BMI and pulmonary function measures. - Therefore, increases in BMI were not associated with lung function impairment at age 6.
Karacan S. *et al.* 2008[62]	Cross-sectional	99 (47 men and 52 women)	66-88	- A significant inverse relationship between BMI and FVC was observed in both sexes - FEV_1/FVC was inversely associated with BMI only in males
Koziel S. *et al.* 2007[22]	Cross-sectional	930 (423 males and 509 females)	40-50	In males, both FVC and FEV_1 were positively correlated with BMI, while only FVC had a positive relationship with BMI in females.
Li AM, *et al.* 2003[44]	Cross-sectional	64 (16 girls and 48 boys)	IQR=10-14	No significant trend was found between BMI and any of the lung function parameters.
Ochs-Balcom HM, *et al.* 2006[57]	Cross-sectional: random sample from general population	2153	35-79	In women, a significant inverse association was found between weight, BMI and FVC, whereas in males both FVC and FEV_1 were inversely associated with BMI and weight
Saxena Y, *et al.* 2009[90]	Cross-sectional: random sample from general population	80	20-40	BMI was inversely associated with pulmonary function (FEV_1 and FVC) in both males and females
Spathopoulos D, *et al.* 2009[41]	Cross-sectional analysis	2715	6-11	- All the lung function measures were significantly reduced in overweight or obese children as compared to normal weight children. - Multivariate regression showed that increase in BMI was a strong independent determinant for reduced spirometric parameters - Regression analysis performed separately by gender revealed important differences between boys and girls. - BMI and FVC had a significant correlation in girls but not in boys - FEV_1 and FEF_{25-75}, the BMI effect was stronger in girls than boys -The link between FEV_1/FVC ratio and BMI was more prominent in males.
Steele RM, *et al.* 2009[3]	Cross-sectional analysis of RCT data	320	μ=40.4	- BMI was associated with reduced lung function in both sexes, independent of the degree of physical activity and aerobic fitness

Table 2.2 Summary of longitudinal studies examining the association between BMI or weight change and pulmonary function

Study	Type	Number of participants	Age range	Findings
Aaron SD, *et al.* 2004[38]	Longitudinal, Prospective	58 obese women	μ=44	- Weight loss of >13% resulted in improvement in FEV_1, FVC and TLC
Bottai M, *et al.* 2002[30]	Longitudinal, Prospective	1 426	>24 yrs	- Increases in BMI led to a decrease in VC, FVC, and FEV_1 - Link was stronger in men as compared to women - Weight-loss improved pulmonary function - Detrimental effect on lung function of increases in BMI was higher in individuals who were overweight or obese at baseline
Bua J, *et al.* 2005[115]	Longitudinal	193 juvenile obese and 205 non-obese men	7+	- A positive correlation between childhood BMI (age 7) and adult FVC and FEV_1 was found, while adult BMI when above 25kg/m^2 was inversely correlated with FVC and FEV_1
Carey IM, *et al.* 1999[31]	Longitudinal	3 391	18-73	- Changes in weight, and BMI led to a decline in lung function especially among males where the effect was much stronger - Largest negative effects in middle-aged men and among those who were of the highest weight
Chen Y, *et al.* 1993[32]	Cohort study	709	25-59	- Higher values of BMI at baseline showed a significant decline in FEV_1 in males only - Weight gain over the 6-year period was a significant predictor of decrease in FVC and FEV_1 in males and females, but the effect was larger in males.
Jones RL, *et al.* 2006[33]	Retrospective	373	18+	- Normal weight group had significantly higher lung volumes in comparison to those with BMI >30kg/m^2 - A more significant effect of BMI on FRC and ERV was observed - Statistically significant differences between the normal weight and all other BMI groups. - Highly significant correlation between FRC, ERV and BMI with exponential best-fit model.
Lazarus R, Sparrow D, *et al.* 1997[92]	Longitudinal	2 280 men	30-79	- FEV_1/FVC ratio and MMEF increased while FVC decreased with higher measurements of BMI. - Sub-group analysis by age: Significant relation between BMI and FEV_1/FVC was seen at all ages - For FVC and MMEF with BMI, the correlation was significant for ages 40 to 69 only - No significant relationship between BMI and FEV_1 values.
Pistelli F, *et al.* 2008[34]	Longitudinal	1 212	24+	Remaining or becoming obese increases pulmonary function (FVC, FEV_1) decline, meanwhile becoming non-obese decreases it.
Thyagarajan B, *et al.* 2008[4]	Cohort study	4 734	18-30	- Lung function (FVC, FEV_1) generally declined with higher baseline BMI and increasing BMI over time. - But individuals in the lowest BMI category at baseline "gained FVC and lost the least amount of FEV_1 even as they gained weight during the study."

Ubilla C, *et al.* 2008[51]	Longitudinal	1 221	21-28	- In males, BMI over 30kg/m^2 was inversely related to lung function, while those with a BMI of 20–25kg/m^2 had the highest FEV_1 and FVC - In females, those with BMI between 20-25kg/m^2 had the highest FEV_1 and FVC measures, while BMI below 20 resulted in a lower FEV_1 and FVC and BMI above 30 led to a higher FEF_{25-75}.
Wang ML, *et al.* 2009[35]	Longitudinal	1 884 (1 721 males and 163 women)	Middle -aged	- The FEV_1 level was associated with age, height, ethnicity, sex, cigarette smoking, and changes in body weight. - The effect of weight gain on pulmonary function loss was greater in men than women. - An interaction between being overweight at the time of the test and effect of weight gain on FEV_1 was tested separately in men and women. The results showed that the negative impact of weight gain on FEV_1 was larger for men who were overweight at the time of the test in comparison to those who were not. However, this was not seen in the women. Moreover, it was noted that decline in FEV_1 was larger in the group with the highest baseline body weight.

2.8 Measures of Central Adiposity and Respiratory Function

Because of the complexity of the relationship between BMI and pulmonary function, many studies have used measures of central adiposity such as waist circumference, waist-to-hip ratio and sagittal abdominal diameter, which "correlate better with the additional adipose mass that alters lung function".[41]

Many studies have concluded that central adiposity is significantly associated with impaired respiratory function. These findings are summarized in Tables 2.3 and 2.4 presented below. The most commonly used markers of abdominal obesity are waist circumference (WC), waist-to-hip ratio (WHR) and sagittal abdominal diameter (SAD). Longitudinal analysis has found that increases in WC was associated with a decrement in lung function especially in males in comparison to females and the effect is much stronger among men who are of the highest weight at baseline.[31] Some studies have reported that the inverse trend in the association between WC and pulmonary function was only observed in males.[51] Cross-sectional examinations have also revealed an inverse correlation between WC and FEV_1 and FVC in males[3, 6, 36, 52] and females after adjusting for various covariates such as age, smoking status, and height.[3, 36, 52] Moreover, the effect has been found to be greater in males[3] and in individuals who are in the highest weight category as compared to those in the lowest weight group.[52]

Both cross-sectional and longitudinal studies have investigated the association between WHR and lung function. Inverse linear relationships between WHR and pulmonary function measures (FEV_1 and FVC) have been observed in both males and females in some studies,[53] while others have shown a significant correlation in males only.[31] Cross-sectional surveys have consistently found inverse correlations between WHR and FVC and FEV_1 in males[3, 6, 22, 54, 55, 56] and either weaker or no relationships in females.[22, 54, 55, 57] However, the damaging effect of increased WHR on other static lung volumes such as RV, TLC and ERV has been detected in women.[54]

Abdominal height has also been used in epidemiological investigations as a surrogate measure of visceral adiposity although not as often because of the difficulty in measurement compared with WC and WHR. In a population-based study[57], stratified analysis by BMI showed that abdominal height was inversely correlated with FEV_1 and FVC in women when BMI $\geq$ 25kg/m^2. In the <25 BMI category, the relationship between both FEV_1 and FVC and abdominal height was not significant. In males, there was a significant inverse trend between abdominal height and FVC in all BMI categories and in the $\geq$25 BMI group for the FEV_1. This indicated that abdominal obesity might cause lung dysfunction even in the overweight persons.[57] Another study conducted in a small sample of males found that after adjusting for age, height and weight, abdominal height was inversely correlated with both FVC and FEV_1.[56] A longitudinal study of healthy elderly persons showed that after taking FEV_1 at baseline into consideration, variation in sagittal abdominal diameter was the strongest predictor of FEV_1 at 7-year follow-up. Similarly, for FVC after taking into account baseline FVC, the measure with the strongest correlation with FVC at 7-year follow-up was sagittal abdominal diameter.[58]

Although measures of abdominal adiposity have been shown to correlate well with ventilatory function, they only provide an estimate of the adipose tissue around the waist. In order to study the effects of overall body fat and fat distribution, body composition has to be determined.

Table 2.3 Summary of longitudinal and cross-sectional studies examining the association between waist circumference, a body fat distribution measure, and lung function

Study	Type	Number of participants	Age range	Findings
Carey IM, *et al.* 1999[31]	Longitudinal	3391	18-73	- Changes in WC led to a decline in lung function especially among males where the effect was much stronger - Largest negative effects in middle-aged men and among those who were of the highest weight
Chen R, *et al.* 2001[52]	Cross-sectional population survey	1836 (865 males and 971 females)	25-64	- Inverse correlation between waist circumference and FEV_1 and FVC in both genders. - The effect was greater among individuals who had the highest weight as compared to the lowest weight group - Increases in waist circumference also led to a higher odds ratio of airway obstruction
Chen Y, *et al.* 2007[36]	Cross-sectional	1674	18+	There was an inverse correlation between WC and lung function parameters (FVC, FEV_1). This relationship was seen in all participants regardless of sex, age or BMI. No significant association was seen between WC and FEV_1/FVC
Ochs-Balcom HM, *et al.* 2006[57]	Cross-sectional: random sample from general population	2153	35-79	Inverse correlation between WC and lung function in both males and females
Saxena Y, *et al.* 2009[90]	Cross-sectional (random sample from gen pop)	80	20-40	WC showed a strong inverse association with FVC and FEV_1 in both males and females.

Steele RM, *et al.* 2009[3]	Cross-sectional analysis of RCT data	320	Mean age=40.4	- WC was associated with reduced lung function in both sexes. - The relationship was still present after adjusting for age, smoking status, height, PAEE, and VO_2max.
Ubilla C, *et al.* 2008[51]	Longitudinal	1221	21-28	- In males, an inverse trend between WC and pulmonary function was found. - In females, WC was inversely related to lung function in the lowest and upper WC quartiles
Wannamethee SG, *et al.* 2005[5]	Cross-sectional	2744 males	60-79	WC was inversely correlated with FEV_1 and FVC in both non-obese and obese male groups.
Lazarus R, Gore CJ, *et al.* 1998[63]	Cross-sectional	1235 (621 men and 614 women)	18-78	Adjusted FVC was inversely related to WC in males only

Table 2.4 Summary of longitudinal and cross-sectional studies examining the association between waist-to-hip ratio, a body fat distribution measure, and lung function

Study	Type	Number of participants	Age range	Findings
Canoy D, *et al.* 2004[53]	Longitudinal: Multicentre prospective	21,550 (9,674 men and 11,876 women)	45-79	There was an inverse linear relationship between WHR and lung function measures (FEV_1 and FVC) in both males and females
Boran P, *et al.* 2007[42]	Cross-sectional controlled study	130	7-15	No correlation was observed between lung function measures and WHR
Carey IM, *et al.* 1999[31]	Longitudinal	3391	18-73	Changes in WHR were significantly associated with lung function decline among men but not women
Ceylan E, *et al.* 2009[54]	Cross-sectional (sample of healthy volunteers)	53 (22 males and 31 females)	18-66 (40.2)	- In men, an inverse correlation between WHR and FVC, TLC and FRC was found. - In women, an inverse relationship was observed between WHR and RV, TLC and ERV.
Harik-Khan R, *et al.* 2001[55]	Longitudinal study but cross-sectional analysis	1094 men and 540 women	18-102	- An inverse correlation between WHR and FEV_1 in men but not in women. - Also, WHR was associated with FVC decline in males and females but the effect was stronger in males.
Koziel S, *et al.* 2007[22]	Cross-sectional	930 (423 males and 509 females)	40-50	- Among males, FVC decreased with increasing WHR. In females, no significant association between WHR and FVC. - WHR was inversely associated with FEV_1 in males only.
Ochs-Balcom HM, *et al.* 2006[57]	Cross-sectional: random sample from general population	2153	35-79	- In women, a significant association between WHR and FVC only - In men WHR was inversely correlated with FVC and FEV_1

Saxena Y, *et al.* 2009[90]	Cross-sectional (random sample from gen pop)	80	20-40	WHR had an inverse correlation with lung function in both men and women
Steele RM, *et al.* 2009[3]	Cross-sectional analysis of RCT data	320	Mean age=40.4	- WHR was associated with impaired lung function in men only - The relationship was still present after adjusting for age, smoking status, height, PAEE, and VO_2max.
Wannamethee SG, *et al.* 2005[5]	Cross-sectional	2744 males	60-79	WHR was inversely correlated with FEV_1 and FVC in both non-obese and obese male groups.
Lazarus R, Gore CJ, *et al.* 1998[63]	Cross-sectional	1235 (621 men and 614 women)	18-78	Adjusted FVC was inversely correlated with WHR in males only

2.9 Body Composition Measures and Lung Function

There are several methods available for estimating body composition that range in level of accuracy including magnetic resonance imaging and computed tomography scans, dual energy X-ray absorptiometry, bioelectrical impedance analysis and skinfold measurements.

Magnetic resonance imaging (MRI) and computed tomography (CT) are the most precise measures of body fat, yet there use in epidemiological studies is impractical due to limited access and high costs involved with these procedures. Moreover, there is a concern of significant exposure to ionizing radiation associated with CT imaging.[24]

Body composition measurement using dual energy X-ray absorptiometry (DXA) is a relatively new method that is accurate, less invasive and less expensive in comparison to MRI and CT imaging.[24] Several studies have looked at the association between DXA-measured adiposity variables and pulmonary function. One study consisting of a volunteer sample of 27 Black women with mean age of 67 years found that % truncal fat measured by DXA was inversely correlated with percent predicted FVC, while none of the anthropometric parameters of central obesity including WC, WHR and SAD showed a significant association.[59] The authors also found that total body mass measured by DXA and BMI were associated with both FVC and FEV_1.[59] However, there were several limitations to this study including the fact that it was a small volunteer sample, the participants were senior Black women only, which limits the generalizability of the findings to men, other ethnicities and age groups.[59] Another study in 64 obese children found that although there was no significant trend between BMI and any of the lung function parameters; however, using the DXA scan, significant inverse associations were observed between both trunk and subtotal body fat percentage (total minus head) with FRC, TLC, and RV.[44] Mohamed *et al.*,[60] in a sample of 118 non-obese people aged 18–58 years, found that body muscular mass (BF- LBM*Height), which is bone-free lean body mass adjusted for height, had a positive effect on all pulmonary function parameters (FVC, FEV_1, PEF) for both males and females. The authors also reported that both simple fat mass and fat mass adjusted for height or weight had no significant effect on lung function testing variables, thus indicating that the inverse effect of body fat is limited to the obese.[60] However, this study was limited to healthy Italian adults and the lack of an association between fat mass (FM) and lung function variables in normal people could have been as a result of the small number of participants.[60] A longitudinal study of 77 elderly persons showed that patients with decreased fat-free mass (FFM) and increased abdominal fat, measured by sagittal abdominal diameter, displayed the highest risk of respiratory function decline.[58] An investigation of a sample of 97 elderly males indicated that body fat percentage and fat mass showed an inverse relationship with FVC while FFM showed a positive correlation.[56] Another two reports on obese individuals undergoing weight loss through a hypocaloric diet[39, 40] reported a significant decrease in body composition (FM_{total} and FM_{trunk}) and anthropometric parameters but not in LBM after the weight-loss program. A significant increase in lung function measures such as VC, FEV_1, ERV, and MVV was also observed indicating an overall improvement in ventilatory function. Despite the fact that DXA has been shown to be accurate for measuring fat mass and fat-free mass, it has only been employed in small-scale studies, which limits generalizability.

Epidemiological investigations have also estimated body fat composition by bioelectrical impedance analysis (BIA), which is a much simpler yet less reliable method as compared to DXA.[24] Ceylan *et al.*[54] using this method to determine body fat percentage and FFM demonstrated that excess body fat led to a decrement in lung volume measures (FRC and ERV) in both Turkish males and females. Also, an inverse correlation was observed between FVC and body fat meanwhile FVC was positively related to FFM in men only. Fat mass and percent body fat were found to be inversely correlated with FEV_1 and FVC in a study of 2744 men by Wannamethee *et al.*[5] In addition, FFM was positively associated with FEV_1 and to a lesser degree with FVC.[5] A British study of 320 individuals reported that fat mass and body fat percentage were correlated with impaired lung function (FEV_1 and FVC) in both sexes.[3] Even though these studies demonstrate a relation between BIA determined body components and lung function, these studies were done in specific age, sex or ethnic groups thus limiting generalizability.

2.10 Skinfold Measurements and Pulmonary Function

Skinfold measurement is an anthropometric method that can be used to determine overall body composition or be used as a surrogate marker of regional subcutaneous fat distribution. Table 2.5 summarizes the results of previous examinations using skinfold measures. One study[61] using a sample of 384 people, ages 55-86, measured skinfolds at four sites (biceps, triceps, supra-iliac and subscapular) and determined body density from log of sum of the skinfolds with Durnin and Womersley (1974) equation. Using Siri's formula

(1961) body fat percentage and FFM were calculated. The authors found that the strongest predictor of FEV_1 was FFM indicating the requirement of muscle mass for improved pulmonary function in the elderly. On the contrary, total and regional adiposity, measured by %BF and subscapular skinfold thickness, respectively, was not a significant predictor of FEV_1. In another investigation[62] of 99 elderly participants, ages 66-88, body composition measures (FM, FFM, %BF) were obtained using skinfold measurements at different sites - triceps and suprailiac skinfolds in women, and thigh and subscapular skinfolds in men, using Sloan and Weir's method (1970). The authors also found a positive relationship between FFM versus FVC and FEV_1 in both sexes. However, an inverse correlation was observed between %BF and FVC, FEV_1 in both men and women. FEV_1/FVC was also inversely associated with %BF and FM in males and females.

A Turkish study[54] consisting of 53 people, ages 18-66, reported that FVC and ERV were inversely associated with subscapular skinfold in men. Triceps skin fold was also inversely correlated with FEV_1 and FRC, while suprailiac skinfold showed an inverse correlation with FEV_1, FVC, FRC, ERV and TLC. In women, subscapular, biceps and triceps skinfolds were all inversely associated with only FRC and ERV. In another report using a sample of 930 males and females, ages 40-50, it was shown that in females, FVC and FEV_1 decreased with rising subscapular thickness. In males, increases in both abdominal and subscapular skinfolds led to a decline in FVC only. This suggested that lung volume is not only affected by visceral fat indicated by WHR but also subcutaneous fat on the abdomen and the thorax. Among females, abdominal subcutaneous fat and visceral fat has a small or no impact while subcutaneous fat on the upper thorax indicated by subscapular skinfold impaired lung function.[22] Lazarus *et al.*,[63] in a sample of 1235 participants, ages 18–78, also analyzed the relationship between body fat, FFM and ventilatory function. Skinfold thickness from 6 sites (biceps, triceps, subscapular, mid-abdominal, supra-spinal, and medial calf) was measured and body density was calculated using the Durnin and Womersley (1974) equation. Adjusted FVC was inversely associated with percentage body fat and positively associated with fat-free mass in both sexes. FVC was also inversely associated with subscapular skinfold thickness, which indicates thoracic adiposity, in both sexes.

Cotes *et al.* showed that the inclusion of fat% and fat free mass, measured using four skinfolds and the Durnin and Womersley (1974) method, increased the accuracy of the reference equations for respiratory function, while BMI had the opposite effect.[64]

A population-based cross-sectional study in children and adolescents[47] illustrated that body fat percentage, determined using sex-specific equations based on skinfold measurements, had no significant effect on lung function parameters when adjusted for height. When lung function measures were adjusted for height and weight, which allowed assessment of the effect of fat tissue only because body weight measures both lean and fat mass, an inverse correlation between body fat percentage and both FVC and FEV_1 was found in all 2464 study participants. Joshi *et al.*[65] in a study of 132 youth, ages 18-21 analyzed the association between pulmonary function and body fat percentage measured by entering the sum of the skin fold thickness at triceps, biceps, suprailiac and subscapular regions into Durnin and Womersley's table (1974). The authors reported a significant inverse correlation between % of body fat and ERV, FVC, MVV, and PEF in both sexes, while FEV_1 was inversely associated only in males. Other studies in children have found fat free mass to be a significant positive predictor in regression models for FVC and FEV_1.[66, 67]

Table 2.5 Summary of longitudinal and cross-sectional studies examining the association between skinfold measurements and respiratory function

Study	Type	Method of measurement	Number of participants	Age range	Findings
Amara CE, *et al.* 2001[61]	Cross-sectional (random sample)	Skinfold measurement (biceps, triceps, supra-iliac and subscapular) used to determine body fat percentage and FFM	384 (203 women and 181 men)	55-86	Significantly higher FEV_1 values among those with higher FFM
Burchfiel CM, *et al.* 1996[116]	Longitudinal, prospective	Subscapular skin fold, triceps skinfold, ratio of subscapular:triceps skinfolds	4451 Japanese-American men	45-68 at base-line	- Increase in subscapular skin fold thickness was inversely related to rapid FEV_1 decline.
Ceylan E, *et al.* 2009[54]	Cross-sectional (healthy volunteers)	Skinfold measurements of biceps, triceps, subscapular and umbilical area	53 (22 males and 31 females)	18-66 (40.2)	- In men there was an inverse relation between subscapular skin fold and FVC and ERV. - Triceps skin fold was inversely associated with FEV_1 and FRC, while suprailiac skinfold showed an inverse correlation with FEV_1, FVC, FRC, ERV and TLC. - In women, subscapular, biceps and triceps were all inversely associated with both FRC and ERV.
Cotes JE, *et al.* 2001[64]	Healthy volunteers	Fat% and FFM determined using four skinfolds and the Durnin and Womersley method	Men (383 ship yard workers) women (97 from range of occupations)	25+	-The inclusion of fat% and FFM, measured using four skinfolds increased the accuracy of the reference equations for respiratory function
Joshi AR, *et al.* 2008[65]	Cross-sectional (student volunteers)	Extremity skinfolds measured at triceps and biceps and trunk skinfolds at suprailiac and subscapular regions. Durnin and Womersley method to determine fat%	132 (68 males and 64 females)	18-21	- In males, a significant inverse correlation between % of body fat and ERV, FVC, MVV, PEFR and FEV_1. - In females, an inverse relationship was seen between body fat% and ERV, FVC, MVV and PEFR but none with FEV_1.
Karacan S, *et al.* 2008[62]	Cross-sectional	Skinfold measurements (four sites: triceps and suprailiac for women, and thigh and subscapular for men). %BF and FM determined using Sloan and Weir's equation	99 (47 men and 52 women)	66-88	- A positive relationship was found between FFM versus FVC and FEV_1 in both sexes - An inverse trend was observed between %BF versus FVC and FEV_1 in both males and females -%BF showed the strongest relationship with both FEV_1 and FVC - In women, a significant inverse relation was seen between FM and FVC. - FEV_1/FVC was inversely associated with %BF and FM in both sexes

Koziel S, *et al.* 2007[22]	Cross-sectional	Abdominal and subscapular skinfolds	930 (423 males and 509 females)	40-50	- In females, FVC and FEV_1 decreased with rising subscapular thickness. - In males, increases in both abdominal and subscapular skinfolds led to a decline in FVC
Lazarus R, Gore CJ, *et al.* 1998[63]	Cross-sectional	Body fat % and FFM estimated from skinfold thickness measurements from 6 sites (biceps, triceps, subscapular, mid-abdominal, supraspinal, and medial calf) and Durnin and Womersley method	1235 adults (621 men and 614 women)	18-78	- FVC was inversely associated with BF% and subscapular skinfold thickness in both sexes - A positive trend between FFM and FVC was observed in males and females.
Lazarus R, Colditz G, *et al.* 1997[47]	Cross-sectional random population sample	BF% was calculated using sex-specific regression equations based on skinfolds at four sites (biceps, triceps, subscapular, and suprailiac)	2464 children (1222 males and 1242 females)	9,12 and 15	BF% had no significant trend with lung function parameters adjusted for height only but when these measures were adjusted for height and weight, which allowed the assessment of effect of fat tissue only because body weight includes both lean and fat mass, an inverse correlation between BF% and both FVC and FEV_1 was found within each age and sex category and for all participants in the combined analysis.
Lazarus R, Sparrow D, *et al.* 1997[92]	Longitudinal	Subscapular skinfold	507 men	30-79	- Subscapular skinfold had an inverse effect on FVC and FEV_1 values in men aged 30 to 59 years only.

2.11 Limitations of Previous Epidemiological Research

There are some major limitations for all of the investigations that have examined the relationship between ventilatory function and skinfold measurements using either skinfold thickness as a marker of regional fat distribution or using it to determine fat mass and fat free mass separately. Most of the studies have been conducted in specific target populations (i.e. particular ethnicity, sex, age group), thus limiting generalizability. Another issue with selecting participants from specific age, sex and ethnic group rather than from the general population is that it makes inter-study comparisons very difficult. Also the varying inclusion criteria, and lung function parameters used has led to discrepancies in the relationship between adiposity and pulmonary function. Another important area of concern is that skinfold measurements are an indirect method for determining body fat percentage and therefore not very accurate. The Durnin and Womersley method used by many studies, like most other body composition equations, actually estimates body density and subsequently body fat percentage using Siri's Formula. So the calculated %BF has accumulated error from the application of two equations. In addition, some of the studies have small sample sizes[54, 62, 65, 67] and/or are volunteer-based,[54, 62, 64, 65] which could have led to selection bias.

As for other adiposity measures such as BMI, waist circumference, and waist-to-hip ratio, their effects on pulmonary function have been examined in much greater depth. However, the controversy surrounds as to which measure is the most important predictor of lung dysfunction.[22] Discovering the answer to this question is even more important in obese persons, in whom skinfold measurements are not appropriate. There are several reasons as to why this is the case. First of all, the calipers do not open wide enough to obtain certain skinfold estimates in highly obese people.[69] Moreover, it is difficult to take a pinch so as to lift sufficient skinfold for measurement, due to the thickness of the fat tissue. Also, the proper technique requires that both sides of the skinfold pinch should be parallel, but due to the large amount of subcutaneous fat in obese persons, "the resulting skinfold may thus be more triangular in shape with sides that are not parallel but further apart at the base. This can make selection of a site for caliper placement more difficult." [69] Another issue is that, in obese individuals, the skinfold method tends to underestimate body fat.[69] Therefore, skinfold measures are only appropriate for subjects with BMI $<30kg/m^2$. So for obese individuals, we have to resort to the anthropometric methods in order to examine the effect of adiposity on lung function. The main concern with using BMI, waist circumference, hip circumference and waist-to-hip ratio as measures of adiposity is that these measures are also related to body size, which predicts lung function. Overall, it can be seen that there are drawbacks to all of these adiposity parameters. Thus, there is a dire need for studies exploring the effect of all these indicators on pulmonary function in larger and ethnically diverse general population samples.

3. RESEARCH OBJECTIVES

The purpose of our study is to examine the associations of various patterns of fat distribution with respiratory function. The present study used skinfold thickness at various sites along with BMI, waist circumference, hip circumference and waist-to-hip-ratio as measures of adiposity and related them to pulmonary function measures. Although various parameters have been used to measure respiratory function in epidemiological investigations, we used FVC and FEV_1 because they are the most commonly used indicators.[65]

3.1 The Study Hypothesis

The hypothesis is that skinfold measures have a stronger inverse effect on ventilatory function in comparison to the anthropometric measures because skinfold thickness is not associated with body size.

3.2 The Study Objectives

1. To examine the associations between anthropometric and skinfold measures of adiposity and pulmonary function;

2. To determine which measure of adiposity has the strongest association with pulmonary function; and

3. To determine the variation in the relationships between measures of adiposity and pulmonary function among different sex, age and BMI subgroups.

4. SIGNIFICANCE OF THIS STUDY

Although numerous studies have examined the association between body weight, BMI and pulmonary function and have found weak correlations, relatively few have investigated the effect of the amount and regional distribution of fat and lean mass separately on pulmonary function.[70] These parameters can be estimated using skinfold thickness measurement, which is an anthropometric technique that is inexpensive and feasible for a large epidemiological study. Skinfold thickness has been shown to be inversely related to ventilatory function in some populations but the results are not generalizable. This investigation was conducted in a large population-based, cross-sectional sample of individuals over a wide range of ages. To the best of our knowledge, this is the first Canadian nation-wide study exploring the relation between adiposity and pulmonary function in an ethnically diverse sample. It will allow us to make inferences, specifically in a Canadian context, about the adverse effects of adiposity on pulmonary function, which is important from a clinical and public health perspective.

5. STUDY DESIGN

This investigation used data from the Canadian Health Measures Survey (CHMS), a national survey initiated by Statistics Canada in 2007.[71] This cross-sectional survey directly measured various markers of health in a nationally representative sample of 5604 participants aged 6 to 79. Complete details of the study design, methodology, sampling strategy, protocols, and ethical concerns can be found elsewhere.[72]

The purpose of the survey was to "ascertain relationships among disease risk factors, health protection practices, and health status based on direct measures." [73] It consisted of two components: a general health interview followed by physical assessment at a mobile examination centre (MEC). The household interview collected information about aspects of lifestyle, nutrition, medical history, physical fitness, smoking habits, alcohol use and socio-economic status. The second part involved direct measurements such as height, weight, waist circumference, skinfolds, blood pressure, hand-grip strength, physical fitness testing, spirometry, oral health examination and blood and urine sampling to assess various health conditions. The household questionnaire was designed using the computer-assisted personal interviewing (CAPI) method, in which the answers are entered into a computer system that customizes the questionnaire to the respondent based on already collected information and guides them through the interview process.

For the sampling procedure, Canada was divided into 257 stratified sites distributed within five regions: Atlantic, Quebec, Ontario, Prairies (including Yellowknife) and British Columbia (including Whitehorse). These sites were created using the Labour Force Survey (LFS) sampling frame and each one of them consisted of an area with at least 10,000 inhabitants and a maximum participant travel distance to the Mobile Examination Clinic (MEC) of 50 and 100 km in urban and rural areas, respectively.[72] A sample of 15 sites was selected using systematic sampling with selection probabilities based on the population size of the sites.[72] The data from the sites were collected consecutively over a two-year time period. The 15 sites were "classified to take account of seasonality and the temporal effect, subject to operational and logistical constraints." [72] To adjust for the temporal effect, the number of sites per region were evenly allotted between year one and year two of the survey.[72] For the correction of seasonal variation, sites within the same region were allocated over the summer and winter months.[74] These adjustments were not possible for the Atlantic region because only one site was selected from that region.[72]

For each of the 15 sites selected, the household composition data from the 2006 Census was obtained and households were stratified into six strata based on residents' age at the start of data collection in each site[72, 75]. The stratification of households was done in a hierarchical manner starting at the most difficult target age group to the least.[75] Based on this method, all households with at least one 6-to-11-year-old person were grouped into the 6 to 11 stratum.[75] Then the remaining households where at least one 12-to-19-year-old was present were grouped into the 12 to 19 stratum and so on for the 60-to-79-year-olds, 20-to-39-year-olds, and finally the 40-to-59-year-olds.[75] Thus, there were a total of five age-group strata and one other stratum, which included vacant dwellings at the time of the 2006 Census or those with residents outside the desired age range.[75] Simple random sampling with replacement of households was conducted in each stratum.[75] After removing out-of-scope units (i.e. vacant, demolished, no residents between ages 6-79, etc.), a total of 8 772 households were selected for the survey.[72] The household response rate was 69.6%, which meant that 6 106 households provided the necessary information about all its members.[72] From each of the dwellings that responded, one or two members were randomly selected to participate in the survey for a total of 7483 individuals.[72] Every time a household had at least one individual between the ages of 6 and 11, two people were selected: one randomly selected from the 6 to 11 age group and another randomly selected from the 12 to 79 age category.[75] When no 6-to-11-year-old children were living in the household, only one individual aged 12 to 79 was chosen.[75]

Of these persons, 88.3% (6 604 individuals) actually completed the household questionnaire and 84.9% (5 604 individuals) went on to participate in the physical examination portion of the study. Thus, a combined response rate of 51.7% was obtained at the national scale. This rate did not result from multiplication of individual and household response rates because from some dwellings, two members were chosen. [72]

6. METHODS

As noted in the previous chapter, complete details of the study methods have been documented elsewhere.[72] We now summarize information about inclusion/exclusion criteria, participant selection, measurements and questionnaires that are relevant to the present study.

6.1 Inclusion Criteria

All 5604 individuals who participated in cycle 1 of the Canadian Health Measures Survey, conducted from March 2007 through February 2009. These people were between the age of 6 and 79 and resided in one of 5 regions defined to represent 96.3% of the Canadian population.

6.2 Exclusion Criteria

Individuals with a stoma, heart attack within the last 3 months, major surgery on chest or abdomen within the last 3 months, or eye surgery within the last 6 weeks were not eligible for pulmonary function testing. Moreover, individuals who had an acute respiratory condition like cold, flu or bronchitis, persistent cough, difficulty breathing at resting condition, or were on tuberculosis medication were also excluded. Women who were pregnant>27 weeks were also excluded from pulmonary function tests.

6.3 The Adult Sample

There were a total of 5604 individuals who participated in cycle 1 of the Canadian Health Measures Survey. From the dataset, two age groups were created. The first one included participants from ages 6 to 17 and the second one included all the adults (ages 18 and over). These groups were created based on the subject's age at the time of the household interview. The adult sample consisted of 3721 individuals, of which 3686 were eligible for spirometry (35 cases were excluded). Pulmonary function data were available for 3638 respondents. Respondents who had zero acceptable maneuvers out of 8 trials were eliminated (69 cases), leaving 3569 participants. Adults that had unacceptable or highly questionable FVC and/or FEV_1 reproducibility and quality were also excluded (134 cases). Thus, the remaining 3435 individuals had complete spirometric data of acceptable quality available. In total, 286 individuals were excluded, which is less than 8% of the total adult sample. From the 3435 observations, 27 more observations were deleted, which included pregnant women (16 cases), and participants who were missing measured weight, and/or BMI, waist circumference, and hip circumference. The final sample size used for the analysis was 3408.

6.4 The Children Sample

The children's sample consisted of participants under the age of 18 at the time of the household survey. There were 1883 participants 6-17 years of age in this sample. Participants that were eligible for pulmonary function tests included 1876 children (7 observations were deleted). The sample that had all the relevant spirometric data available consisted of 1736 persons (140 cases with either not applicable or not stated status or with 0 acceptable maneuvers out of 8 trials were deleted). Moreover, participants with highly questionable reproducibility and quality for FVC and FEV_1 were also deleted (152 cases), thus leaving use with 1584 observations. One person with missing waist-to-hip ratio, waist circumference, and hip circumference was also deleted leaving us with a sample of 1583 children for data analysis.

6.5 Pulmonary Function

A Koko spirometer was used to assess pulmonary function. The participants were advised to sit with good posture and not to bend over at the waist during expiration. They also had to wear a nose clip to avoid air escaping through the nose. The participants had to exhale for at least 6 seconds or 3 seconds for children between the ages of 6 and 10. A minimum of 3 trials were done and a maximum of 8 if necessary. The best trial was chosen, which was determined by the sum of FVC and FEV_1.

Two types of assessment criteria had to be met for the spirometric trial to be acceptable.[72] The first type included the within-maneuver criteria and the second type was the between-maneuver criteria.[72] During the first type of assessment, the health measurement specialist (HMS) ensured that the trial was usable meaning it had a good start without a great deal of hesitation and that there was no coughing during the first second of the procedure.[72] In addition, the trial had to be acceptable, which means free from glottis closure, early termination, leaks, obstruction, and extra breaths taken during the procedure.[72] Also, there had to be no moment during the maneuver where the person did not continue to exhale and that the maximum effort was placed throughout the procedure.[72] During the between-maneuver assessment, trial reproducibility was examined. This involved checking that the two largest FVC and FEV_1 values were within a certain range of each other (≤100 ml if FVC ≤ 1.0 L and ≤150 ml if FVC >1.0 L) once three acceptable spirograms were acquired.[72] If both types of assessment criteria were met after three trials, the testing was ended, otherwise it continued with additional trials until both criteria were met with a maximum of eight tests.[72]

An expert reviewed all spirometry data prior to release. The reviewer's task was to examine all trials in order to ensure that they were acceptable and the reproducibility criteria of 150 ml and quality criteria (maximal effort given by subject) were met and to confirm that all invalid curves based on American Thoracic Society testing criteria[76] were rejected. The

FVC quality factor and FEV_1 quality factor variables were used to indicate whether acceptable and reproducible FVC and FEV_1 values were obtained.[72] Using information from these variables, test results that were unacceptable or had highly questionable reproducibility and quality were excluded from the analysis.

6.6 Anthropometric Measures of Adiposity

6.6.1 Measurement of BMI, waist circumference and hip circumference

Standing height was measured for all participants who were able to stand on their own and who did not suffer from any condition that prevented them from standing up straight such as a cast on the leg. Measurement was recorded to the nearest 0.01cm using a fixed stadiometer while the subject had their breath held, standing erect with his/her bare feet together. Weight was measured to the nearest 0.1kg using a digital scale. Both weight and standing height were used to calculate body mass index (BMI) using the following formula: weight (kg)/(height (m))^2. Waist circumference was measured to the nearest 0.1 cm using a measuring tape at the midpoint between the last floating rib and the top of the iliac crest. All of the above procedures were based on the Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA).[77] Hip circumference was measured as the maximum circumference over the buttocks or hips depending on which was greater. This measurement was taken over light clothing and was based on the Canadian Standardized Test of Fitness.[78] The waist-to-hip ratio (WHR) was calculated as the ratio of the two measurements.

6.6.2 Skinfold measurements

The skinfold measurement procedure was performed using the Harpenden skinfold caliper and it was also based on CPAFLA.[77] It was limited to participants with BMI < 30 kg/m^2. Measurements were taken at five different sites: iliac crest, biceps, medial calf, triceps, and subscapular areas. The caliper jaw was positioned at the 1 cm mark, below the point where the skinfold was lifted and the measurement was taken once the indicator had stabilized.

Two measurements were obtained at each site to improve reproducibility, with each measurement recorded to the nearest 0.2 mm. If the difference between two measurements at a given site was larger than 0.4 mm, a third measurement was obtained. Then the average of the two most closely related values was recorded but if all three measurements were equidistant then mean of all three was recorded. The sum of the five skinfold measurements were also determined for each participant.

In the CHMS, skinfold measurements were only done on persons with body mass index (BMI) of less than 30kg/m^2. Therefore, respondents with BMI of 30 kg/m^2 or higher (obese people) were excluded. Among adults, there were 860 out of 3408 participants that had a missing value for the variable "Sum of 5 skinfolds (SFMDS5)", which meant that either they were not eligible because of the BMI cut-off or valid values for at least one or all of triceps, biceps, subscapular, iliac crest or medial calf skinfold averages were not present. From the 860 only 26 had BMI <30 and were true missing. All the remaining individuals were not eligible because their BMI was ≥ 30. Thus, all 860 cases were excluded for the skinfold analysis resulting in a sample size of 2548.

Since the BMI categories (normal weight, overweight, and obese) for children were based on the U.S. Center for Disease Control (CDC) BMI-for-age classification system, some children classified as obese were still eligible for skinfold measurements because their BMI was less than 30kg/m^2. There were 58 out of 1583 children that were missing a value for the sum of 5 skinfolds variable. From those, 50 children had BMI ≥ 30, which meant that they did not meet the eligibility criteria. The other 8 individuals were eligible but their skinfold measurements were missing. The final number of children included in the skinfold analysis was 1525.

6.7 Definition of Main Exposure Variables

6.7.1 Anthropometric and Skinfold Measures

The anthropometric measures used from the survey included the respondent's standing height in meters, weight in kilograms, body mass index in kilograms per meter squared, waist circumference in centimeters, hip circumference in centimeters and waist-to-hip ratio.

For skinfold analysis, the average thickness of two (or three) measurements for each site was used. The sites included triceps, biceps, subscapular, iliac crest, medial calf. The sum of all five skinfolds was also used. This variable was obtained by adding the average value for each of the five skinfold sites.

6.7.2 Pulmonary function indicators

Pulmonary function measures studied were the largest forced vital capacity (FVC) in liters, then largest forced expiratory volume in 1 second (FEV_1), and the best FEV_1/FVC ratio. Due to small airway size in children, largest forced expiratory volume at 0.75 seconds ($FEV_{0.75}$) was also examined as an outcome. All values were chosen from acceptable trials only.

6.8 Selection and Definition of Covariates

Several variables were considered a priori as covariates in the analysis because these variables have been shown to be associated with lung function in previous literature. These included height, age, ethnicity, smoking status, physical activity index, vitamin D level, exposure to environmental tobacco smoke at home and outside the home. Ethnicity was collapsed into two groups (White, non-White) because of the small number of participants in the minority groups.

Smoking status had three categories (current daily smoker, regular ex-smoker and occasional or non-smoker). Current daily smokers included participants who were currently smoking everyday. Regular ex-smokers included those who reported being a current non-smoker (former daily smoker) or occasional smoker (former daily smoker). Occasional or non-smokers were those who had never smoked (at least 100 cigarettes in lifetime), those who were current non-smokers but former occasional smokers or those who have always been occasional smokers.[79]

Physical activity index used participants' total daily energy expenditure in kcal/kg/day and classified them into three groups, which included active (3.0 kcal/kg/day or higher), moderately active (from 1.5 to less than 3.0 kcal/kg/day) and inactive (between 0 to less than 1.5 kcal/kg/day).[79] The daily energy expenditure values were calculated using frequency, duration and the Metabolic Equivalent Task (MET) value of each physical activity the participants were involved in over the past three months.[79]

Plasma vitamin D (25(OH)D) levels were measured in nmol/L using the LIAISON 25-Hydroxyvitamin D Total Assay (Diasorin S.p.A.;Vercelli, Italy), a chemiluminescence immunoassay (CLIA).[80] This is a very commonly used assay for determining concentration of (25(OH)D) in serum or plasma.[81] It is a valid method for determining vitamin D (25(OH)D) levels due to its strong Spearman's rank correlation (ρ=0.95) with the reference method, liquid chromatography-tandem mass spectrometry (LC-MS/MS).[82] In addition, it is an appropriate procedure for use in large-scale studies because the LC-MS/MS necessitates more costly equipment, skilled staff and longer run times.[81]

Exposure to environmental tobacco smoke at home was determined by asking the question: "Overall, (excluding your own smoking,) in the past month were you exposed to second-hand smoke inside this home: (... every day, ... almost every day, ... at least once a week, ... at least once in the past month or ... never)?" [83] The participants were grouped into two categories based on their answer. Those who replied everyday or almost everyday were categorized into the 'exposed' group and those who responded at least once a week or less were categorized into the 'non-exposed' group.

Similarly, exposure to environmental tobacco smoke outside the home was determined by asking the question: "Overall, (excluding your own smoking,) (and) (excluding inside your own home), in the past month were you exposed to second-hand smoke: (... every day, ... almost every day, ... at least once a week, ... at least once in the past month or ... never)?" [83] This included exposure to second-hand smoke at work, in a private vehicle or in public places. Again, the respondents were grouped into two categories based on their response. Those who were answered everyday or almost everyday were classified as 'exposed' and those who were replied once in a while or never were classified into the 'non-exposed' group.

6.9 Missing Values and Outliers

6.9.1 Smoking

There were seven people who had missing values for the smoking variable. We assumed that these values were missing completely at random (MCAR) and used the hot-deck imputation method to assign values to these respondents. For this method, the adult sample was divided into four age groups (18-34 years, 35-54, 55-64, 65 or older). Then frequency tables by sex, age group and smoking status were created for the entire sample and for each of the seven persons the most frequent smoking status within their age and sex-group was assigned to them.

6.9.2 Environmental Tobacco Smoke Outside the Home

Three respondents were missing a response to the environmental tobacco smoke outside the home variable and again the assumption that this data was missing completely at random (MCAR) was made. Values for these participants were also imputed using the hot-deck method based on their age and sex group.

6.9.3 Vitamin D Levels

There were fifty-six respondents that had missing vitamin D values. For imputation of these values, a regression model for predicting vitamin D levels was created. Based on information from previous literature, age (years), sex, BMI (kg/m^2) and ethnicity (White or non-White) were entered into the model as predictors. Vitamin D was log transformed to improve fit of the model. Using this regression model, vitamin D levels were assigned to the missing respondents.

6.9.4 Other Variables

One subject had implausible values for hip circumference and waist-to-hip ratio. Instead of deletion of the entire observation, those values were considered missing. For imputation of these values, data on an individual with the same sex, BMI group and waist circumference was retrieved from the dataset and the values for his hip circumference and waist-to-hip-ratio were used.

6.10 Statistical Analysis

6.10.1 Descriptive Statistics

The means of adiposity and lung function variables were calculated separately for males and females and compared using unpaired t-tests. The ventilatory function parameters were also compared among different BMI groups in males and females separately. In order to do this in adults, three BMI groups were created (normal ≤24.99, overweight 25.00-29.99, and obese ≥30.00 kg/m^2). Due to the small number of individuals in the underweight category, they were combined with the normal weight group.

The children's sample was also grouped into three BMI categories (normal weight, overweight, and obese) based on the U.S. Center for Disease Control (CDC) BMI-for-age classification system. The small sample of underweight children was combined with the normal weight category.

Statistical significance was determined by a p-value of less than 0.05. Since, the CHMS used a multi-stage survey design, bootstrapping was utilized to calculate variance estimates. All of the point estimates were weighted to represent the Canadian population.

6.10.2 Regression Analysis

Multiple linear regression analysis was used to separately examine the association between each measure of adiposity (body weight and BMI) and fat distribution (WC, HC, WHR, and skinfold thickness) with the three measures of pulmonary function (FEV_1 (and $FEV_{0.75}$ for children only) FVC, and FEV_1/ FVC). In order to do this, a two-stage regression modeling approach was employed, where in the first stage, each lung function testing variable was adjusted for the effects of height, age and ethnicity. Age- and height-squared terms were also tested and kept in the models if p-values were less than 0.10. Separate models were developed for males and females, resulting in a total of six models from the first stage.

In the second stage, the residuals (difference between measured and predicted lung function values) from the six regression models were regressed against each of the adiposity and body fat distribution measures along with adjustment of smoking status, physical activity, exposure to second-hand smoke, and vitamin D levels. For the children's sample, smoking and other lifestyle factors displayed no significant effect on the association between adiposity measures and lung function parameters and therefore, they were excluded from the regression models. Each adiposity measure was entered separately into the models to avoid multi-collinearity, which was assessed using a Pearson correlation matrix. The standardized beta coefficients from the multiple regression modeling allowed us to compare the magnitude and direction of the impact of various anthropometric parameters (independent variables) on ventilatory function testing variables (dependent variables). Standardized beta coefficients are estimates that result when predictor and outcome variables have been standardized to have variances of one.[84] They represent change in the dependent variable, measured in standard deviations, per standard deviation change in the independent variables.[84] Standardized beta coefficients are used to directly compare independent variables measured in different units; however, statistical significance tests cannot be run against these coefficients.[85] Consequently, unstandardized coefficients are needed since "the standard errors are calculated with reference to them, (and) not the standardized coefficients." [85]

Survey weights were applied to all the regression models to take the complex sampling design into account, i.e. differences in probability of selection and participation, and to obtain nationally representative estimates.[74, 86] The bootstrap method was used to adjust for downward bias in standard errors and intra-cluster correlation that would occur if the design structure was not taken into account.[86] The underlying assumption of normality was justified on the basis of the central limit theorem, since the sample size was large.[87] Separate analysis for children (ages 6-17) and adults (ages 18-79) was conducted. The analysis was further stratified by sex and BMI group. For adults, the sample was divided into 3 BMI groups – normal weight, overweight and obese, while children's dataset was separated into 2 BMI groups (normal weight and overweight or obese) due to the relatively small sample sizes in the overweight and obese groups. All the statistical analyses were conducted using a statistical software package (SAS, version 9.3; SAS Institute; Cary, NC).

6.10.3 Bootstrapping

Since the CHMS incorporated a complex survey design and weights, there was no straightforward way to determine the measures of precision (variance).[72] Thus, re-sampling methods were employed in order to get precise variance estimates.[72] The recommended method for CHMS data analysis was the bootstrap method.[72] In this method, repeated samples were drawn from a given data set a specific number of times,[88] which in our case was 500. Each of these bootstrap samples were the same size as the original sample and were obtained by sampling with replacement, so they were not identical to the actual sample. From each one of these bootstrap samples, a statistic of interest was calculated (i.e. mean, regression coefficient.[88] Then the distribution of that statistic was used to calculate the variance.[88] Using the Statistics Canada developed macro program called "Bootvar", and the bootstrap weights, variances of descriptive statistics and regression models were determined.[72]

7. RESULTS

7.1 Adult Sample

7.1.1 Demographics

The adult study sample consisted of 3408 participants, 1605 men and 1803 women. The mean age of the weighted adult sample was 44.31(SE 0.14). Demographic characteristics of the study sample are shown in Table 7.1. All the parameters presented were significantly different between men and women. Mean height and all the adiposity measures, except hip circumference were lower in women. Lung function measures (FVC and FEV_1) were also lower in women than men, while FEV_1/FVC was higher in women.

Table 7.1 Mean (standard error) of anthropometric and spirometric variables of the adult sample by sex (n=3408)

	Men (n=1605)	Women (n=1803)
Age (years)	43.67 (0.24)	44.96 (0.20)
Standing height (m)	1.75 (0.0037)	1.63 (0.0021)
Weight (kg)	84.51 (0.78)	70.41 (0.87)
Body mass index (kg/m^2)	27.48 (0.18)	26.68 (0.31)
Waist circumference (cm)	95.62 (0.60)	86.73 (0.86)
Hip circumference (cm)	102.90 (0.39)	104.48 (0.60)
Waist-to-hip ratio	0.93 (0.0035)	0.83 (0.0040)
FVC (L)	4.84 (0.054)	3.48 (0.020)
FEV_1 (L)	3.73 (0.042)	2.72 (0.020)
FEV_1/FVC	0.77 (0.0035)	0.78 (0.0034)

FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/ FVC, ratio of FEV_1 to FVC.

Respiratory function indicators were also compared among different BMI groups for men and women separately. In men (Table 7.2), there was no statistically significant difference ($p>0.05$) between the normal weight and overweight groups for FVC and FEV_1. However, the obese group had significantly lower mean values for both FVC and FEV_1 than the normal and overweight groups. The FEV_1/ FVC ratio was not significantly different between the three BMI groups.

For women (Table 7.3), there were significant differences in the mean values for FVC and FEV_1 between all three BMI categories, with overweight individuals having lower measurements as compared to the normal group and obese individuals having the lowest values. For FEV_1/FVC, the mean value of the obese BMI group was significantly higher than the overweight category.

Table 7.2 Mean (standard error) of anthropometric and lung function measures for each body mass index group among men (n=1605)

	Normal Weight (BMI<25.0) (n=504)	Overweight (BMI=25.0-29.9) (n=708)	Obese (BMI≥30.0) (n=393)
Age (years)	38.54 (0.68)	45.64 (0.70)	46.87 (1.01)
Standing height (m)	1.75 (0.0046)	1.76 (0.0060)	1.74 (0.0061)
Weight (kg)	69.66 (0.62)	84.98 (0.80)	103.42 (0.93)
Body mass index (kg/m^2)	22.70 (0.11)	27.44 (0.11)	33.92 (0.22)
Waist circumference (cm)	81.93 (0.45)	96.27 (0.47)	112.68 (0.54)
Hip circumference (cm)	95.00 (0.35)	103.09 (0.33)	113.07 (0.57)
Waist-to-hip ratio	0.86 (0.0033)	0.93 (0.0039)	1.00 (0.0041)
FVC (L)	4.95 (0.066)	4.91 (0.078)	4.58 (0.11)
FEV_1 (L)	3.81 (0.051)	3.76 (0.066)	3.55 (0.069)
FEV_1/FVC	0.77 (0.0051)	0.77 (0.0051)	0.77 (0.0037)

FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/ FVC, ratio of FEV_1 to FVC.

Table 7.3 Mean (standard error) of anthropometric and lung function measures for each body mass index group among women (n=1803)

	Normal Weight (BMI<25.0) (n=806)	Overweight (BMI=25.0-29.9) (n=556)	Obese (BMI≥30.0) (n=441)
Age (years)	41.88 (0.44)	47.66 (0.79)	47.77 (0.86)
Standing height (m)	1.63 (0.0029)	1.62 (0.0038)	1.61 (0.0030)
Weight (kg)	58.53 (0.32)	72.17 (0.40)	92.36 (0.99)
Body mass index (kg/m^2)	21.95 (0.089)	27.36 (0.088)	35.46 (0.35)
Waist circumference (cm)	75.26 (0.44)	89.36 (0.51)	106.73 (0.79)
Hip circumference (cm)	95.80 (0.20)	105.58 (0.31)	120.76 (0.65)
Waist-to-hip ratio	0.79 (0.0043)	0.85 (0.0042)	0.89 (0.0039)
FVC (L)	3.61 (0.027)	3.46 (0.036)	3.26 (0.035)
FEV_1 (L)	2.81 (0.026)	2.69 (0.035)	2.56 (0.027)
FEV_1/FVC	0.78 (0.0051)	0.77 (0.0041)	0.78 (0.0035)

FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

7.1.2 Demographics for skinfold subsample

The skinfold subsample only consisted of people with body mass index of less than 30kg/m^2. Table 7.4 shows descriptive statistics of the skinfold subsample by sex. There were 2548 participants in this group with 1203 men and 1345 women. From the table, it was observed that mean values for weight, BMI, waist circumference and waist-to-hip ratio were all significantly lower in women than men. However, the mean values of all the skinfold measurements, except iliac crest for which there was no significant difference, were much higher in women. Moreover, both FVC and FEV_1 were lower in women ($p<0.0001$) than men. There was no significant difference between men and women for FEV_1/FVC.

Table 7.4 Mean (standard error) of anthropometric and spirometric variables of the adult skinfold subsample by sex (n=2548)

	Men (n=1203)	Women (n=1345)	*P*-value
Age (years)	42.66 (0.34)	44.07 (0.41)	0.023
Standing height (m)	1.75 (0.0041)	1.63 (0.0026)	<0.0001
Weight (kg)	78.44 (0.68)	63.72 (0.46)	<0.0001
Body mass index (kg/m^2)	25.43 (0.13)	24.00 (0.14)	<0.0001
Waist circumference (cm)	90.17 (0.43)	80.57 (0.61)	<0.0001
Hip circumference (cm)	99.64 (0.35)	99.54 (0.33)	0.80
Waist-to-hip ratio	0.90 (0.0025)	0.81 (0.0042)	<0.0001
Skinfold average thickness (mm)			
Triceps	10.46 (0.23)	19.88 (0.24)	<0.0001
Biceps	5.18 (0.093)	9.11 (0.18)	<0.0001
Subscapular	16.28 (0.30)	18.43 (0.29)	<0.0001
Iliac crest	21.53 (0.44)	21.13 (0.32)	0.37
Medial calf	9.43 (0.22)	18.25 (0.32)	<0.0001
Sum of five skinfolds	62.89 (1.12)	86.80 (1.15)	<0.0001
FVC (L)	4.92 (0.062)	3.55 (0.022)	<0.0001
FEV_1 (L)	3.78 (0.050)	2.76 (0.024)	<0.0001
FEV_1/FVC	0.77 (0.0037)	0.78 (0.0040)	0.086

FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

Skinfold thickness and pulmonary function was also compared between normal and overweight persons in men and women separately (Tables 7.5 and 7.6). In overweight men, all the adiposity measures were significantly higher as compared to the normal weight people. However, there was no significant difference in the ventilatory function predictors between those of normal weight and the overweight. In women, mean values for all the measures of adiposity were much higher in overweight group in comparison to normal weight group. As for lung function variables, there were significant differences in all three. Mean values for FVC, FEV_1 and FEV_1/FVC were lower among overweight women in contrast to normal weight women.

Table 7.5 Mean (standard error) of anthropometric and lung function measures for normal and overweight men in the skinfold subsample (n=1203)

	Normal Weight (BMI<25.0) (n=501)	Overweight (BMI=25.0-29.9) (n=702)	*P*-value
Age (years)	38.54 (0.69)	45.68 (0.72)	<0.0001
Standing height (m)	1.75 (0.0046)	1.76 (0.0059)	0.32
Weight (kg)	69.66 (0.62)	84.89 (0.80)	<0.0001
Body mass index (kg/m^2)	22.70 (0.11)	27.43 (0.11)	<0.0001
Waist circumference (cm)	81.92 (0.45)	96.23 (0.47)	<0.0001
Hip circumference (cm)	95.00 (0.35)	103.04 (0.33)	<0.0001
Waist-to-hip ratio	0.86 (0.0033)	0.93 (0.0039)	<0.0001
Skinfold average thickness (mm)			
Triceps	8.69 (0.18)	11.76 (0.30)	<0.0001
Biceps	4.03 (0.058)	6.03 (0.093)	<0.0001
Subscapular	12.13 (0.21)	19.33 (0.42)	<0.0001
Iliac crest	16.12 (0.29)	25.51 (0.57)	<0.0001
Medial calf	7.35 (0.19)	10.97 (0.30)	<0.0001
Sum of five skinfolds	48.31 (0.72)	73.59 (1.28)	<0.0001
FVC (L)	4.95 (0.066)	4.90 (0.080)	0.49
FEV_1 (L)	3.82 (0.051)	3.76 (0.067)	0.39
FEV_1/FVC	0.77 (0.0051)	0.77 (0.0047)	0.70

FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

Table 7.6 Mean (standard error) of anthropometric and lung function measures for normal and overweight women in the skinfold subsample (n=1345)

	Normal Weight (BMI<25.0) (n=801)	Overweight (BMI=25.0-29.9) (n=544)	*P*-value
Age (years)	41.86 (0.45)	47.65 (0.85)	<0.0001
Standing height (m)	1.63 (0.0029)	1.62 (0.0038)	0.0095
Weight (kg)	58.54 (0.33)	72.14 (0.39)	<0.0001
Body mass index (kg/m^2)	21.94 (0.086)	27.33 (0.091)	<0.0001
Waist circumference (cm)	75.25 (0.43)	89.20 (0.49)	<0.0001
Hip circumference (cm)	95.81 (0.21)	105.60 (0.32)	<0.0001
Waist-to-hip ratio	0.79 (0.0042)	0.85 (0.0038)	<0.0001
Skinfold average thickness (mm)			
Triceps	17.19 (0.37)	24.25 (0.35)	<0.0001
Biceps	7.24 (0.25)	12.14 (0.23)	<0.0001
Subscapular	14.00 (0.37)	25.61 (0.44)	<0.0001
Iliac crest	17.69 (0.55)	26.72 (0.47)	<0.0001
Medial calf	15.29 (0.25)	23.07 (0.29)	<0.0001
Sum of five skinfolds	71.41 (1.54)	111.80 (1.27)	<0.0001
FVC (L)	3.61 (0.027)	3.47 (0.035)	0.0001
FEV_1 (L)	2.81 (0.025)	2.70 (0.034)	0.0003
FEV_1/FVC	0.78 (0.0050)	0.77 (0.0043)	0.0054

FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

7.1.3 Stage one regression analysis

Multivariate regression models were developed for each of the three outcome variables (FVC, FEV_1 and FEV_1/FVC). The independent variables included in the models were standing height in meters, age in years, and ethnicity (White or non-White). The quadratic terms for age and height were also tested in the models. Separate models were built for men and women thus resulting in six models from the first stage (Tables 7.7 and 7.8). In both sexes, height, age and ethnicity accounted for about 60% of the variance in the FVC and FEV_1 models. For the ratio of FEV_1/FVC, the proportions were much lower – about 20% in both men and women. This is due to the fact that the proportion of variance accounted for by these variables was very similar between FVC and FEV_1 models, they explained a much smaller percentage of variance for FEV_1/FVC models.

Table 7.7 Results from multiple linear regression models for predicting lung function in men (n=1605)

	FVC (L)			FEV_1 (L)			FEV_1/FVC		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
Height	6.6818	0.3533	<0.0001	4.2480	0.2660	<0.0001	3.9271	1.3956	0.0049
$Height^2$			0.15			0.39	-1.1558	0.3992	0.0038
Age	-0.0089	0.0066	0.1784	-0.0174	0.0071	0.0139	-0.0008	0.0006	0.1539
Age^2	-0.0002	0.0001	0.0062	-0.0001	0.0001	0.0582*	-0.00001	0.0000	0.0170
Ethnic group	0.5486	0.0710	<0.0001	0.3015	0.0673	<0.0001	-0.0330	0.0068	<0.0001
Adjusted R^2		0.6015			0.5911			0.2181	

*P-values <0.10 were considered significant. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; SE, standard error.

Table 7.8 Results from multiple linear regression models for predicting lung function in women (n=1803)

	FVC (L)			FEV_1 (L)			FEV_1/FVC		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
Height	4.8211	0.2815	<0.0001	3.2722	0.1987	<0.0001	-0.1273	0.0238	<0.0001
$Height^2$			0.98			0.39			0.37
Age	0.0056	0.0047	0.2278	-0.0135	0.0051	0.0087	-0.0038	0.0009	<0.0001
Age^2	-0.0003	0.0001	<0.0001	-0.0001	0.0001	0.0317	0.00002	0.0000	0.0850*
Ethnic group	0.4420	0.0726	<0.0001	0.2858	0.0620	<0.0001	-0.0214	0.0063	0.0007
Adjusted R^2		0.6213			0.6306			0.2393	

*P-values <0.10 were considered significant. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; SE, standard error.

7.1.4 Stage-two regression analysis

Table 7.9 shows the Pearson correlation coefficients between the adiposity measures. All of the measures had significant correlations with each other (*P*<0.0001). This implied that these independent variables should be tested separately in regression models in order to avoid multicollinearity. In terms of the strength of the relationships, waist-to-hip ratio versus other adiposity variables had substantially lower r-values (<0.83) while for all the other measures, correlations were higher (>0.83).

Table 7.9 Pearson correlation coefficients* between anthropometric measures used in linear regression modeling. Upper right triangle is for men and lower left triangle is for women

	Weight	BMI	WC	HC	WHR
Weight (kg)	-	0.9093	0.8690	0.9229	0.5055
BMI (kg/m^2)	0.9331	-	0.9184	0.8834	0.6283
WC (cm)	0.8923	0.9212	-	0.8358	0.8200
HC (cm)	0.9409	0.9304	0.8625	-	0.3759
WHR	0.4462	0.5128	0.7479	0.3145	-

*All correlations were significant (*P*<0.0001).
BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio.

Results from multiple linear regression analysis for the associations between adiposity measures (weight, BMI, waist circumference, hip circumference and waist-to-hip-ratio) and respiratory function measures (FVC, FEV_1 and FEV_1/FVC) for men and women are shown in Tables 7.10 and 7.11, respectively. Standardized β-coefficients were also determined for each model and are presented below. All of the models adjusted for current smoking, former regular smoking, physical activity (active or not), exposure to second-hand smoke inside the home, and vitamin D level. Moderately active versus non-active was not significant in the models, so it was dropped. Also, exposure to passive smoke outside the home was not a significant covariate; therefore, it was also excluded from the final models.

There was a significant inverse association between all five measures of adiposity and residual FVC (P<0.05) in both men and women (Tables 7.10 and 7.11), after adjusting for confounding factors. The strongest predictor of residual FVC in men and women was waist circumference with the highest standardized β-coefficients (-0.1666 for men; -0.1647 for women). The effect of waist circumference on lung function was similar between men and women.

Table 7.10 Linear regression analysis for anthropometric measures associated with residual pulmonary function measures in men (n=1605)*

	FVC (L)			FEV_1 (L)			FEV_1/FVC		
	β	SE	$β_{std}$	β	SE	$β_{std}$	β	SE	$β_{std}$
Weight (kg)	-0.0043**	0.0021	-0.1155	-0.0013	0.0013	-0.0419	0.0004**	0.0001	0.0870
Body mass index (kg/m²)	-0.0157**	0.0064	-0.1254	-0.0046	0.0042	-0.0431	0.0014**	0.0004	0.0983
Waist circumference (cm)	-0.0072**	0.0022	-0.1666	-0.0034**	0.0013	-0.0925	0.0004**	0.0001	0.0768
Hip circumference (cm)	-0.0076**	0.0037	-0.1134	-0.0025	0.0022	-0.0437	0.0006**	0.0003	0.0779
Waist-to-hip ratio	-1.0999**	0.2854	-0.1469	-0.6464**	0.2390	-0.1008	0.0356	0.0294	0.0416

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
** P-values less than 0.05.
FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; $β_{std,}$ standardized regression coefficient; SE, standard error.

Table 7.11 Linear regression analysis for anthropometric measures associated with residual pulmonary function measures in women (n=1803)*

	FVC (L)			FEV_1 (L)			FEV_1/FVC		
	β	SE	β_{std}	β	SE	β_{std}	β	SE	β_{std}
Weight (kg)	-0.0039**	0.0007	-0.1428	-0.0014**	0.0006	-0.0587	0.0005**	0.0001	0.1149
Body mass index (kg/m^2)	-0.0106**	0.0023	-0.1474	-0.0040**	0.0019	-0.0641	0.0012**	0.0004	0.1141
Waist circumference (cm)	-0.0047**	0.0010	-0.1647	-0.0022**	0.0008	-0.0877	0.0004**	0.0001	0.0979
Hip circumference (cm)	-0.0050**	0.0012	-0.1386	-0.0024**	0.0011	-0.0759	0.0004**	0.0002	0.0816
Waist-to-hip ratio	-0.6946**	0.2504	-0.1237	-0.3174	0.1660	-0.0646	0.0596**	0.0223	0.0704

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
**P-values less than 0.05.
FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; $\beta_{std,}$ standardized regression coefficient; SE, standard error.

Examination of the relationship between residual FEV_1 and adiposity factors in men showed that only waist circumference and waist-to-hip ratio were significantly associated. Meanwhile, in women, weight, BMI, waist circumference, and hip circumference were all significantly correlated with residual FEV_1 and waist-to-hip ratio tended towards significance (see Appendix II for p-values of all the models). The best indicator for residual FEV_1 in men was waist-to-hip ratio (β_{std}= -0.1008) and in women, it was waist circumference (β_{std}= -0.0877).

The residual FEV_1/ FVC ratio was significantly positively associated with all adiposity predictors, except for waist-to-hip ratio in men and all obesity measures in women as illustrated above. The strongest positive association was found with BMI in men (β_{std}=0.0983) and with weight in women (β_{std}=0.1149).

Tables 7.12 to 7.20 show the associations between adiposity measures and lung function testing variables stratified by sex and BMI groups. Figures 7.1-7.6 in Appendix III show scatter plots of these adiposity parameters in correlation with residual FVC and FEV_1 in various sex and BMI groups. In normal weight men, there was a significant positive association between FVC and weight, BMI, and hip circumference (Table 7.12). Figure 7.1 in Appendix III also showed these positive correlations, which were indicated by the increasing slopes. However, in women none of the obesity predictors were significant as indicated by the non-significant p-values (Table 7.13) and nearly horizontal lines of best fit on the residual FVC scatter plots (Figure 7.2 in Appendix III). In the overweight group, a statistically significant inverse correlation was seen between FVC with waist circumference and waist-to-hip ratio in both sexes. The corresponding scatter plots also showed lines of best fit with a negative slopes (Figures 7.3 and 7.4 in Appendix III). Although, waist circumference had the highest standardized regression coefficient (β) values in both men (-0.2141) and women (-0.2002); however, they were not much different from the ones observed between waist-to-hip ratio and FVC (Table 7.18). For the obese category, a significant inverse trend was observed between all body fat measures and FVC in men (Table 7.12 and Figure 7.5 in Appendix III) and all adiposity factors except for waist circumference and waist-to-hip ratio in women (Table 7.13 and Figure 7.6 in Appendix III). The magnitude of the association between waist circumference and FVC was stronger in the obese men than in overweight men, with a standardized β value of -0.2540. For the obese women, the most significant predictor was BMI with a standardized β value of -0.1707.

Table 7.12 Linear regression analysis for anthropometric measures associated with residual forced vital capacity (FVC) by body mass index group in men*

	Normal weight (n=504) (BMI<25.0)			Overweight (n=708) (BMI=25.0-29.9)			Obese (n=393) (BMI≥30.0)		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0112	0.0044	0.0118	-0.0040	0.0034	0.2371	-0.0070	0.0027	0.0110
BMI (kg/m^2)	0.0742	0.0282	0.0085	-0.0404	0.0224	0.0719	-0.0297	0.0080	0.0002
WC (cm)	0.0062	0.0066	0.3473	-0.0186	0.0042	<0.0001	-0.0142	0.0031	<0.0001
HC (cm)	0.0209	0.0073	0.0041	-0.0087	0.0052	0.0933	-0.0118	0.0035	0.0009
WHR	-0.1517	0.7496	0.8396	-1.6783	0.3875	<0.0001	-1.2500	0.3446	0.0003

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

Table 7.13 Linear regression analysis for anthropometric measures associated with residual forced vital capacity (FVC) by body mass index group in women*

	Normal weight (n=806) (BMI<25.0)			Overweight (n=556) (BMI=25.0-29.9)			Obese (n=441) (BMI≥30.0)		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0008	0.0029	0.7834	-0.0024	0.0032	0.4477	-0.0045	0.0018	0.0119
BMI (kg/m^2)	0.0049	0.0124	0.6936	-0.0176	0.0167	0.2914	-0.0152	0.0054	0.0047
WC (cm)	-0.0018	0.0039	0.6543	-0.0116	0.0038	0.0026	-0.0047	0.0028	0.0990
HC (cm)	0.0007	0.0043	0.8700	-0.0016	0.0055	0.7773	-0.0053	0.0024	0.0237
WHR	-0.2803	0.5390	0.6030	-1.1257	0.2936	0.0001	-0.0923	0.4378	0.8331

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

Tables 7.14-7.15 and Figure 7.1-7.6 (Appendix III) show the association of body fat measures with residual FEV_1 in different BMI groups. In men, increases in weight, BMI and hip circumference had a positive effect on FEV_1, within the normal weight range (Table 7.14 and Figure 7.1 in Appendix III). However, in women, none of the adiposity factors were significant as shown by the almost horizontal lines of best fit on the scatter plots (Figure 7.2 in Appendix III) and the non-significant p-values (Table 7.15). In overweight men, only waist circumference and waist-to-hip ratio were significant predictors for residual FEV_1 with increases in each resulting in decline in residual FEV_1. Both of them affected FEV_1 to a similar extent pointed out by the parallel slopes of their scatter plots (Figure 7.3 in Appendix III) and by the similar values for standardized beta coefficients (-0.1473 for WC and -0.1518 for WHR). In overweight women, only waist-to-hip ratio was significantly associated with residual FEV_1 (Table 7.15), such that increased WHR was associated with reduced FEV_1 (Figure 7.4 in Appendix III). The association between waist circumference and FEV_1 tended towards significance (Table 7.15). In obese men, increases in all of the adiposity factors were associated with decreased FEV_1 (Table 7.14 and Figure 7.5 in Appendix III). Waist circumference had a most dramatic inverse effect, where a 1-cm increase in it resulted in approximately 11-mL drop in FEV_1. In obese women, only BMI and hip circumference had a significant inverse trend with residual FEV_1, with BMI having the strongest effect (Table 7.15 and Figure 7.6 in Appendix III). On average, a unit increase in BMI was associated with about a 9-mL drop in FEV_1 in the obese women.

Table 7.14 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1) by body mass index group in men*

	Normal weight (n=504) (BMI<25.0)			Overweight (n=708) (BMI=25.0-29.9)			Obese (n=393) (BMI≥30.0)		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0090	0.0046	0.0476	-0.0010	0.0022	0.6615	-0.0054	0.0024	0.0251
BMI (kg/m^2)	0.0560	0.0240	0.0197	-0.0040	0.0204	0.8452	-0.0228	0.0091	0.0126
WC (cm)	0.0033	0.0068**	0.6273	-0.0110	0.0040	0.0064	-0.0112	0.0035	0.0013
HC (cm)	0.0148	0.0065	0.0234	-0.0012	0.0043	0.7795	-0.0096	0.0034	0.0050
WHR	-0.2950	0.7746	0.7033	-1.2432	0.4499	0.0057	-0.9369	0.4296	0.0292

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
**499 bootstrap replicates were used for variance calculation.
BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

Table 7.15 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1) by body mass index group in women*

	Normal weight (n=806) (BMI<25.0)			Overweight (n=556) (BMI=25.0-29.9)			Obese (n=441) (BMI≥30.0)		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0014	0.0023	0.5324	-0.0011	0.0027	0.6888	-0.0025	0.0014	0.0776
BMI (kg/m^2)	0.0062	0.0076	0.4144	-0.0031	0.0140	0.8235	-0.0093	0.0038	0.0150
WC (cm)	-0.0028	0.0029	0.3441	-0.0071	0.0040	0.0730	-0.0029	0.0023	0.2052
HC (cm)	-0.0008	0.0038	0.8360	-0.0025	0.0043	0.5572	-0.0039	0.0018	0.0322
WHR	-0.3365	0.3868	0.3843	-0.6281	0.3139	0.0454	0.0526	0.3672	0.8860

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

Results of Table 7.16 and 7.17 show that none of the adiposity factors were significantly associated with residual FEV_1/FVC ratio.

Table 7.16 Linear regression analysis for anthropometric measures associated with residual FEV_1/FVC ratio by body mass index group in men*

	Normal weight (n=504) (BMI<25.0)			Overweight (n=708) (BMI=25.0-29.9)			Obese (n=393) (BMI≥30.0)		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
Weight (kg)	-0.0002	0.0005	0.7174	0.0003	0.0003	0.3249	-0.0002	0.0003	0.4161
BMI (kg/m^2)	-0.0022	0.0023	0.3461	0.0040	0.0024	0.0901	-0.0009	0.0010	0.3542
WC (cm)	-0.0007	0.0008	0.3928	0.0004	0.0006	0.4861	-0.0004	0.0004	0.3554
HC (cm)	-0.0008	0.0008	0.3264	0.0009	0.0006	0.0907	-0.0006	0.0004	0.1692
WHR	-0.0610	0.0970	0.5294	-0.0099	0.0611	0.8716	0.0039	0.0502	0.9378

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

Table 7.17 Linear regression analysis for anthropometric measures associated with residual FEV_1/FVC ratio by body mass index group in women*

	Normal weight (n=806) (BMI<25.0)			Overweight (n=556) (BMI=25.0-29.9)			Obese (n=441) (BMI≥30.0)		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0002	0.0005	0.7243	0.0002	0.0004	0.5572	0.0003	0.0002	0.2593
BMI (kg/m^2)	0.0005	0.0023	0.8439	0.0032	0.0026	0.2247	0.0006	0.0006	0.2954
WC (cm)	-0.0006	0.0004	0.1464	0.0005	0.0005	0.2301	0.0002	0.0003	0.5071
HC (cm)	-0.0004	0.0006	0.5032	-0.0004	0.0006	0.4767	0.00001	0.0002	0.9792
WHR	-0.0619	0.0443	0.1624	0.0737	0.0446	0.0979	0.0436	0.0472	0.3555

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

Table 7.18 Standardized regression coefficients (βs) for anthropometric measures associated with residual forced vital capacity (FVC) by sex and body mass index group

	Normal weight (n=1310)		Overweight (n=1264)		Obese (n=834)	
	Men (n=504)	Women (n=806)	Men (n=708)	Women (n=556)	Men (n=393)	Women (n=441)
Weight (kg)	0.1428*	0.0118	-0.0607	-0.0409	-0.1723*	-0.1472*
Body mass index (kg/m^2)	0.2142*	0.0219	-0.0987	-0.0608	-0.2005*	-0.1707*
Waist circumference (cm)	0.0748	-0.0273	-0.2141*	-0.2002*	-0.2540*	-0.1277
Hip circumference (cm)	0.1597*	0.0085	-0.0713	-0.0196	-0.1785*	-0.1363*
Waist-to-hip ratio	-0.0161	-0.0378	-0.1768*	-0.1876*	-0.1307*	-0.0156

*P-values less than 0.05.

Table 7.19 Standardized regression coefficients (βs) for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1) by sex and body mass index group

	Normal weight (n=1310)		Overweight (n=1264)		Obese (n=834)	
	Men (n=504)	Women (n=806)	Men (n=708)	Women (n=556)	Men (n=393)	Women (n=441)
Weight (kg)	0.1323*	0.0235	-0.0171	-0.0198	-0.1554*	-0.0973
Body mass index (kg/m^2)	0.1854*	0.0311	-0.0113	-0.0120	-0.1792*	-0.1245*
Waist circumference (cm)	0.0454	-0.0487	-0.1473*	-0.1367	-0.2330*	-0.0931
Hip circumference (cm)	0.1292*	-0.0107	-0.0114	-0.0357	-0.1695*	-0.1190*
Waist-to-hip ratio	-0.0359	-0.0509	-0.1518*	-0.1161*	-0.1141*	0.0107

*P-values less than 0.05.

Table 7.20 Standardized regression coefficients (βs) for anthropometric measures associated with residual FEV_1/FVC ratio by sex and body mass index group

	Normal weight (n=1310)		Overweight (n=1264)		Obese (n=834)	
	Men (n=504)	Women (n=806)	Men (n=708)	Women (n=556)	Men (n=393)	Women (n=441)
Weight (kg)	-0.0192	0.0152	0.0422	0.0302	-0.0522	0.0610
Body mass index (kg/m^2)	-0.0509	0.0122	0.0881	0.0821	-0.0608	0.0491
Waist circumference (cm)	-0.0640	-0.0555	0.0414	0.0706	-0.0737	0.0421
Hip circumference (cm)	-0.0475	-0.0271	0.0690	-0.0397	-0.0868	0.0012
Waist-to-hip ratio	-0.0522	-0.0498	-0.0094	0.0917	0.0041	0.0556

7.1.5 Stage-two regression analysis for skinfold subsample

For the skinfold sample, a Pearson correlation matrix was created to see the associations among the various skinfold measures. Results from this analysis (Table 7.21) showed that all of the skinfold measures had statistically significant correlations among each other. In general, the magnitude of the correlations was between r-values of 0.5 to 0.7, except for sum of five skinfolds. This measure had a stronger association with all the other skinfold measures (r-values>0.7) because it was obtained by adding all of the other five skinfold measures.

Table 7.21 Pearson correlation coefficients* between skinfold measures used in linear regression modeling. Upper right triangle is for men and lower left triangle is for women

	Triceps	Biceps	Subscapular	Iliac crest	Medial calf	Sum of five skinfolds
Triceps (mm)	-	0.7114	0.5515	0.6155	0.6580	0.8009
Biceps (mm)	0.7255	-	0.6489	0.6106	0.5904	0.7929
Subscapular (mm)	0.6019	0.6363	-	0.6776	0.4482	0.8434
Iliac crest (mm)	0.5480	0.5478	0.6924	-	0.5542	0.9020
Medial calf (mm)	0.6951	0.6039	0.4497	0.4400	-	0.7377
Sum of five skinfolds (mm)	0.8474	0.8140	0.8486	0.8183	0.7644	-

*All correlations were significant (*P*<0.0001).

Tables 7.22 and 7.23 show the relationship of skinfold measures with each of the three pulmonary function testing variables (FVC, FEV_1 and FEV_1/ FVC). The standardized βs of the all the models are also presented, which allow direct comparison between models. Each regression model was adjusted for smoking, physical activity, exposure to second-hand smoke inside the home, and vitamin D level.

In men, all of the skinfold measures and in women, all measures except for medial calf were significant predictors of residual FVC. The strongest predictor in men was subscapular skinfold with a standardized β of -0.2285. For women, the best indicator for residual FVC was biceps skinfold with standardized β of -0.1374.

Table 7.22 Linear regression analysis for skinfold measures associated with residual pulmonary function measures in men (n=1203)*

	FVC (L)			FEV_1 (L)			FEV_1/FVC		
	β	SE	β_{std}	β	SE	β_{std}	β	SE	β_{std}
Skinfold average thickness (mm)									
Triceps	-0.0198**	0.0070	-0.1377	-0.0096	0.0065	-0.0762	0.0009**	0.0004	0.0540
Biceps	-0.0520**	0.0114	-0.1862	-0.0235**	0.0090	-0.0960	0.0032**	0.0009	0.0938
Subscapular	-0.0182**	0.0036	-0.2285	-0.0115**	0.0040	-0.1637	0.0004	0.0005	0.0389
Iliac crest	-0.0056**	0.0027	-0.0919	-0.0014	0.0026	-0.0270	0.0005**	0.0002	0.0689
Medial calf	-0.0147**	0.0049	-0.1121	-0.0083	0.0043	-0.0720	0.0007	0.0004	0.0428
Sum of five skinfolds	-0.0045**	0.0011	-0.1766	-0.0022**	0.0011	-0.1013	0.0002**	0.0001	0.0682

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
** P-values less than 0.05.
FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; $\beta_{std,}$ standardized regression coefficient; SE, standard error.

Table 7.23 Linear regression analysis for skinfold measures associated with residual pulmonary function measures in women (n=1345)*

	FVC (L)			FEV_1 (L)			FEV_1/FVC		
	β	SE	β_{std}	β	SE	β_{std}	β	SE	β_{std}
Skinfold average thickness (mm)									
Triceps	-0.0063**	0.0027	-0.0919	-0.0022	0.0019	-0.0356	0.0007	0.0004	0.0683
Biceps	-0.0139**	0.0043	-0.1374	-0.0046	0.0026	-0.0507	0.0015**	0.0005	0.0941
Subscapular	-0.0059**	0.0012	-0.1240	-0.0024**	0.0008	-0.0575	0.0006**	0.0002	0.0771
Iliac crest	-0.0054**	0.0021	-0.1093	-0.0014	0.0011	-0.0326	0.0008**	0.0003	0.1044
Medial calf	-0.0040	0.0024	-0.0689	-0.0011	0.0019	-0.0211	0.0005	0.0003	0.0591
Sum of five skinfolds	-0.0019**	0.0006	-0.1282	-0.0006	0.0003	-0.0479	0.0002**	0.0001	0.0984

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
**P-values less than 0.05.
FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; $\beta_{std,}$ standardized regression coefficient; SE, standard error.

Increases in biceps, subscapular and sum of five skinfolds were significantly correlated with FEV_1 decline in men, while medial calf showed borderline significance (see Appendix II for p-values of all the models). In women, only subscapular skinfold was a significant marker, while biceps and sum of five skinfolds displayed borderline significance (see Appendix II for p-values of all the models). The strongest predictor was subscapular skinfold for both men and women, with standardized β values of -0.1637 and -0.0575, respectively. The magnitude of the effect was almost 3 times stronger in men as compared to women. Moreover, subscapular skinfold accounted for 7.10% of the model variance in men and 5.10% of the model variance in women (see Appendix II for R-squared values of all the models).

The relation between skinfold measures and residual FEV_1/FVC. All of the skinfold predictors, except for subscapular and medial calf for men and triceps and medial calf for women, were significant at the 0.05 significance level. Biceps and iliac crest skinfolds on men and women exhibited the strongest positive effect, respectively.

The associations between skinfold measures and pulmonary function were also analyzed for each body mass index group. Since the skinfold sample did not include obese participants, comparisons were made just between normal and overweight respondents. Figures 7.7-7.10 (Appendix III) show scatter plots of the skinfold parameters in correlation with residual FVC and FEV_1 in various sex and BMI groups.

Skinfold measures had no significant impact on FVC in normal weight men, but all of the skinfold measures had a significant negative correlation with FVC in overweight men (Table 7.24 and Figures 7.7 & 7.9 in Appendix III). According to Table 7.30, the strongest association was observed between subscapular skinfold, which showed that a one standard deviation increase in this skinfold resulted in a 0.34 standard deviation decline in FVC.

In normal weight women (Table 7.25 and Figure 7.8 in Appendix III), all skinfold measures were negatively associated with residual FVC except for iliac crest and medial calf. In the overweight group, all predictors were significant except for triceps and medial calf (Table 7.25 and Figure 7.10 in Appendix III). The most significant predictor for normal and overweight women was sum of five skinfolds, which resulted in a 0.24 standard deviation decrease in FVC with a one standard deviation increase in it. (Table 7.30).

Table 7.24 Linear regression analysis for skinfold measures associated with residual forced vital capacity (FVC) by body mass index group in men*

	Normal weight (n=501) (BMI<25.0)			Overweight (n=702) (BMI=25.0-29.9)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	0.0019	0.0143	0.8958	-0.0331	0.0063	<0.0001
Biceps	-0.0390	0.0230	0.0904	-0.0714	0.0142	<0.0001
Subscapular	-0.0118	0.0075	0.1149	-0.0269	0.0029	<0.0001
Iliac crest	-0.0017	0.0047	0.7100	-0.0098	0.0030	0.0011
Medial calf	0.0049	0.0083	0.5529	-0.0249	0.0047	<0.0001
Sum of five skinfolds	-0.0015	0.0022	0.4997	-0.0082	0.0009	<0.0001

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table 7.25 Linear regression analysis for skinfold measures associated with residual forced vital capacity (FVC) by body mass index group in women*

	Normal weight (n=801) (BMI<25.0)			Overweight (n=544) (BMI=25.0-29.9)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	-0.0111	0.0047	0.0192	-0.0081	0.0051	0.1094
Biceps	-0.0195	0.0058	0.0008	-0.0232	0.0077	0.0027
Subscapular	-0.0101	0.0030	0.0008	-0.0105	0.0021	<0.0001
Iliac crest	-0.0064	0.0037	0.0864	-0.0095	0.0033	0.0040
Medial calf	-0.0071	0.0040	0.0809	-0.0044	0.0038	0.2457
Sum of five skinfolds	-0.0031	0.0011	0.0041	-0.0045	0.0011	<0.0001

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table 7.26 and Figures 7.7 &7.9 (Appendix III) show the relationship between skinfold measures and FEV_1 stratified by BMI group in men. In normal weight men, there was no significant association between any of the skinfold measures and FEV_1. For men that were overweight, all the skinfold predictors were inversely correlated with FEV_1 except for iliac crest. The best predictor, according to the standardized β values (Table 7.31) was subscapular skinfold. A one standard deviation increase of this skinfold produced a 0.27 standard deviation decrease in FEV_1. In women that were normal weight, all skinfold factors were significant except for iliac crest and medial calf (Table 7.27). The statistically significant predictors had an inverse association with residual FEV_1 indicated by the negative slopes on the scatter plots (Figure 7.8 in Appendix III). In overweight women, biceps, subscapular, and sum of five skinfold measures displayed a statistically significant inverse correlation with FEV_1 (Table 7.27 and Figure 7.10 in Appendix III). Subscapular and sum of five skinfolds were most strongly predicting FEV_1 in normal weight and overweight women, respectively (Table 7.31). For normal weight women, one standard deviation increment in subscapular skinfold was associated with 0.11 standard deviation reduction in FEV_1. And in overweight women, an increase of one standard deviation in sum of five skinfolds resulted in 0.15 standard deviation reduction in FEV_1.

Table 7.26 Linear regression analysis for skinfold measures associated with residual forced expiratory volume in one second (FEV_1) by body mass index group in men*

	Normal weight (n=501) (BMI<25.0)			Overweight (n=702) (BMI=25.0-29.9)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	0.0093	0.0131	0.4783	-0.0234	0.0052	<0.0001
Biceps	-0.0093	0.0240	0.6974	-0.0451	0.0119	0.0001
Subscapular	-0.0125	0.0086	0.1467	-0.0186	0.0034	<0.0001
Iliac crest	-0.0018	0.0046	0.6988	-0.0046	0.0033	0.1661
Medial calf	0.0061	0.0105	0.5607	-0.0201	0.0049	<0.0001
Sum of five skinfolds	-0.0011	0.0024	0.6538	-0.0054	0.0011	<0.0001

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table 7.27 Linear regression analysis for skinfold measures associated with residual forced expiratory volume in one second (FEV_1) by body mass index group in women*

	Normal weight (n=801) (BMI<25.0)			Overweight (n=544) (BMI=25.0-29.9)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	-0.0073	0.0037	0.0487	-0.0053	0.0035	0.1340
Biceps	-0.0099	0.0043	0.0210	-0.0137	0.0058	0.0181
Subscapular	-0.0074	0.0027	0.0068	-0.0060	0.0016	0.0001
Iliac crest	-0.0038	0.0020	0.0605	-0.0044	0.0024	0.0686
Medial calf	-0.0037	0.0037	0.3122	-0.0036	0.0033	0.2711
Sum of five skinfolds	-0.0019	0.0007	0.0091	-0.0026	0.0007	0.0003

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

The results of multiple linear regression analysis between residual FEV_1/FVC ratio and skinfold measures by BMI group (Tables 7.28 and 7.29) demonstrate that in normal weight people, no association was statistically significant in both sexes. For the overweight men, none of the relationships were significant. However, in women, subscapular, iliac crest and sum of five skinfolds were the three measures that were significantly correlated with FEV_1/FVC. Table 7.32 shows that iliac crest skinfold has the largest positive effect on the ratio of FEV_1/FVC (β_{std}=0.1463).

Table 7.28 Linear regression analysis for skinfold measures associated with residual FEV_1/FVC ratio by body mass index group in men*

	Normal weight (n=501) (BMI<25.0)			Overweight (n=702) (BMI=25.0-29.9)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	0.0007	0.0012	0.5824	0.0003	0.0004	0.4537
Biceps	0.0039	0.0029	0.1831	0.0014	0.0010	0.1748
Subscapular	-0.0011	0.0013	0.4132	0.0002	0.0005	0.7459
Iliac crest	-0.0003	0.0006	0.6440	0.0005	0.0004	0.1688
Medial calf	-0.0001	0.0011**	0.9612	-0.0000	0.0006	0.9401
Sum of five skinfolds	-0.0001	0.0003	0.7092	0.0001	0.0001	0.2559

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
**499 bootstrap replicates were used for variance calculation.
β, regression coefficient; SE, standard error.

Table 7.29 Linear regression analysis for skinfold measures associated with residual FEV_1/FVC ratio by body mass index group in women*

	Normal weight (n=801) (BMI<25.0)			Overweight (n=544) (BMI=25.0-29.9)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	0.0005	0.0006	0.4654	0.0002	0.0005	0.6486
Biceps	0.0012	0.0012	0.3245	0.0009	0.0006	0.1273
Subscapular	0.0000	0.0005	0.9794	0.0007	0.0002	<0.0001
Iliac crest	0.0003	0.0006	0.5482	0.0010	0.0002**	<0.0001
Medial calf	0.0007	0.0006	0.2812	-0.0002	0.0005	0.6222
Sum of five skinfolds	0.0001	0.0002	0.4058	0.0003	0.0001	0.0056

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
**499 bootstrap replicates were used for variance calculation.
β, regression coefficient; SE, standard error.

Table 7.30 Standardized regression coefficients (βs) for skinfold measures associated with residual forced vital capacity (FVC) by sex and body mass index group

	Normal weight (n=1302)		Overweight (n=1246)	
	Men (n=501)	Women (n=801)	Men (n=702)	Women (n=544)
Skinfold average thickness (mm)				
Triceps	0.0096	-0.1315*	-0.2447*	-0.1042
Biceps	-0.0805	-0.1424*	-0.2733*	-0.2219*
Subscapular	-0.1011	-0.1373*	-0.3389*	-0.2177*
Iliac crest	-0.0209	-0.1044	-0.1578*	-0.1825*
Medial calf	0.0257	-0.0974	-0.2034*	-0.0748
Sum of five skinfolds	-0.0409	-0.1526*	-0.3056*	-0.2402*

* P-values less than 0.05.

Table 7.31 Standardized regression coefficients (βs) for skinfold measures associated with residual forced expiratory volume in one second (FEV_1) by sex and body mass index group

	Normal weight (n=1302)		Overweight (n=1246)	
	Men (n=501)	Women (n=801)	Men (n=702)	Women (n=544)
Skinfold average thickness (mm)				
Triceps	0.0546	-0.0965*	-0.1971*	-0.0752
Biceps	-0.0221	-0.0808*	-0.1966*	-0.1449*
Subscapular	-0.1229	-0.1121*	-0.2675*	-0.1384*
Iliac crest	-0.0244	-0.0691	-0.0842	-0.0934
Medial calf	0.0367	-0.0576	-0.1866*	-0.0674
Sum of five skinfolds	-0.0340	-0.1053*	-0.2287*	-0.1543*

* P-values less than 0.05.

Table 7.32 Standardized regression coefficients (βs) for skinfold measures associated with residual FEV_1/FVC ratio by sex and body mass index group

	Normal weight (n=1302)		Overweight (n=1246)	
	Men (n=501)	Women (n=801)	Men (n=702)	Women (n=544)
Skinfold average thickness (mm)				
Triceps	0.0271	0.0328	0.0192	0.0217
Biceps	0.0650	0.0528	0.0464	0.0654
Subscapular	-0.0744	0.0010	0.0181	0.1110*
Iliac crest	-0.0279	0.0329	0.0713	0.1463*
Medial calf	-0.0023	0.0561	-0.0031	-0.0309
Sum of five skinfolds	-0.0263	0.0425	0.0445	0.1014*

* P-values less than 0.05.

7.2 The Children Sample

7.2.1 Demographics

The children study sample had 1583 respondents, 789 boys and 794 girls. The weighted mean age was 12.15 (SE 0.096). The baseline characteristics of the study sample are shown in Table 7.33. Standing height, weight and waist-to-hip ratio were significantly higher in boys as compared to the girls. FVC, $FEV_{0.75}$ and FEV_1 were all significantly higher in boys while FEV_1/FVC ratio was significantly higher in girls.

Table 7.33 Mean (standard error) of anthropometric and spirometric measurements of the children sample by sex (n=1583)

	Boys (n=789)	Girls (n=794)	*P*-value
Age (years)	12.21 (0.12)	12.16 (0.13)	0.7601
Standing height (m)	1.56 (0.0074)	1.51 (0.0068)	<0.0001
Weight (kg)	52.20 (1.38)	47.71 (0.66)	0.0028
Body mass index (kg/m^2)	20.55 (0.36)	20.15 (0.25)	0.2831
Waist circumference (cm)	70.63 (1.06)	68.32 (0.88)	0.0633
Hip circumference (cm)	85.28 (1.00)	85.39 (0.53)	0.9187
Waist-to-hip ratio	0.83 (0.0027)	0.80 (0.0058)	<0.0001
FVC (L)	3.51 (0.069)	2.99 (0.026)	<0.0001
$FEV_{0.75}$ (L)	2.60 (0.039)	2.31 (0.022)	<0.0001
FEV_1 (L)	2.89 (0.047)	2.54 (0.023)	<0.0001
FEV_1/FVC	0.83 (0.0048)	0.85 (0.0018)	<0.0001

FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

Anthropometric and lung function variables were also compared among different BMI groups for boys and girls separately (Tables 7.34 and 7.35). The mean FVC was significantly higher in the overweight boys as compared to the normal weight boys. Comparisons between overweight or obese children and normal weight and obese children showed no significant differences in mean FVC (p-values are not shown). Similar results were found for $FEV_{0.75}$ and FEV_1 also, where there was a significant increase in mean values from normal weight to overweight category, but no significant differences between overweight and obese or normal weight and obese groups. For mean FEV_1/FVC the obese group had a significantly lower value in comparison to the normal weight group.

Table 7.34 Mean (standard error) of anthropometric and lung function measures for each body mass index group among boys (n=789)

	Normal Weight (n=573)	Overweight (n=118)	Obese (n=98)
Age (years)	12.18 (0.12)	12.22 (0.33)	12.36 (0.58)
Standing height (m)	1.55 (0.0062)	1.59 (0.018)	1.60 (0.029)
Weight (kg)	45.79 (0.61)	59.22 (1.97)	76.57 (4.81)
Body mass index (kg/m^2)	18.45 (0.13)	22.69 (0.31)	28.73 (0.92)
Waist circumference (cm)	65.16 (0.54)	75.76 (0.96)	92.29 (2.53)
Hip circumference (cm)	80.59 (0.58)	91.04 (1.16)	102.48 (2.73)
Waist-to-hip ratio	0.81 (0.0020)	0.83 (0.0039)	0.90 (0.0050)
FVC (L)	3.39 (0.067)	3.84 (0.13)	3.78 (0.21)
$FEV_{0.75}$ (L)	2.53 (0.041)	2.81 (0.093)	2.74 (0.15)
FEV_1 (L)	2.81 (0.048)	3.12 (0.11)	3.04 (0.17)
FEV_1/FVC	0.83 (0.0055)	0.82 (0.0075)	0.81 (0.011)

FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

For girls, mean FVC values were significantly higher for the overweight group than the normal weight group. The obese group also had significantly higher values when compared to the normal weight group but not when compared to the overweight group. For $FEV_{0.75}$ and FEV_1 the obese group had a significantly higher mean compared to the normal group, however all other comparisons were not significant. The mean value for FEV_1/FVC was significant lower in the obese group than the normal category.

Table 7.35 Mean (standard error) of anthropometric and lung function measures for each body mass index group among girls (n=794)

	Normal Weight (n=626)	Overweight (n=94)	Obese (n=74)
Age (years)	12.11 (0.17)	11.95 (0.48)	12.74 (0.60)
Standing height (m)	1.50 (0.0093)	1.52 (0.016)	1.57 (0.025)
Weight (kg)	42.70 (0.56)	55.57 (1.86)	73.23 (3.34)
Body mass index (kg/m^2)	18.32 (0.11)	23.32 (0.45)	29.18 (0.62)
Waist circumference (cm)	63.69 (0.29)	76.10 (1.22)	91.35 (2.13)
Hip circumference (cm)	81.60 (0.44)	92.12 (1.78)	103.82 (2.42)
Waist-to-hip ratio	0.78 (0.0038)	0.83 (0.010)	0.88 (0.015)
FVC (L)	2.90 (0.051)	3.09 (0.083)	3.44 (0.15)
$FEV_{0.75}$ (L)	2.26 (0.033)	2.36 (0.088)	2.61 (0.10)
FEV_1 (L)	2.48 (0.037)	2.59 (0.090)	2.88 (0.12)
FEV_1/FVC	0.86 (0.0026)	0.84 (0.015)	0.84 (0.0073)

FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

7.2.2 Demographics for skinfold subsample

Lung function testing variables were also compared between boys and girls in the children's sample. This examination, presented in Table 7.36, displayed that all the skinfold measures were significantly higher and all of the pulmonary function parameters were significantly lower in girls, except for FEV_1/FVC, which was significantly higher in girls.

Table 7.36 Mean (standard error) of anthropometric and spirometric variables of the children skinfold subsample by sex (n=1525)

	Boys (n=762)	Girls (n=763)	*P-value*
Age (years)	12.05 (0.13)	12.07 (0.15)	0.9106
Standing height (m)	1.55 (0.0069)	1.51 (0.0078)	<0.0001
Weight (kg)	49.02 (0.86)	45.83 (0.52)	<0.0003
Body mass index (kg/m^2)	19.66 (0.20)	19.53 (0.17)	0.4461
Waist circumference (cm)	68.31 (0.67)	66.72 (0.71)	0.0208
Hip circumference (cm)	83.23 (0.71)	84.02 (0.41)	0.2792
Waist-to-hip ratio	0.82 (0.0022)	0.80 (0.0057)	<0.0001
Skinfold average thickness (mm)			
Triceps	11.54 (0.29)	14.75 (0.30)	<0.0001
Biceps	5.89 (0.15)	7.34 (0.22)	<0.0001
Subscapular	8.88 (0.31)	11.21 (0.35)	<0.0001
Iliac crest	12.75 (0.58)	17.03 (0.65)	<0.0001
Medial calf	11.46 (0.27)	14.83 (0.40)	<0.0001
Sum of five skinfolds	50.52 (1.50)	65.16 (1.84)	<0.0001
FVC (L)	3.44 (0.067)	2.95 (0.035)	<0.0001
$FEV_{0.75}$ (L)	2.56 (0.041)	2.29 (0.028)	<0.0001
FEV_1 (L)	2.84 (0.048)	2.51 (0.031)	<0.0001
FEV_1/FVC	0.83 (0.0045)	0.86 (0.0016)	<0.0001

FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

Ventilatory function measures were also examined in children's sample stratified by sex and BMI. The outcome of this analysis showed that the overweight boys had a significantly higher mean value for FVC as compared to the normal weight category, but a significantly lower value was observed for the obese group in contrast to the overweight participants. For $FEV_{0.75}$, and FEV_1, there was a significant increase in mean values from normal weight to overweight group. However, the obese group had a significantly lower $FEV_{0.75}$ and FEV_1 than the overweight group. The FEV_1/FVC ratio showed a significant decline in the obese group relative to the overweight and normal weight groups.

Table 7.37 Mean (standard error) of anthropometric and lung function measures for each body mass index group in the boys' skinfold subsample (n=762)

	Normal Weight (n=573)	Overweight (n=118)	Obese (n=71)
Age (years)	12.18 (0.12)	12.22 (0.33)	10.61 (0.52)
Standing height (m)	1.55 (0.0062)	1.59 (0.018)	1.52 (0.032)
Weight (kg)	45.79 (0.61)	59.22 (1.97)	59.49 (3.56)
Body mass index (kg/m^2)	18.45 (0.13)	22.69 (0.31)	25.02 (0.50)
Waist circumference (cm)	65.16 (0.54)	75.76 (0.96)	82.85 (1.64)
Hip circumference (cm)	80.59 (0.58)	91.04 (1.16)	92.67 (1.66)
Waist-to-hip ratio	0.81 (0.0020)	0.83 (0.0039)	0.89 (0.0085)
Skinfold average thickness (mm)			
Triceps	9.77 (0.23)	15.70 (0.34)	19.80 (1.01)
Biceps	4.78 (0.13)	8.29 (0.26)	11.48 (0.37)
Subscapular	6.91 (0.19)	12.91 (0.69)	19.11 (1.33)
Iliac crest	9.32 (0.46)	20.80 (0.77)	28.64 (1.90)
Medial calf	9.43 (0.22)	16.12 (0.79)	21.05 (0.81)
Sum of five skinfolds	40.21 (1.10)	73.81 (2.35)	100.07 (4.80)
FVC (L)	3.39 (0.067)	3.84 (0.13)	3.26 (0.23)
$FEV_{0.75}$ (L)	2.53 (0.041)	2.81 (0.093)	2.32 (0.16)
FEV_1 (L)	2.81 (0.048)	3.12 (0.11)	2.58 (0.18)
FEV_1/FVC	0.83 (0.0055)	0.82 (0.0075)	0.80 (0.012)

FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

For girls, FVC was significantly higher in the overweight category compared to the normal weight category. With regards to $FEV_{0.75}$, FEV_1, and FEV_1/FVC, there was no statistically significant difference among the BMI groups.

Table 7.38 Mean (standard error) of anthropometric and lung function measures for each body mass index group in the girls' skinfold subsample (n=763)

	Normal Weight (n=625)	Overweight (n=94)	Obese (n=44)
Age (years)	12.11 (0.17)	11.95 (0.48)	11.84 (0.65)
Standing height (m)	1.50 (0.0093)	1.52 (0.016)	1.53 (0.030)
Weight (kg)	42.69 (0.57)	55.57 (1.86)	64.67 (3.72)
Body mass index (kg/m^2)	18.31 (0.11)	23.32 (0.45)	26.84 (0.70)
Waist circumference (cm)	63.68 (0.29)	76.10 (1.22)	85.24 (2.67)
Hip circumference (cm)	81.59 (0.44)	92.12 (1.78)	97.56 (2.63)
Waist-to-hip ratio	0.78 (0.0038)	0.83 (0.010)	0.88 (0.023)
Skinfold average thickness (mm)			
Triceps	13.11 (0.21)	19.74 (0.72)	24.82 (1.02)
Biceps	6.36 (0.13)	10.25 (0.39)	13.48 (0.92)
Subscapular	9.14 (0.21)	16.38 (0.67)	26.24 (1.88)
Iliac crest	14.20 (0.39)	25.01(1.14)	35.74 (2.78)
Medial calf	12.81 (0.25)	21.66 (0.63)	25.84 (1.52)
Sum of five skinfolds	55.62 (1.03)	93.04 (2.87)	126.12 (6.73)
FVC (L)	2.90 (0.051)	3.09 (0.083)	3.18 (0.18)
$FEV_{0.75}$ (L)	2.26 (0.033)	2.36 (0.088)	2.46 (0.14)
FEV_1 (L)	2.48 (0.037)	2.59 (0.090)	2.70 (0.15)
FEV_1/FVC	0.86 (0.0026)	0.84 (0.015)	0.85(0.0088)

FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 s; FEV_1/FVC, ratio of FEV_1 to FVC.

7.2.3 Stage one regression analysis

Multivariate regression models were developed for each of the four outcome variables (FVC, $FEV_{0.75}$, FEV_1 and FEV_1/FVC) by sex, resulting in a total of eight models from the first stage. The covariates adjusted for in the models included standing height in meters, age in years, and ethnicity (White or non-White). The quadratic terms for age and height were also tested for significance. The results of this analysis are presented in Tables 7.39 and 7.40ab. In boys, height, age and ethnicity explained about 85-90% of the variance in the models for FVC, $FEV_{0.75}$ and FEV_1, while for FEV_1/FVC, a mere 5% of the variability was accounted for by height and ethnicity. Age was not a significant predictor in the model for the ratio. For girls, the R-squared values for FVC, $FEV_{0.75}$, and FEV_1 models ranged from about 83% to 85%, whereas, for the ratio of FEV_1/FVC, it was only about 4%. The extremely low R-squared values for the FEV_1/FVC models in both boys and girls can be explained by the fact that the proportion of variance accounted for by height, age and ethnicity was very similar between FVC and FEV_1 models, so they accounted for very little variance in the ratio of these two outcome variables.

Table 7.39a Results from multiple linear regression models for predicting lung function in boys (n=789)

	FVC (L)			$FEV_{0.75}$ (L)		
	β	SE	*P*	β	SE	*P*
Height	-0.9519	1.8490	0.6067	-2.5838	1.6746	0.1229
$Height^2$	2.0838	0.6131	0.0007	2.1008	0.5533	0.0001
Age	-0.3040	0.0335	<0.0001	-0.2112	0.0459	<0.0001
Age^2	0.0155	0.0011	<0.0001	0.0111	0.0018	<0.0001
Ethnic group	0.3352	0.1058	0.0015	0.1043	0.0829	0.2082
Model R^2		0.9005			0.8695	

FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; β, regression coefficient; SE, standard error.

Table 7.39b Results from multiple linear regression models for predicting lung function in boys (n=789)

	FEV_1 (L)			FEV_1/FVC		
	β	SE	*P*	β	SE	*P*
Height	-2.6736	1.7754	0.1321	-0.6301	0.2466	0.0106
$Height^2$	2.3188	0.5925	0.0001	0.1994	0.0818	0.0147
Age	-0.2505	0.0459	<0.0001			0.6236
Age^2	0.0128	0.0017	<0.0001			0.7923
Ethnic group	0.1613	0.0962	0.0938*	-0.0355	0.0078	<0.0001
Model R^2		0.8850			0.0518	

*P-values <0.10 were considered significant.

FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; SE, standard error.

Table 7.40a Results from multiple linear regression models for predicting lung function in girls (n=794)

	FVC (L)			$FEV_{0.75}$ (L)		
	β	SE	*P*	β	SE	*P*
Height	-6.1477	1.9169	0.0013	-1.3967	1.9613	0.4764
$Height^2$	3.4365	0.6877	<0.0001	1.3898	0.6564	0.0342
Age	0.0671	0.0089	<0.0001	0.0621	0.0069	<0.0001
Age^2			0.1145			0.2453
Ethnic group	0.3814	0.1014	0.0002	0.2021	0.0610	0.0009
Model R^2		0.8403			0.8335	

FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; β, regression coefficient; SE, standard error.

Table 7.40b Results from multiple linear regression models for predicting lung function in girls (n=794)

	FEV_1 (L)			FEV_1/FVC		
	β	SE	*P*	β	SE	*P*
Height	-2.8269	1.9871	0.1549	-0.1315	0.0250	<0.0001
$Height^2$	2.0014	0.6704	0.0028			0.8197
Age	0.0687	0.0081	<0.0001	0.0221	0.0101	0.0279
Age^2			0.1463	-0.0007	0.0004	0.0951*
Ethnic group	0.2584	0.0750	0.0006	-0.0232	0.0084	0.0057
Model R^2		0.8473			0.0378	

*P-values <0.10 were considered significant.

FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; SE, standard error.

7.2.4 Stage-two regression analysis

Pearson correlation coefficients were determined for all the anthropometric measures under investigation (Table 7.41). The results showed that all of the correlations, with the exception of two, were highly significant with p-values less than 0.001. These included the correlation between hip circumference and waist-to-hip-ratio in boys and weight and waist-to-hip-ratio in girls. The magnitude of the associations was larger than r=0.85 among all the adiposity measures except for waist-to-hip ratio versus fat measures, which were all below r=0.45.

Table 7.41 Pearson correlation coefficients* between anthropometric measures used in linear regression modeling. Upper right triangle is for boys and lower left triangle is for girls

	Weight	BMI	WC	HC	WHR
Weight (kg)	-	0.8722	0.9164	0.9631	0.1235
BMI (kg/m^2)	0.8997	-	0.9521	0.8814	0.3925
WC (cm)	0.9216	0.9440	-	0.9206	0.4332
HC (cm)	0.9783	0.8794	0.8994	-	0.0543[1]
WHR	-0.0394[1]	0.2241	0.3090	0.1332	-

*P-values <0.001

[1]P-values>0.05

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio.

The results of linear regression analysis between each of the anthropometric factors and residual lung function variables are presented in Tables 7.42 and 7.43. Standardized β coefficients were also calculated to allow comparison between models and are presented in Table 7.44. The analysis was stratified by sex. Smoking, exposure to second hand smoke, vitamin D level, and other lifestyle factors had no significant effect on the association between obesity variables and respiratory function, so they were excluded from the models.

Forced vital capacity (FVC) in boys showed a significant positive relationship with BMI, waist circumference and hip circumference (Table 7.42). The strongest positive predictor was BMI, which had the highest standardized β value (0.1614) and explained 2.6% of the variation in residual FVC (see Appendix II for R-squared values of the models). For girls, all of the measures of body fat had a significant positive correlation with residual FVC (Table 7.43). Like in boys, the strongest predictor was BMI with a standardized coefficient value of 0.3114 and explained 9.7% of the variation in residual FVC. When comparing the two sexes, BMI had a stronger impact in girls than boys.

Table 7.42 Linear regression analysis for anthropometric measures associated with residual pulmonary function measures in boys (n=789)

	FVC (L)		$FEV_{0.75}$ (L)		FEV_1 (L)		FEV_1/FVC	
	β	SE	β	SE	β	SE	β	SE
Weight (kg)	0.0019	0.0010	0.0008	0.0009	0.0007	0.0009	-0.0002	0.0001
Body Mass Index (kg/m^2)	0.0137*	0.0059	0.0057	0.0039	0.0053	0.0039	-0.0016*	0.0007
Waist circumference (cm)	0.0027*	0.0014	0.0004	0.0012	0.00005	0.0011	-0.0006*	0.0002
Hip circumference (cm)	0.0029*	0.0013	0.0014	0.0010	0.0012	0.0010	-0.0003	0.0002
Waist-to-hip ratio	0.2791	0.3426	-0.4256	0.3469	-0.5251	0.3381	-0.2049*	0.0473

* P-values less than 0.05.
FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; SE, standard error.

Table 7.43 Linear regression analysis for anthropometric measures associated with residual pulmonary function measures in girls (n=794)

	FVC (L)		$FEV_{0.75}$ (L)		FEV_1 (L)		FEV_1/FVC	
	β	SE	β	SE	β	SE	β	SE
Weight (kg)	0.0044*	0.0010	0.0022*	0.0008	0.0026*	0.0008	-0.0004*	0.0001
Body Mass Index (kg/m^2)	0.0245*	0.0042	0.0125*	0.0044	0.0144*	0.0044	-0.0019*	0.0006
Waist circumference (cm)	0.0065*	0.0011	0.0029*	0.0014	0.0033*	0.0013	-0.0007*	0.0002
Hip circumference (cm)	0.0050*	0.0013	0.0025*	0.0010	0.0030*	0.0010	-0.0004*	0.0002
Waist-to-hip ratio	0.8475*	0.1765	0.2278	0.2660	0.2325	0.2283	-0.1293	0.0668

* P-values less than 0.05.
FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; SE, standard error

$FEV_{0.75}$, the proportion of the FVC exhaled in 0.75 seconds, was not associated with any of the adiposity parameters in boys (Table 7.42), while in girls, it was positively correlated with all the adiposity measures except for waist-to-hip ratio. The strongest predictor of residual $FEV_{0.75}$ in girls was BMI. FEV_1 was also not associated with any of the body fat measures in boys. On the other hand, it was positively related to all of the adiposity measures except for waist-to-hip ratio in girls (Table 7.43). Body mass index was the best predictor of residual FEV_1 in girls.

The relationship between measures of adiposity and residual FEV_1/FVC was also examined. In boys, all predictors, except for weight and hip circumference, had significant inverse associations with the FEV_1/FVC ratio. The strongest effect was exhibited by waist-to-hip ratio, which had the highest standardized β value (Table 7.44). In girls, all of the factors, with the exception of waist-to-hip ratio, had significant inverse associations with FEV_1/FVC.

Table 7.44 Standardized regression coefficients (βs) for anthropometric measures associated with residual lung function measures by sex[1]

	FVC (L)		$FEV_{0.75}$ (L)		FEV_1 (L)		FEV_1/FVC	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Weight (kg)	0.0982	0.2127*	0.0512	0.1410*	0.0424	0.1518*	-0.0744	-0.1074*
Body mass index (kg/m²)	0.1614*	0.3114*	0.0802	0.2102*	0.0707	0.2255*	-0.1262*	-0.1545*
Waist circumference (cm)	0.0906*	0.2327*	0.0143	0.1345*	0.0019	0.1447*	-0.1335*	-0.1470*
Hip circumference (cm)	0.0982*	0.1940*	0.0544	0.1304*	0.0470	0.1429*	-0.0727	-0.0972*
Waist-to-hip ratio	0.0385	0.1412*	-0.0697	0.0503	-0.0814	0.0478	-0.1899*	-0.1364

[1]n=789 for boys and n=794 for girls.
* P-values less than 0.05.
FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

Lung function by BMI group was also examined among boys and girls separately. Figures 7.11-7.14 (Appendix III) show scatter plots of the anthropometric measures in association with residual FVC and FEV_1 in the different sex and BMI groups.

In normal weight boys, BMI had a significant positive effect on FVC as observed from the positive beta value (Table 7.45) and positive slope of the residual FVC versus BMI scatter plot (Figure 7.11 in Appendix III). Among overweight or obese boys, waist circumference and waist-to-hip ratio had a significant inverse association with FVC (negative slopes of scatter plots in Figure 7.13 in Appendix III), while the association between BMI and FVC was borderline significant (p=0.0522). The best predictor of FVC in the overweight or obese group was waist-to-hip ratio with a standardized β of -0.2666 (Table 7.53). Therefore, a one standard deviation increase in waist-to-hip ratio yielded 0.27 standard deviation decrement in FVC.

Table 7.45 Linear regression analysis for anthropometric measures associated with residual forced vital capacity (FVC) by body mass index group in boys

	Normal weight (n=573)			Overweight or obese (n=216)		
	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0025	0.0015	0.0934	-0.0018	0.0016	0.2637
BMI (kg/m^2)	0.0328	0.0072	0.0000	-0.0119	0.0062	0.0522
WC (cm)	0.0048	0.0036	0.1850	-0.0058	0.0018	0.0011
HC (cm)	0.0026	0.0022	0.2339	-0.0031	0.0025	0.2169
WHR	0.5290	0.6607	0.4234	-1.7108	0.6937	0.0137

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

Normal weight girls showed a significant positive correlation between all the adiposity measures and FVC except for waist-to-hip ratio (Table 7.46 and Figure 7.12 in Appendix III). For overweight or obese girls, all the adiposity factors were non-significant except for BMI, which displayed a significant positive association with FVC (Figure 7.14 in Appendix III). The best positive predictor of FVC in both groups was BMI with standardized coefficients of 0.2705 for normal weight and 0.1949 for overweight or obese (Table 7.53).

Table 7.46 Linear regression analysis for anthropometric measures associated with residual forced vital capacity (FVC) by body mass index group in girls

	Normal weight (n=626)			Overweight or obese (n=168)		
	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0039	0.0016	0.0151	0.0018	0.0013	0.1737
BMI (kg/m^2)	0.0371	0.0119	0.0018	0.0125	0.0049	0.0103
WC (cm)	0.0071	0.0029	0.0150	0.0023	0.0018	0.1878
HC (cm)	0.0040	0.0017	0.0189	0.0019	0.0017	0.2619
WHR	0.2859	0.3191	0.3703	0.2769	0.4022	0.4912

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

With $FEV_{0.75}$ as the outcome variable in normal weight boys, all of the adiposity measures, except for BMI, showed non-significant relationships (Table 7.47). In the overweight or obese boys, none of the adiposity factors were statistically significant.

Table 7.47 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$) by body mass index group in boys

	Normal weight (n=573)			Overweight or obese (n=216)		
	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0017	0.0011	0.1240	-0.0011	0.0015	0.4576
BMI (kg/m^2)	0.0222	0.0077	0.0039	-0.0087	0.0062	0.1607
WC (cm)	0.0018	0.0023	0.4141	-0.0042	0.0026	0.1028
HC (cm)	0.0020	0.0017	0.2227	-0.0019	0.0019	0.3049
WHR	-0.3729	0.3899	0.3388	-1.4222	0.7859	0.0703

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

In normal weight girls (Table 7.48), weight, BMI and hip circumference displayed significant positive correlations with $FEV_{0.75}$, while in overweight or obese girls, none of the adiposity parameters were significant. Like for FVC, the most important predictor of $FEV_{0.75}$ was BMI with a standardized coefficient value of 0.1910 (Table 7.54).

Table 7.48 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$) by body mass index group in girls

	Normal weight (n=626)			Overweight or obese (n=168)		
	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0021	0.0009	0.0251	0.0006	0.0008	0.4454
BMI (kg/m^2)	0.0195	0.0073	0.0078	0.0049	0.0040	0.2252
WC (cm)	0.0026	0.0016	0.1056	0.0005	0.0013	0.7095
HC (cm)	0.0024	0.0011	0.0378	0.0000	0.0010	0.9930
WHR	-0.3239	0.2512	0.1972	0.2454	0.3810	0.5196

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

According to beta values in Table 7.49 and increasing slope of the scatter plot (Figure 7.11 in Appendix III), BMI had a significant positive correlation with FEV_1 in normal weight boys, whereas waist circumference and waist-to-hip ratio had significant inverse associations with FEV_1 in overweight or obese boys shown by declining slopes in Figure 7.13 (Appendix III). The association between waist-to-hip ratio and FEV_1 was the strongest. An increase of one standard deviation of waist-to-hip ratio was correlated with 0.27 standard deviation lower FEV_1 (Table 7.55).

Table 7.49 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1) by body mass index group in boys

	Normal weight (n=573)			Overweight or obese (n=216)		
	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0019	0.0012	0.1082	-0.0014	0.0015	0.3593
BMI (kg/m^2)	0.0244	0.0076	0.0013	-0.0103	0.0059	0.0828
WC (cm)	0.0021	0.0025	0.4082	-0.0050	0.0023	0.0333
HC (cm)	0.0022	0.0018	0.2284	-0.0023	0.0020	0.2364
WHR	-0.3721	0.4625	0.4211	-1.6701	0.7777	0.0317

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

In normal weight girls (Table 7.50 and Figure 7.12 in Appendix III), all the adiposity measures except for waist-to-hip ratio had a significant positive relationship with FEV_1, whilst none of the adiposity factors were significant predictors for FEV_1 in the overweight or obese group of girls. Again, the best predictor of FEV_1 in normal weight girls was BMI with a standardized β of 0.2164 (Table 7.55).

Table 7.50 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1) by body mass index group in girls

	Normal weight (n=626)			Overweight or obese (n=168)		
	β	SE	*P*	β	SE	*P*
Weight (kg)	0.0025	0.0009	0.0072	0.0008	0.0008	0.3094
BMI (kg/m^2)	0.0238	0.0084	0.0045	0.0060	0.0037	0.0996
WC (cm)	0.0034	0.0017	0.0450	0.0006	0.0011	0.5567
HC (cm)	0.0029	0.0012	0.0148	0.0003	0.0011	0.7835
WHR	-0.3370	0.2509	0.1793	0.1943	0.3454	0.5737

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

Only waist-to-hip ratio showed a significant inverse association with FEV_1/FVC ratio in normal weight boys, and none of the measures were correlated with FEV_1/FVC in the overweight or obese group.

Table 7.51 Linear regression analysis for anthropometric measures associated with residual FEV_1/FVC ratio by body mass index group in boys

	Normal weight (n=573)			Overweight or obese (n=216)		
	β	SE	*P*	β	SE	*P*
Weight (kg)	-0.0001	0.0002	0.7144	-0.00003	0.0002	0.9014
BMI (kg/m^2)	-0.0010	0.0014	0.4863	-0.0006	0.0011	0.5739
WC (cm)	-0.0006	0.0003	0.1024	-0.0002	0.0004	0.5840
HC (cm)	-0.0001	0.0002	0.7989	-0.0000	0.0004	0.9296
WHR	-0.2115	0.0539	0.0001	-0.1097	0.0827	0.1843

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

For the normal weight girls, FEV_1/FVC was significantly associated with BMI, waist circumference and waist-to-hip ratio but in the overweight or obese group, there was no significant correlation between any of the adiposity factors and FEV_1/FVC ratio. According to the standardized βs in Table 7.56, waist-to-hip ratio had the largest inverse effect on FEV_1/FVC in the normal weight girls.

Table 7.52 Linear regression analysis for anthropometric measures associated with residual FEV_1/FVC ratio by body mass index group in girls

	Normal weight (n=626)			Overweight or obese (n=168)		
	β	SE	*P*	β	SE	*P*
Weight (kg)	-0.0003	0.0002	0.2957	-0.0002	0.0003	0.5594
BMI (kg/m^2)	-0.0027	0.0011	0.0143	-0.0011	0.0014	0.4396
WC (cm)	-0.0008	0.0003	0.0150	-0.0003	0.0004	0.4089
HC (cm)	-0.0002	0.0002	0.3554	-0.0003	0.0004	0.3656
WHR	-0.1532	0.0756	0.0427	-0.0020	0.1019	0.9840

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; β, regression coefficient; SE, standard error.

Table 7.53 Standardized regression coefficients (βs) for anthropometric measures associated with residual forced vital capacity (FVC) by sex and body mass index group

	Normal weight (n=1199)		Overweight or obese (n=384)	
	Boys (n=573)	Girls (n=626)	Boys (n=216)	Girls (n=168)
Weight (kg)	0.0989	0.1415*	-0.1106	0.1176
Body mass index (kg/m^2)	0.2091*	0.2705*	-0.1495	0.1949*
Waist circumference (cm)	0.1021	0.1613*	-0.2094*	0.1071
Hip circumference (cm)	0.0723	0.1292*	-0.1044	0.0878
Waist-to-hip ratio	0.0583	0.0375	-0.2666*	0.0610

* P-values less than 0.05.

Table 7.54 Standardized regression coefficients (βs) for anthropometric measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$) by sex and body mass index group

	Normal weight (n=1199)		Overweight or obese (n=384)	
	Boys (n=573)	Girls (n=626)	Boys (n=216)	Girls (n=168)
Weight (kg)	0.0834	0.1002*	-0.0707	0.0483
Body mass index (kg/m^2)	0.1722*	0.1910*	-0.1157	0.0894
Waist circumference (cm)	0.0480	0.0801	-0.1616	0.0266
Hip circumference (cm)	0.0678	0.1015*	-0.0688	0.0005
Waist-to-hip ratio	-0.0501	-0.0569	-0.2365	0.0640

* P-values less than 0.05.

Table 7.55 Standardized regression coefficients (βs) for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1) by sex and body mass index group

	Normal weight (n=1199)		Overweight or obese (n=384)	
	Boys (n=573)	Girls (n=626)	Boys (n=216)	Girls (n=168)
Weight (kg)	0.0859	0.1138*	-0.0871	0.0587
Body mass index (kg/m^2)	0.1769*	0.2164*	-0.1341	0.1047
Waist circumference (cm)	0.0501	0.0968*	-0.1882*	0.0324
Hip circumference (cm)	0.0681	0.1150*	-0.0805	0.0151
Waist-to-hip ratio	-0.0466	-0.0550	-0.2703*	0.0480

* P-values less than 0.05.

Table 7.56 Standardized regression coefficients (βs) for anthropometric measures associated with residual FEV_1/FVC ratio by sex and body mass index group

	Normal weight (n=1199)		Overweight or obese (n=384)	
	Boys (n=573)	Girls (n=626)	Boys (n=216)	Girls (n=168)
Weight (kg)	-0.0160	-0.0591	-0.0119	-0.0652
Body mass index (kg/m^2)	-0.0427	-0.1224*	-0.0504	-0.0954
Waist circumference (cm)	-0.0814	-0.1166*	-0.0521	-0.0847
Hip circumference (cm)	-0.0115	-0.0461	-0.0081	-0.0892
Waist-to-hip ratio	-0.1565*	-0.1271*	-0.1109	-0.0026

* P-values less than 0.05.

7.2.5 Stage-two regression analysis for skinfold subsample

For the skinfold subsample, Pearson correlations were determined between all six skinfold measures in boys and girls separately. The results of this analysis are shown in Table 7.57. The findings show that all of the skinfold measures are highly correlated with each other and thus need to be included separately in regression models in order to avoid multicollinearity. The R-values were between 70% to 95% for all the skinfold measures. Sum of five skinfolds had the strongest relationship with all the measures in both sexes because this variable was obtained by summing up all the other skinfolds.

Table 7.57 Pearson correlation coefficients* between skinfold measures used in linear regression modeling. Upper right triangle is for boys and lower left triangle is for girls

	Triceps	Biceps	Subscapular	Iliac crest	Medial calf	Sum of five skinfolds
Triceps (mm)	-	0.9067	0.7595	0.7826	0.8725	0.9153
Biceps (mm)	0.8226	-	0.7917	0.8125	0.8792	0.9269
Subscapular (mm)	0.7667	0.7297	-	0.8734	0.7601	0.9114
Iliac crest (mm)	0.7895	0.7313	0.8437	-	0.8021	0.9451
Medial calf (mm)	0.8429	0.7725	0.7365	0.7656	-	0.9237
Sum of five skinfolds (mm)	0.9167	0.8600	0.9078	0.9366	0.9021	-

*All P-values are <0.0001.

Tables 7.58 and 7.59 show the relationship between skinfold measures and FVC in boys and girls, respectively. In boys, subscapular skinfold is the only significant predictor for FVC, while in girls, all skinfold measures had a significant positive association except for medial calf. The predictor having the largest effect on FVC in girls was triceps skinfold (Table 7.60).

Table 7.58 Linear regression analysis for skinfold measures associated with residual pulmonary function measures in boys (n=762)

	FVC (L)		$FEV_{0.75}$ (L)		FEV_1 (L)		FEV_1/FVC	
	β	SE	β	SE	β	SE	β	SE
Skinfold average thickness (mm)								
Triceps	-0.0031	0.0022	-0.0074	0.0041	-0.0083*	0.0040	-0.0017*	0.0008
Biceps	-0.0019	0.0038	-0.0068	0.0056	-0.0091	0.0057	-0.0025*	0.0011
Subscapular	0.0062*	0.0026	-0.0008	0.0027	-0.0011	0.0025	-0.0019*	0.0006
Iliac crest	0.0011	0.0013	-0.0021	0.0019	-0.0027	0.0018	-0.0011*	0.0004
Medial calf	-0.0018	0.0022	-0.0040	0.0031	-0.0053	0.0032	-0.0013*	0.0005
Sum of five skinfolds	0.0001	0.0005	-0.0009	0.0007	-0.0011	0.0007	-0.0004*	0.0001

* P-values less than 0.05.
FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; SE, standard error.

Table 7.59 Linear regression analysis for skinfold measures associated with residual pulmonary function measures in girls (n=763)

	FVC (L)		$FEV_{0.75}$ (L)		FEV_1 (L)		FEV_1/FVC	
	β	SE	β	SE	β	SE	β	SE
Skinfold average thickness (mm)								
Triceps	0.0096*	0.0040	0.0063	0.0035	0.0071*	0.0036	-0.0003	0.0007
Biceps	0.0140*	0.0066	0.0065	0.0063	0.0078	0.0065	-0.0013	0.0013
Subscapular	0.0073*	0.0035	0.0052	0.0034	0.0057	0.0035	-0.0002	0.0006
Iliac crest	0.0049*	0.0023	0.0032	0.0020	0.0036	0.0021	-0.0002	0.0004
Medial calf	0.0063	0.0043	0.0042	0.0037	0.0047	0.0038	-0.0002	0.0007
Sum of five skinfolds	0.0018*	0.0008	0.0011	0.0008	0.0013	0.0008	-0.0001	0.0002

* P-values less than 0.05.

FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC; β, regression coefficient; SE, standard error

Table 7.60 Standardized regression coefficients (βs) for skinfold measures associated with residual lung function measures by sex*

	FVC (L)		$FEV_{0.75}$ (L)		FEV_1 (L)		FEV_1/FVC	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Skinfold average thickness (mm)								
Triceps	-0.0397	0.1491	-0.1101	0.1282	-0.1162	0.1347	-0.1457	0.0010
Biceps	-0.0146	0.1283	-0.0600	0.0780	-0.0763	0.0870	-0.1271	0.0054
Subscapular	0.0785	0.1369	-0.0115	0.1275	-0.0160	0.1301	-0.1577	0.0007
Iliac crest	0.0249	0.1402	-0.0542	0.1181	-0.0668	0.1236	-0.1616	0.0019
Medial calf	-0.0260	0.1180	-0.0682	0.1040	-0.0859	0.1080	-0.1224	0.0008
Sum of five skinfolds	0.0088	0.1474	-0.0649	0.1251	-0.0772	0.1307	-0.1580	0.0017

*n=762 for boys and n=763 for girls.

FVC, forced vital capacity; $FEV_{0.75}$, forced expiratory volume in 0.75 second; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, ratio of FEV_1 to FVC.

There was no significant correlation between any of the skinfold measures and $FEV_{0.75}$ in both sexes. Triceps skinfold was the only parameter to have a statistically significant association with FEV_1 in boys and girls. In boys, there was an inverse correlation (Table 7.58), while in girls, there was a positive association (Table 7.59).

As for the FEV_1/FVC ratio, all the skinfold parameters were inversely associated with the outcome in boys and whereas none of the measures were significantly correlated with

FEV_1/FVC ratio in girls. The best predictor of FEV_1/FVC ratio in boys was iliac crest skinfold with a standardized β coefficient value of -0.1616 (Table 7.60).

Analysis on skinfold sample stratified by sex and BMI group was also conducted. Figures 7.15-7.18 (Appendix III) show scatter plots of the skinfold measures in association with residual FVC and FEV_1 in the different sex and BMI groups. The results showed that only triceps skinfold had a significant inverse association with FVC in boys classified as normal according to the CDC BMI-for-age system, however, all of the skinfold indicators displayed inverse correlations with FVC in the overweight or obese category (Table 7.61 and Figure 7.17 in Appendix III). According to Table 7.69, which presents the standardized β values, the best predictor of FVC in overweight or obese boys was triceps skinfold. An increase of one standard deviation in the triceps skinfold was associated with a 0.39 standard deviation decline in FVC in this group.

Table 7.61 Linear regression analysis for skinfold measures associated with residual forced vital capacity (FVC) by body mass index group in boys

	Normal weight (n=573)			Overweight or obese (n=189)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	-0.0136	0.0068	0.0454	-0.0295	0.0086	0.0006
Biceps	-0.0268	0.0162	0.0983	-0.0304	0.0126	0.0155
Subscapular	0.0038	0.0151	0.8001	-0.0157	0.0050	0.0016
Iliac crest	-0.0035	0.0067	0.5989	-0.0125	0.0040	0.0017
Medial calf	-0.0114	0.0066	0.0829	-0.0186	0.0055	0.0008
Sum of five skinfolds	-0.0023	0.0022	0.3135	-0.0052	0.0015	0.0006

β, regression coefficient; SE, standard error.

In girls, no association was found between any of the skinfold measures and forced expiratory volume in both BMI categories represented by the non-significant p-values and almost horizontal lines of best fit on the scatter plots (Table 7.62 and Figures 7.16 and 7.18 in Appendix III).

Table 7.62 Linear regression analysis for skinfold measures associated with residual forced vital capacity (FVC) by body mass index group in girls

	Normal weight (n=625)			Overweight or obese (n=138)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	0.0095	0.0065	0.1431	-0.0041	0.0043	0.3488
Biceps	0.0173	0.0122	0.1567	-0.0055	0.0077	0.4765
Subscapular	0.0027	0.0069	0.6967	0.0045	0.0035	0.2066
Iliac crest	0.0039	0.0039	0.3079	0.0005	0.0028	0.8460
Medial calf	0.0027	0.0066	0.6778	0.0006	0.0034	0.8506
Sum of five skinfolds	0.0014	0.0015	0.3658	0.0002	0.0007	0.7783

β, regression coefficient; SE, standard error.

Tables 7.63 and 7.64 display the association between skinfold measures and $FEV_{0.75}$ stratified by BMI and sex. In normal weight boys and girls, none of the skinfold parameters had a statistically significant relationship with the outcome, while in the overweight or obese boys all the skinfolds had a significant inverse effect on $FEV_{0.75}$. In overweight or obese girls, only triceps skinfold had a statistically significant p-value and the association was positive. The standardized regression coefficients presented in Table 7.70, show that the best indicator for $FEV_{0.75}$ in overweight or obese boys was triceps skinfold with a value of -0.3496, which means that an increment of one standard deviation unit was correlated with 0.35 standard deviation reduction in $FEV_{0.75}$.

Table 7.63 Linear regression analysis for skinfold measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$) by body mass index group in boys

	Normal weight (n=573)			Overweight or obese (n=189)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	-0.0125	0.0072	0.0810	-0.0276	0.0068	0.0001
Biceps	-0.0203	0.0144	0.1578	-0.0268	0.0094	0.0042
Subscapular	0.0037	0.0121	0.7633	-0.0166	0.0029	0.0000
Iliac crest	-0.0051	0.0046	0.2709	-0.0112	0.0031	0.0003
Medial calf	-0.0094	0.0053	0.0789	-0.0152	0.0045	0.0007
Sum of five skinfolds	-0.0022	0.0018	0.2246	-0.0047	0.0010	0.0000

β, regression coefficient; SE, standard error.

Table 7.64 Linear regression analysis for skinfold measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$) by body mass index group in girls

	Normal weight (n=625)			Overweight or obese (n=138)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	0.0030	0.0037	0.4116	0.0056*	0.0027	0.0399
Biceps	0.0006	0.0073	0.9370	0.0019	0.0050	0.7020
Subscapular	0.0033	0.0039	0.3931	0.0040	0.0043	0.3522
Iliac crest	0.0019	0.0023	0.4126	0.0024	0.0026	0.3461
Medial calf	0.0013	0.0040	0.7526	0.0041	0.0038	0.2816
Sum of five skinfolds	0.0006	0.0009	0.4894	0.0011	0.0009	0.2238

*499 bootstrap replicates were used for variance calculation.
β, regression coefficient; SE, standard error.

Forced expiratory volume in 1 second had non-significant associations with all of the skinfold indicators in normal weight boys (Table 7.65 and Figure 7.15 in Appendix III) and girls (Table 7.66 and Figure 7.16 in Appendix III). In overweight or obese boys, all of the skinfold predictors were inversely correlated with the outcome, illustrated by the statistically significant p-values (Table 7.65) and negative slopes on the scatter plots (Figure 7.17 in Appendix III). The most important skinfold measure in this group was triceps skinfold with a standardized coefficient value of -0.3668. On the contrary, none of the relationships in the overweight or obese girls were statistically significant (Tables 7.66 and Figure 7.18 in Appendix III).

Table 7.65 Linear regression analysis for skinfold measures associated with residual forced expiratory volume in one second (FEV_1) by body mass index group in boys

	Normal weight (n=573)			Overweight or obese (n=189)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	-0.0135	0.0079	0.0879	-0.0297	0.0074	0.0001
Biceps	-0.0249	0.0159	0.1175	-0.0300	0.0101	0.0030
Subscapular	0.0034	0.0135	0.8016	-0.0183	0.0033	0.0000
Iliac crest	-0.0058	0.0055	0.2870	-0.0126	0.0035	0.0003
Medial calf	-0.0113	0.0062	0.0692	-0.0172	0.0048	0.0004
Sum of five skinfolds	-0.0025	0.0020	0.2179	-0.0053	0.0012	0.0000

β, regression coefficient; SE, standard error.

Table 7.66 Linear regression analysis for skinfold measures associated with forced expiratory volume in one second (FEV_1) by body mass index group in girls

	Normal weight (n=625)			Overweight or obese (n=138)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	0.0055	0.0044	0.2115	0.0036	0.0028	0.1869
Biceps	0.0053	0.0086	0.5387	0.0005	0.0053	0.9292
Subscapular	0.0043	0.0047	0.3676	0.0043	0.0043	0.3130
Iliac crest	0.0029	0.0026	0.2658	0.0019	0.0024	0.4377
Medial calf	0.0022	0.0046	0.6368	0.0038	0.0035	0.2767
Sum of five skinfolds	0.0010	0.0010	0.3413	0.0009	0.0008	0.2475

β, regression coefficient; SE, standard error.

In normal weight boys, significant inverse associations were found between iliac crest, sum of five skinfolds and FEV_1/FVC ratio. In the overweight or obese boys, subscapular and sum of five skinfolds were inversely correlated with the outcome (Table 7.67). According to Table 7.72, iliac crest (β_{std}=-0.0992) and subscapular skinfold (β_{std}=-0.1775) had the highest magnitude of association with the outcome in normal and overweight or obese groups, respectively.

Table 7.67 Linear regression analysis for skinfold measures associated with residual FEV_1/FVC ratio by body mass index group in boys

	Normal weight (n=573)			Overweight or obese (n=189)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	-0.0009	0.0007	0.2147	-0.0020	0.0011	0.0821
Biceps	-0.0013	0.0009	0.1603	-0.0023	0.0016	0.1580
Subscapular	-0.0006	0.0012	0.6160	-0.0018	0.0007	0.0067
Iliac crest	-0.0011	0.0004	0.0024	-0.0008	0.0004	0.0752
Medial calf	-0.0007	0.0005	0.1084	-0.0010	0.0006	0.0923
Sum of five skinfolds	-0.0003	0.0001	0.0445	-0.0004	0.0002	0.0151

β, regression coefficient; SE, standard error.

For normal weight girls, biceps skinfold had a significant inverse effect on the FEV_1/FVC ratio; meanwhile triceps skinfold had a positive association with the outcome in the overweight or obese category (Table 7.68). Their corresponding standardized coefficient values were -0.1119 for biceps skinfold and 0.2445 for triceps skinfold.

Table 7.68 Linear regression analysis for skinfold measures associated with residual FEV_1/FVC ratio by body mass index group in girls

	Normal weight (n=625)			Overweight or obese (n=138)		
	β	SE	*P*	β	SE	*P*
Skinfold average thickness (mm)						
Triceps	-0.0008	0.0007	0.2431	0.0022	0.0007	0.0008
Biceps	-0.0030	0.0012	0.0097	0.0017	0.0010	0.1048
Subscapular	0.0003	0.0006	0.6588	0.0003	0.0007	0.6362
Iliac crest	-0.0002	0.0003	0.4838	0.0004	0.0008	0.5665
Medial calf	-0.0001	0.0005	0.8061	0.0010	0.0009	0.2614
Sum of five skinfolds	-0.0001	0.0001	0.4337	0.0002	0.0002	0.2606

β, regression coefficient; SE, standard error.

Table 7.69 Standardized regression coefficients (βs) for skinfold measures associated with residual forced vital capacity (FVC) by sex and body mass index group

	Normal weight (n=1198)		Overweight or obese (n=327)	
	Boys (n=573)	Girls (n=625)	Boys (n=189)	Girls (n=138)
Skinfold average thickness (mm)				
Triceps	-0.1275*	0.1066	-0.3869*	-0.0806
Biceps	-0.1273	0.1011	-0.2701*	-0.0774
Subscapular	0.0243	0.0302	-0.2582*	0.1307
Iliac crest	-0.0490	0.0824	-0.3264*	0.0211
Medial calf	-0.1185	0.0373	-0.3003*	0.0147
Sum of five skinfolds	-0.0896	0.0775	-0.3608*	0.0218

* P-values less than 0.05.

Table 7.70 Standardized regression coefficients (βs) for skinfold measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$) by sex and body mass index group

	Normal weight (n=1198)		Overweight or obese (n=327)	
	Boys (n=573)	Girls (n=625)	Boys (n=189)	Girls (n=138)
Skinfold average thickness (mm)				
Triceps	-0.1421	0.0454	-0.3496*	0.1291*
Biceps	-0.1165	0.0045	-0.2307*	0.0316
Subscapular	0.0280	0.0502	-0.2630*	0.1365
Iliac crest	-0.0848	0.0530	-0.2836*	0.1077
Medial calf	-0.1177	0.0229	-0.2375*	0.1090
Sum of five skinfolds	-0.1034	0.0449	-0.3192*	0.1300

* P-values less than 0.05.

Table 7.71 Standardized regression coefficients (βs) for skinfold measures associated with residual forced expiratory volume in one second (FEV_1) by sex and body mass index group

	Normal weight (n=1198)		Overweight or obese (n=327)	
	Boys (n=573)	Girls (n=625)	Boys (n=189)	Girls (n=138)
Skinfold average thickness (mm)				
Triceps	-0.1441	0.0764	-0.3668*	0.0790
Biceps	-0.1342	0.0384	-0.2508*	0.0073
Subscapular	0.0245	0.0596	-0.2833*	0.1376
Iliac crest	-0.0913	0.0764	-0.3097*	0.0788
Medial calf	-0.1337	0.0370	-0.2608*	0.0966
Sum of five skinfolds	-0.1131	0.0685	-0.3450*	0.1043

* P-values less than 0.05.

Table 7.72 Standardized regression coefficients (βs) for skinfold measures associated with residual FEV_1/FVC ratio by sex and body mass index group

	Normal weight (n=1198)		Overweight or obese (n=327)	
	Boys (n=573)	Girls (n=625)	Boys (n=189)	Girls (n=138)
Skinfold average thickness (mm)				
Triceps	-0.0570	-0.0558	-0.1543	0.2445*
Biceps	-0.0413	-0.1119*	-0.1204	0.1321
Subscapular	-0.0260	0.0181	-0.1775*	0.0554
Iliac crest	-0.0992*	-0.0288	-0.1241	0.0973
Medial calf	-0.0511	-0.0108	-0.0998	0.1253
Sum of five skinfolds	-0.0705*	-0.0325	-0.1562*	0.1424

* P-values less than 0.05.

8. DISCUSSION

8.1 Adiposity and Lung Function in Adults

For adults, our findings demonstrate that there are significant differences in the association between adiposity and respiratory function among men and women and among the different BMI groups. In normal weight men, weight, BMI, and hip circumference were all positively associated with FVC and FEV_1. This means that increases in these three measures resulted in an improved pulmonary function within the normal BMI range (BMI<25.0). In normal weight women, however, none of weight, BMI, waist circumference, hip circumference and waist-to-hip ratio were significantly correlated with FVC and FEV_1.

In overweight men, waist circumference and waist-to-hip ratio had significant inverse associations with FVC and FEV_1, while weight, BMI and hip circumference were all non-significant in the prediction of FVC and FEV_1. Both, waist circumference and waist-to-hip ratio had a very similar effect on FVC and FEV_1. In overweight women, waist circumference and waist-to-hip ratio were both significantly associated with FVC with both having a very similar impact. For FEV_1, the waist-to-hip ratio was a significant predictor, while waist circumference showed borderline significance. The influence of waist circumference and waist-to-hip ratio on FVC and FEV_1 was not significantly different between men and women. An increase of 1 cm in waist circumference was correlated with about a 19 mL decline in FVC and 11 mL decline in FEV_1 among overweight men and about 12 mL decline in FVC and 7 mL decline in FEV_1 among overweight women.

All the body fat measures under investigation had significant inverse relationships with FVC and FEV_1 in obese men. Waist circumference was the most important negative predictor for both of these lung-testing variables. In general, increasing the waist circumference by 1 cm was associated with 14 mL decline in FVC and 11 mL decline in

FEV_1 in obese men. In obese women, only weight, BMI and hip circumference were inversely correlated with FVC and just BMI and hip circumference with FEV_1. BMI had the strongest influence on both outcome variables. On average, a unit rise in BMI was correlated with 15 mL decline in FVC and 9 mL decline in FEV_1 in obese women. Overall, adiposity had a differential effect on pulmonary function in obese men and obese women.

Similar to previous observations,[4, 36, 51, 89] weight and BMI had a positive impact on FVC and FEV_1 in adults with normal weight and had an inverse correlation with the lung function testing variables in the obese group. In fact, the relationship between weight, BMI and lung function is "u-shaped". Thus, pulmonary function at first improves with increasing weight or BMI, referred to as the 'muscularity effect', and then declines with further increase in weight or BMI, representing the 'obesity effect'.[31, 50] Waist circumference and waist-to-hip ratio were important predictors of lung dysfunction in overweight men and women, and in obese men. Several studies have observed related findings where waist circumference and waist-to-hip ratio were inversely correlated with FVC and FEV_1 in men.[36, 52, 53] For women, the evidence is inconsistent because, in contrast to the present study, most studies have not conducted stratified analysis by BMI. Some analyses have shown no significant relationship of waist circumference, and/or waist-to-hip ratio with pulmonary function in women,[5, 22, 31, 63] while others have shown an inverse association of these predictors with lung function testing variables.[36, 52, 53, 90, 91]

Our findings demonstrate that the most important adiposity measures for respiratory function vary with sex and BMI group. In overweight men and women, both waist circumference and waist-to-hip ratio predicted FVC and FEV_1 equally well. However, in the obese men, the best predictor of FVC and FEV_1 was waist circumference, while the most important indicator in obese women was BMI. The presence of a significant association between waist circumference, waist-to-hip ratio and FEV_1 and FVC in obese men only supports the hypothesis that adiposity has varying effects on pulmonary function in males and females due to differing pattern of fat distribution.[55] Fat deposition in men occurs on the central or upper body, meanwhile in women, it occurs on the peripheral or lower body.[92]

None of the adiposity factors had a significant effect on the FEV_1/FVC ratio within any of the sex and BMI groups. This is because the adiposity indices had a similar impact on FVC and FEV_1, resulting in no influence on the FEV_1/FVC ratio. Previous literature has also shown no significant association of BMI and waist circumference with FEV_1/FVC.[36]

No significant relationship was observed between any of the skinfold measures and pulmonary function testing variables (FVC and FEV_1) in normal weight men. In the overweight category, all of the skinfold predictors demonstrated significant inverse associations with FVC and all, except for the skinfold thickness assessed at the iliac crest, had an inverse correlation with FEV_1.

In normal weight women, all skinfold measures were inversely associated with FVC and FEV_1 except for iliac crest and medial calf. For the overweight group of women, all predictors were significant, except for triceps and medial calf in association with FVC and triceps, iliac crest and medial calf with FEV_1. The skinfold measures did not show a significant influence on the ratio of FEV_1/FVC in normal weight men and women and in overweight men, although in overweight women, subscapular, iliac crest and sum of five skinfolds were significant positive predictors of FEV_1/ FVC. Therefore, in adult male participants, and normal weight adult female participants, the effect of skinfold indices on FVC and FEV_1 was similar, resulting in no relationship with FEV_1/FVC. Meanwhile, in women that were overweight, the inverse effect of subscapular, iliac crest and sum of five skinfolds was much stronger on FVC than FEV_1 resulting in increased FEV_1/FVC ratio.

Overall, increases in skinfold measures were correlated with lower pulmonary function in women, while no relationship between the two was observed in normal weight men. On the other hand, skinfold parameters were more strongly associated with impaired lung function in overweight men as compared to overweight women. Among overweight women, skinfold measures had a much stronger correlation with lung volume indicated by FVC than airway size, which is reflected by FEV_1.

The results suggest that the most important predictor of pulmonary function was subscapular skinfold for adiposity in men. On average, a 1 mm increase in subscapular skinfold was associated with about a 27 mL decline in FVC and 19 mL decline in FEV_1. In fact, subscapular skinfold was the only significant independent variable, when entered along with either waist circumference or waist-to-hip ratio, for predicting lung function (FVC and FEV_1) in the overweight. When sum of five skinfolds was entered in the regression models with either waist circumference or waist-to-hip ratio, both terms tended to be significant, with the exception of regression equation for FEV_1, where waist circumference was not a significant predictor. In adult females, sum of five skinfolds had the strongest influence on lung function testing variables (FVC and FEV_1) in the overweight, although biceps and subscapular skinfold also affected pulmonary function to similar extent. An increment of 1 mm in sum of five skinfolds resulted in a 4.5 mL decline in FVC and 2.6 mL decline in FEV_1. Entering the sum of five skinfolds along with either waist circumference or waist-to-hip ratio led to only skinfold term being significant except when waist-to-hip ratio and sum of five skinfolds were added to predict FVC. In that case, both independent variables were significant. Replacing sum of five skinfold with subscapular skinfold resulted in only skinfold term being significant in all the models. This indicates that subscapular skinfold, measuring subcutaneous fat on the chest wall, is a better predictor of lung function than other anthropometric measures in overweight subjects.

There were four previous studies that were comparable with our findings; however, the quality of these investigations was poor. One very small study of 53 people showed that there was an inverse relationship between subscapular skinfold and FVC in men.[54] It also found that triceps skin fold had an inverse effect on FEV_1, while suprailiac (iliac crest) skinfold was inversely associated with FEV_1 and FVC in men.[54] Another investigation, with a sample of 932 persons aged 40–50 years, found that FVC and FEV_1 decreased with rising subscapular skinfold thickness in women and both abdominal and subscapular skinfold led to a decline in FVC in adult male participants.[22] Lazarus et al., examining the effect of adiposity on FVC only in a sample of 1235 adults, showed that FVC was inversely correlated with subscapular skinfold in both sexes.[63] A longitudinal examination in 507 men aged 30-79, showed that subscapular skinfold had an inverse effect on FVC and FEV_1 in men aged 30 to 59 years but not in the 60-79 age group, suggesting that age modifies the association.[92] Although the abovementioned studies have examined the same relationships as the present examination, each of them has a major shortcoming – the first study has a very small sample size, the second one has a very narrow age range, the third one has a male only sample, and the fourth one uses only FVC as the outcome variable. Thus, our study removes some of the doubt surrounding the associations between skinfold measures and pulmonary function due to its large, population-based study sample.

Concurrent with previous findings, our data suggest that in men lung function (FVC and FEV_1) is not only inversely affected by visceral fat (indicated by waist circumference) but also subcutaneous fat especially on the chest wall (indicated by subscapular skinfold). It was also observed that subscapular skinfold inversely affected pulmonary function to a greater extent than waist circumference. Among women, waist circumference and waist-to-hip ratio impaired respiratory function in overweight participants, while BMI in the obese. Lung function in women was also affected by overall subcutaneous fat indicated by sum of five skinfolds. In fact, the sum of five skinfolds was the best indicator of decline in lung function due to adiposity in overweight women. Therefore, skinfold measurements offer a significant advantage over anthropometric measurements for examining the association between adiposity and pulmonary function in overweight people.

8.2 Adiposity and Lung Function in Children

Among children, our data stratified by BMI and sex, illustrated that BMI was positively associated with FVC, $FEV_{0.75}$ and FEV_1 in normal weight boys. All the other adiposity indices were non-significant. For FVC and FEV_1 in normal weight female children, all adiposity measures were important positive predictors except for waist-to-hip ratio. With $FEV_{0.75}$, waist circumference and waist-to-hip ratio did not show a significant positive relationship. A unit increment in BMI was associated with about a 33 mL increase in FVC, 22 mL increase in $FEV_{0.75}$, and 24 mL increase in FEV_1 among boys and 37mL increase in FVC, 20 mL increase in $FEV_{0.75}$ and 24 mL increase in FEV_1 among girls. The sex differences for these parameters were not significant.

In the case of overweight or obese boys, waist circumference and waist-to-hip ratio were the only parameters to have a significant inverse association with both FVC and FEV_1. $FEV_{0.75}$ was not significantly affected by any of the adiposity factors, although waist-to-hip ratio showed borderline significance. In girls, only BMI had a significant positive effect on FVC. None of the adiposity indices had an important impact on $FEV_{0.75}$ and FEV_1.

The ratio of FEV_1/FVC was inversely affected by waist-to-hip ratio in normal weight boys because WHR had a positive association with FVC and an inverse association with FEV_1. No other relationship was statistically significant. In normal weight girls, BMI, waist circumference and waist-to-hip ratio displayed an inverse relationship with FEV_1/FVC ratio. Similar to the results in boys, waist-to-hip ratio had a positive correlation with FVC and an inverse correlation with FEV_1 leading to an inverse correlation with the ratio. BMI and waist circumference had a positive relationship with both FVC and FEV_1, but the relationship was much stronger with FVC, leading to an inverse association with the ratio of FEV_1/FVC.

Overall, the effect of adiposity on pulmonary function is only seen in overweight boys with waist-to-hip ratio being the most important predictor. Similar conclusions were drawn by another study of 1 586 children, where a positive relationship was observed between BMI and lung function in normal and overweight girls. Likewise, a positive correlation was observed in normal weight boys but not in the overweight group.[49]

Other reports have also examined the effect of adiposity on pulmonary function in children; however, the results have not been stratified by BMI category. Thus we compared our combined analysis with previous investigations. The combined results indicated that BMI and waist circumference were positively associated with FVC and FEV_1 in girls and with FVC only in boys. Also the ratio of FEV_1/FVC was inversely correlated with BMI in both sexes. Similar to our results, Chu *et al.* in a cross-sectional study of 14 654 children ages 13 to 16, showed that increases in BMI were associated with an increase in FVC and FEV_1 in both sexes, whereas FEV_1/FVC declined with increasing BMI in both male and female children.[45] A randomized clinical trial of 1 041 asthmatic children noted higher FVC and FEV_1 and lower FEV_1/FVC values with increasing BMI.[93] A study of Canadian children aged 6-17 years conducted by Chen *et al.* reported that waist circumference was positively associated with FVC and FEV_1 in children.[94] Another study in students between the ages of 8 and 20 illustrated that lung function improved with increasing BMI in children 8-11 years old, but in older children and youth, FVC and FEV_1 levels reached a plateau and actually declined in children with the largest BMI values.[95]

One potential mechanism that helps to explain our results is the differing pattern of fat distribution in males and females. Obese girls tend to deposit fat peripherally whereas obese boys tend to deposit fat in the abdominal region, which may lead to reduction in FVC and FEV_1 by decrease in expiratory reserve volume.[49] Since BMI cannot distinguish between different types of body tissue, it may indicate the strength of respiratory muscles thus explaining the positive relationship in normal weight children. However, in overweight or obese individuals, BMI represents body fat more closely.[49]

For skinfold analysis in children, it was observed that triceps skinfold was the only measure to have an important inverse effect on FVC in normal weight boys. In overweight or obese boys, all the skinfold measures had a significant inverse association with FVC with triceps skinfold exhibiting the strongest correlation. An increase of 1 mm in this skinfold resulted in about a 14 mL decline in FVC in normal weight boys and approximately a 30 mL decline in FVC among overweight or obese participants. This difference was not statistically significant. In girls, skinfold measures seemed to have no impact on FVC in normal weight and overweight or obese groups.

$FEV_{0.75}$ was not affected by skinfold parameters in both normal weight boys and girls. All the skinfold parameters were significant inverse predictors of $FEV_{0.75}$ in overweight or obese male children. Again triceps skinfold had the strongest impact on overweight or obese males, where a 1 mm increase in the skinfold was associated with a 28 mL decline in $FEV_{0.75}$.

However, in overweight or obese girls, triceps skinfold was positively associated with $FEV_{0.75}$.

Skinfold indices had no effect on FEV_1 in normal weight boys and girls and overweight or obese girls. Conversely in overweight or obese boys, all of the skinfold measures had a significant inverse impact on FEV_1 and triceps skinfold demonstrated the strongest association leading to about a 30 mL decline in FEV_1 with every 1 mm increment in it.

One previous investigation[47] has carried out a skinfold analysis in 9, 12 and 15-year-old children. The authors calculated total body fat percentage (TBF%) for each subject using sex-specific regression equations based on skinfold measurements and found an inverse correlation between TBF% and height- and weight-adjusted FVC and FEV_1 for each age and sex group. Almost the same results were found when sum of skinfolds (biceps, triceps, subscapular and suprailiac) was used. In our findings, an inverse relationship was not observed between skinfold measures and respiratory function in females, which could have been the result of having excluded individuals with $BMI \geq 30 kg/m^2$ from the skinfold analysis.

The results for the correlation between skinfold indices and ratio of FEV_1/FVC were quite varied. Iliac crest and sum of five skinfolds were important inverse predictors of FEV_1/FVC ratio in normal weight male children, while subscapular and sum of five skinfold were significantly correlated with the ratio of FEV_1/FVC in overweight or obese boys. This was due to the fact that these measures had a stronger inverse relationship with FEV_1 as compared with FVC leading to a negative impact on the ratio. In normal weight girls, only biceps skinfold had an inverse relationship with the ratio of FEV_1/FVC because this skinfold had a much stronger positive correlation with FVC than FEV_1. On the contrary, in overweight or obese female children, triceps skinfold had a positive effect on FEV_1/FVC, since it was inversely correlated with FVC and positively with FEV_1.

The results of children's data demonstrate that adiposity is linked with impaired pulmonary function in boys only. Lung function testing variables in boys were affected by both anthropometric measures (waist circumference and waist-to-hip ratio) and skinfold measures. The most important skinfold indicator was triceps skinfold. This skinfold measure negatively affected FVC in normal weight boys, and it was the strongest predictor of FVC, $FEV_{0.75}$ and FEV_1 in overweight or obese male children. Triceps skinfold also showed a stronger inverse correlation with respiratory function as compared to any other skinfold and anthropometric measure. When triceps skinfold and either waist circumference or waist-to-hip ratio were entered into the equations for predicting FVC, $FEV_{0.75}$, and FEV_1, triceps skinfold was the only significant term in all the models for overweight or obese boys with BMI lower than $30 kg/m^2$. Adiposity was not associated with impaired lung function in female children.

8.3 Obesity and Respiratory Physiology

There are a number of possible mechanisms for the relationship between adiposity and deteriorated pulmonary function. These include overall stiffening of the respiratory system (reduced compliance), which means a decrease in the ability of the lungs and chest to expand.[96] In fact, total respiratory compliance can be reduced to about one-third of normal values in the obese.[97] This significant decline in total compliance occurs due to several reasons including the build-up of intra-abdominal adipose tissue, which may have a mechanical effect on the diaphragm preventing full descent.[3, 96] Also, "the deposition of fat on the chest wall may impede expansion and excursion of the rib cage, through a direct loading effect or by altering intercostal muscle function." [3] Besides the effects on the diaphragm and the chest wall, lung compliance is also reduced, which may be due to the increase in pulmonary blood volume or airway closure in the dependent zones leading to small regions of atelectasis (alveolar collapse).[96] The increase in blood volume observed in obese individuals is an adaptation to the higher metabolic demand produced by the excess weight.[98]

Excess body fat may also reduce lung function through inflammatory pathways. Higher levels of adipose tissue have been linked with an increased level of the adipokine leptin, which besides regulating energy intake/expenditure, plays a role in inflammation.[3] Leptin receptors are present in the lungs, where leptin may exert direct pro-inflammatory effects, leading to smaller airway size.[3]

Obesity is also a risk factor for chronic respiratory diseases and complications including hypoventilation,[97] obstructive sleep apnea,[97, 99] asthma,[100] and chronic obstructive pulmonary disease (COPD).[101] Although, the mechanistic basis of these associations are not completely understood, there are several hypotheses, notably regarding the possible role of adipokines, leptin and adiponectin.[102] Leptin levels increase with obesity and lead to greater systemic and airway inflammation, which may be associated with pathogenesis of asthma and COPD.[102, 103] Moreover, lower levels of serum adiponectin in obese individuals, have been related to an increased risk of asthma because, in contrast to leptin, adiponection exhibits anti-inflammatory properties.[104]

The sex difference in pulmonary dysfunction due to adiposity may be explained by the differing pattern of fat distribution in males and females.[55] Fat deposition in males is in the truncal or upper body region, whereas in females, it is peripheral or in the lower body.[92] The central pattern of fat distribution is likely to have a mechanical effect on diaphragm and chest wall, whereas fat on the hips and thighs is unlikely to have any direct effect on the lungs. However, even when waist circumference and waist-to-hip ratio were used to adjust for the effect of fat distribution pattern on lung impairment, significant inverse effects were observed only in obese males. A possible explanation is that since men tend to have a much higher percentage of adipose tissue in the viscera, their waist circumference and waist-to-hip ratio mainly measure intra-abdominal fat deposits, which reduce respiratory compliance.[22] By contrast, in women, these measures primarily represent subcutaneous adiposity on the abdomen and hips, which has little effect on lung function.[22]

The differences in associations of various adiposity measures with lung function testing variables were due to variation in what these indicators measure. For instance, BMI is a global measure of body mass that incorporates both lean and fat tissue and does not consider dissimilarities in pattern of fat distribution, thus it has been shown to have weak associations with lung function. On the other hand, waist circumference and waist-to-hip ratio are abdominal fat measures and they are stronger predictors of lung dysfunction as compared to BMI, especially among men. They are less satisfactory measures for women and children because central obesity is not common among these groups. Skinfolds measure subcutaneous fat on various regions of the body depending on the measurement site. Subscapular, biceps or triceps skin fold thickness are markers of thoracic or upper body fat, while overall adiposity is indicated by sum of skinfolds. Skinfold measures seemed to be the most sensitive in predicting poor lung function. It is likely because they estimate body fat and are least related to body size, which positively predicts pulmonary function.

8.4 Strengths and Limitations of Current Study

As far as know, this was the first study examining the association between anthropometric and skinfold measures with pulmonary function in a large population-based Canadian sample. Moreover, since the skinfold method is sensitive to measurement technique and to the type of caliper used, the field staff was given a significant amount of survey-specific training, which primarily focused on the standardization of all the procedures.[69] Also, the Harpenden caliper was used, which is considered as the gold standard for skin fold measurement and has been widely used in research.[105] Another advantage is that the anthropometric measures have very high reproducibility in adults and children, as indicated by previous literature.[106, 107] Although skinfold measurements are less reproducible,[108] several steps were taken in order to ensure high reproducibility including limiting measurements to respondents with BMI<30kg/m^2, taking duplicate readings at each site, and marking each skinfold site and the location where the upper edge of the caliper jaws would be placed.

Additionally, the skinfold method is only an indicator of subcutaneous fat and it does not measure abdominal fat, which can have a major effect on the overall body fat levels of individuals. Instead it assumes that the thickness of subcutaneous adipose tissue represents a constant proportion of the total body fat.[109] Hence, waist circumference, and waist-to-hip ratio of people were also included in the analyses.

The present study also has some limitations. First of all, a major limitation of the current examination is the fact that the Canadian Health Measures Survey (CHMS) was a cross-sectional study, which means that we cannot infer causality and cannot determine temporal changes. It only allows for an assessment to be made at a single point in time.[44] A longitudinal study would be better because it can evaluate changes in pulmonary function with regards to body composition over time.[44] This would allow us to make conclusions with more certainty and to have a deeper understanding of the relationships. However, the major drawback to longitudinal studies is that they are more expensive to carry out and that they take time to complete. Another drawback of this study was that the skinfold measurements were limited to participants with BMI<30 kg/m^2 because of the reduced reliability of the measurement in obese individuals. Consequently, the relationship between skinfold measurement and pulmonary function could not be determined for individuals with BMI≥30 kg/m^2.

8.5 Significance of Present Findings

Our results showed that obesity explained about 4-6% of the total variance in lung function measures (FVC and FEV_1) for adults. To put this into perspective, exposure to environmental tobacco smoke (ETS) has been linked to about a 3% deficit in adult lung function.[110] Outdoor air pollution, specifically an increase of 10 μg/m^3 in annual mean concentration of PM_{10} (particulate matter <10 micrometers in diameter) has been associated with a about a 2-5% decline in FEV_1 and about a 3% reduction in FVC.[111]

The magnitude of these effects may be important at the population level. Data modeling has indicated that a 3% downward shift in the distribution of lung function measure, FVC for example, may result in about a 50% rise in prevalence of FVC ≤ 80%.[112] Such a substantial increase in number of people with low lung function might be important from a public health point of view.[112]

From a clinical standpoint, the concept of minimal important difference (MID) has been recommended. It is defined as “the smallest difference in score in the outcome of interest that informed patients or informed proxies perceive as important, either beneficial or harmful, and which would lead the patient or clinician to consider a change in management.”

[113] "The MID should optimally be determined in a population of subjects similar to that in which the MID is to be applied."[113] However, the MID for FVC and FEV_1 in populations with obesity has not yet been established.

9. CONCLUSIONS

The findings of the present study provide convincing evidence that adiposity is associated with lung dysfunction, and that this relationship is modified by age, sex and BMI. In men both abdominal and subcutaneous fat deposits on the thorax led to impaired lung function. Women were predominately affected by overall measures of fatness, specifically body mass index and sum of five skinfolds. In both sexes, the respective skinfold measures exhibited the strongest inverse correlation with ventilatory function.

This is one of the few studies to provide evidence that excess body fat among male children is associated with poor lung function. The findings showed that adiposity in boys was also correlated with low respiratory function, while in girls a significant relationship was absent. Pulmonary function was affected by both abdominal and subcutaneous fat in the boys. The best indicator of adiposity influencing lung function in this group was triceps skinfold.

Overall, this in depth examination of adiposity and pulmonary function found skinfolds to be more sensitive measures of adiposity. However, the question of whether skinfolds are good predictors of lung function in obese individuals remains uncertain.

10. FUTURE DIRECTIONS

Longitudinal studies examining the effects of different levels of adiposity on lung function in children and adults separately, will help us elucidate the complex relationship between these two parameters and will also provide more validity to the associations observed in this study. Future studies are also needed to help us understand the clinical relevance of the magnitudes of the relationships observed in the present investigation and how do they map onto respiratory complications. At this stage, interventions are needed to reduce overweight and obesity especially among men, women and boys since our study illustrates that adiposity impairs pulmonary function by reducing lung volume and airway size.

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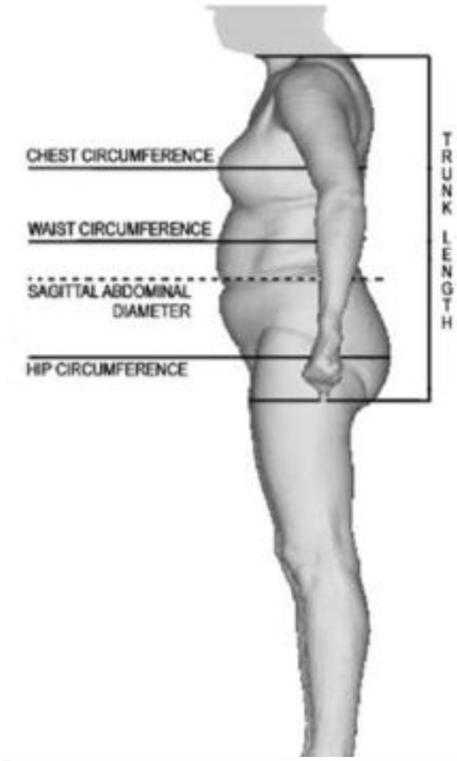
APPENDIX I

Illustrations

(a)



(b)

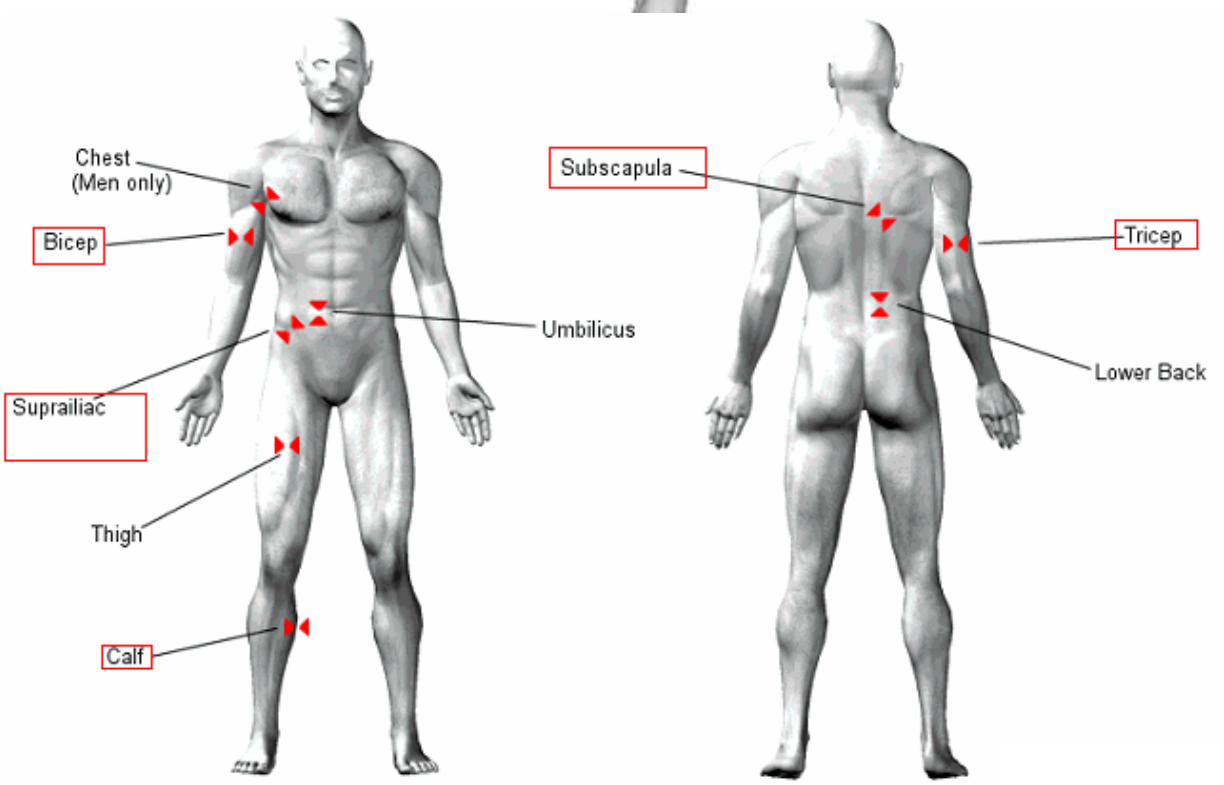
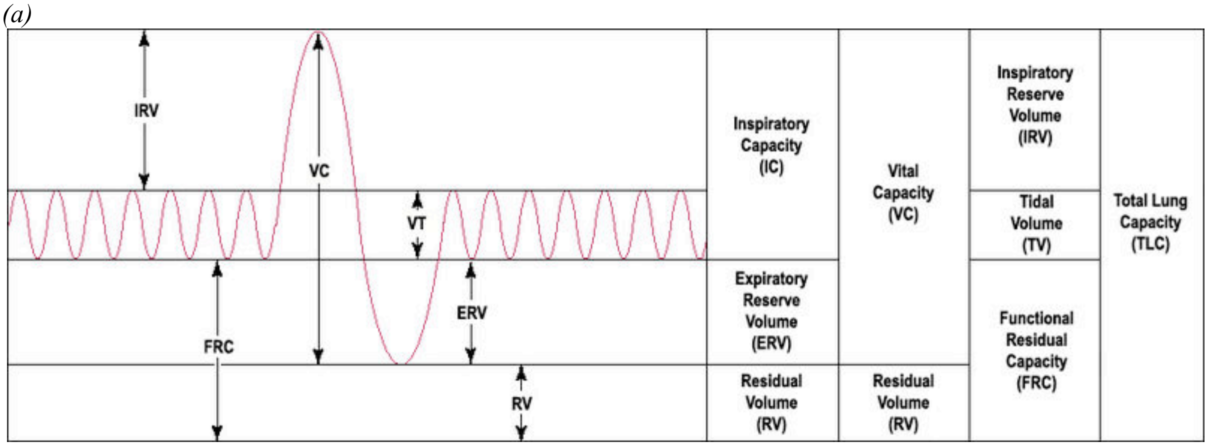


Figure 1.1(a) Some common anthropometric measurements. *Source: Chambers EC, Heshka S, Huffaker LY, et al. Truncal adiposity and lung function in older black women. Lung 2008; 186:13-17.Copyright with permission.*

Figure 1.1(b) Various skinfold measuring sites. All measurements are taken on the right side of the body and the red arrows illustrate the direction of the pinch. The locations measured for the purpose of this study are shown in red boxes. *Source: http://www.getfit-121.co.uk/showarticle.php?mode=18. Copyright with permission.*

(a)



(b)

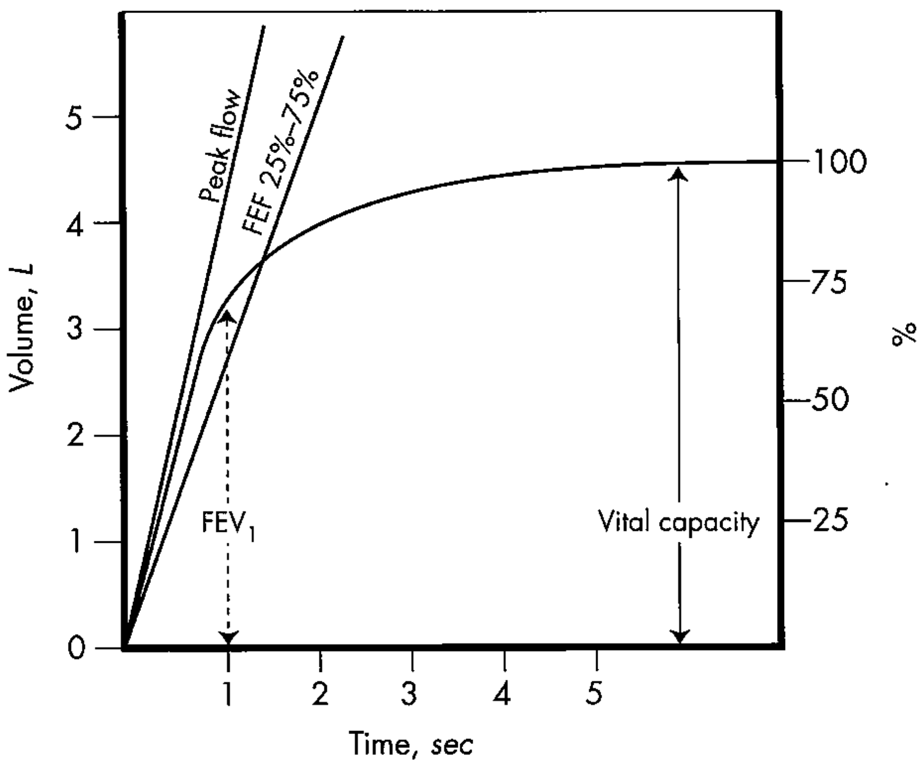


Figure 1.2(a) Various static lung volume parameters.
Source: http://en.wikipedia.org/wiki/Spirometry
Figure 1.2(b) Schematic of a normal spirogram showing the measurements of vital capacity (VC), forced expired volume in one second (FEV_1) and Forced Expiratory Flow between 25–75% of FVC ($FEF_{25\text{-}75\%}$, also known as Maximal Mid-Expiratory Flow (MMEF). *Source: Fleisher, Lee, Lichtor, J. et al. Preoperative Evaluation. Atlas of Anesthesia 2002; 3: 2-ACA0301-03-016A. Copyright with kind permission of Springer Science and Business Media.*

APPENDIX II

Detailed Results from Regression Analysis

The Adult Sample

Table A.1 Linear regression analysis for anthropometric measures associated with residual forced vital capacity (FVC (L)) in men (n=1605)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Weight (kg)	-0.0045	0.0020	0.0251	0.0149	-0.0043	0.0021	0.0431	0.0325
Body mass index (kg/m^2)	-0.0168	0.0059	0.0040	0.0180	-0.0157	0.0064	0.0135	0.0345
Waist circumference (cm)	-0.0074	0.0019	0.0001	0.0296	-0.0072	0.0022	0.0011	0.0454
Hip circumference (cm)	-0.0128	0.0034	0.0002	0.0145	-0.0076	0.0037	0.0412	0.0319
Waist-to-hip ratio	-1.4923	0.4083	0.0003	0.0228	-1.0999	0.2854	0.0001	0.0393

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.2 Linear regression analysis for anthropometric measures associated with residual forced vital capacity (FVC (L)) in women (n=1803)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Weight (kg)	-0.0041	0.0007	<0.0001	0.0231	-0.0039	0.0007	<0.0001	0.0388
Body mass index (kg/m^2)	-0.0112	0.0024	<0.0001	0.0245	-0.0106	0.0023	<0.0001	0.0398
Waist circumference (cm)	-0.0050	0.0009	<0.0001	0.0303	-0.0047	0.0010	<0.0001	0.0448
Hip circumference (cm)	-0.0054	0.0012	<0.0001	0.0223	-0.0050	0.0012	0.0001	0.0376
Waist-to-hip ratio	-0.7269	0.2325	0.0018	0.0168	-0.6946	0.2504	0.0055	0.0335

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.3 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1 (L)) in men (n=1605)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Weight (kg)	-0.0013	0.0014	0.3400	0.0018	-0.0013	0.0013	0.3128	0.0515
Body mass index (kg/m^2)	-0.0049	0.0043	0.2507	0.0021	-0.0046	0.0042	0.2687	0.0515
Waist circumference (cm)	-0.0036	0.0014	0.0110	0.0093	-0.0034	0.0013	0.0110	0.0577
Hip circumference (cm)	-0.0104	0.0036	0.0034	0.0016	-0.0025	0.0022	0.2543	0.0516
Waist-to-hip ratio	-1.3290	0.6401	0.0379	0.0119	-0.6464	0.2390	0.0068	0.0591

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.4 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1 (L)) in women (n=1803)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Weight (kg)	-0.0015	0.0007	0.0395	0.0040	-0.0014	0.0006	0.0309	0.0544
Body mass index (kg/m^2)	-0.0043	0.0020	0.0299	0.0047	-0.0040	0.0019	0.0314	0.0550
Waist circumference (cm)	-0.0026	0.0008	0.0007	0.0102	-0.0022	0.0008	0.0033	0.0584
Hip circumference (cm)	-0.0023	0.0012	0.0450	0.0055	-0.0024	0.0011	0.0285	0.0567
Waist-to-hip ratio	-0.4541	0.1496	0.0024	0.0085	-0.3174	0.1660	0.0559	0.0550

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.5 Linear regression analysis for anthropometric measures associated with residual FEV_1/FVC ratio in men (n=1605)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Weight (kg)	0.0004	0.0001	0.0060	0.0091	0.0004	0.0001	0.0065	0.0584
Body mass index (kg/m^2)	0.0015	0.0004	0.0005	0.0110	0.0014	0.0004	0.0002	0.0602
Waist circumference (cm)	0.0004	0.0002	0.0180	0.0058	0.0004	0.0001	0.0051	0.0565
Hip circumference (cm)	-0.0006	0.0004	0.1663	0.0084	0.0006	0.0003	0.0220	0.0569
Waist-to-hip ratio	-0.0592	0.0708	0.4033	0.0009	0.0356	0.0294	0.2263	0.0526

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.6 Linear regression analysis for anthropometric measures associated with residual FEV_1/ FVC ratio in women (n=1803)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Weight (kg)	0.0005	0.0001	<0.0001	0.0146	0.0005	0.0001	<0.0001	0.1046
Body mass index (kg/m^2)	0.0013	0.0003	0.0001	0.0145	0.0012	0.0004	0.0005	0.1042
Waist circumference (cm)	0.0004	0.0001	0.0023	0.0078	0.0004	0.0001	0.0011	0.1009
Hip circumference (cm)	0.0005	0.0002	0.0008	0.0102	0.0004	0.0002	0.0094	0.0982
Waist-to-hip ratio	0.0255	0.0227	0.2614	0.0009	0.0596	0.0223	0.0075	0.0965

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

The Adult Skinfold Sample

Table A.7 Linear regression analysis between skinfold measures and residual forced vital capacity (FVC (L)) in men (n=1203)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Skinfold average thickness (mm)								
Triceps	-0.0197	0.0062	0.0014	0.0189	-0.0198	0.0070	0.0048	0.0313
Biceps	-0.0500	0.0100	<0.0001	0.0320	-0.0520	0.0114	<0.0001	0.0461
Subscapular	-0.0177	0.0028	<0.0001	0.0490	-0.0182	0.0036	<0.0001	0.0623
Iliac crest	-0.0057	0.0020	0.0044	0.0086	-0.0056	0.0027	0.0362	0.0209
Medial calf	-0.0148	0.0045	0.0010	0.0128	-0.0147	0.0049	0.0025	0.0255
Sum of five skinfolds	-0.0043	0.0009	<0.0001	0.0291	-0.0045	0.0011	0.0001	0.0420

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.8 Linear regression analysis between skinfold measures and residual forced vital capacity (FVC (L)) in women (n=1345)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Skinfold average thickness (mm)								
Triceps	-0.0070	0.0024	0.0040	0.0103	-0.0063	0.0027	0.0216	0.0269
Biceps	-0.0149	0.0043	0.0005	0.0218	-0.0139	0.0043	0.0014	0.0371
Subscapular	-0.0063	0.0013	<0.0001	0.0180	-0.0059	0.0012	0.0000	0.0335
Iliac crest	-0.0061	0.0022	0.0059	0.0150	-0.0054	0.0021	0.0090	0.0303
Medial calf	-0.0043	0.0022	0.0498	0.0056	-0.0040	0.0024	0.1014	0.0235
Sum of five skinfolds	-0.0020	0.0005	0.0001	0.0194	-0.0019	0.0006	0.0009	0.0346

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.9 Linear regression analysis between skinfold measures and residual forced expiratory volume in one second (FEV_1 (L)) in men (n=1203)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Skinfold average thickness (mm)								
Triceps	-0.0075	0.0058	0.1974	0.0036	-0.0096	0.0065	0.1402	0.0514
Biceps	-0.0177	0.0081	0.0280	0.0052	-0.0235	0.0090	0.0087	0.0546
Subscapular	-0.0099	0.0034	0.0038	0.0199	-0.0115	0.0040	0.0038	0.0710
Iliac crest	-0.0003	0.0022	0.9054	0.0000	-0.0014	0.0026	0.5741	0.0465
Medial calf	-0.0068	0.0042	0.0999	0.0035	-0.0083	0.0043	0.0542	0.0509
Sum of five skinfolds	-0.0017	0.0009	0.0663	0.0056	-0.0022	0.0011	0.0369	0.0553

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.10 Linear regression analysis between skinfold measures and residual forced expiratory volume in one second (FEV_1 (L)) in women (n=1345)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Skinfold average thickness (mm)								
Triceps	-0.0017	0.0019	0.3513	0.0008	-0.0022	0.0019	0.2459	0.0491
Biceps	-0.0052	0.0025	0.0400	0.0033	-0.0046	0.0026	0.0784	0.0503
Subscapular	-0.0024	0.0009	0.0061	0.0033	-0.0024	0.0008	0.0019	0.0510
Iliac crest	-0.0015	0.0012	0.2091	0.0011	-0.0014	0.0011	0.1864	0.0489
Medial calf	-0.0005	0.0021	0.8119	0.0001	-0.0011	0.0019	0.5761	0.0483
Sum of five skinfolds	-0.0006	0.0003	0.0914	0.0020	-0.0006	0.0003	0.0662	0.0500

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.11 Linear regression analysis between skinfold measures and residual FEV_1/FVC ratio in men (n=1203)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Skinfold average thickness (mm)								
Triceps	0.0013	0.0005	0.0104	0.0058	0.0009	0.0004	0.0357	0.0484
Biceps	0.0040	0.0011	0.0002	0.0139	0.0032	0.0009	0.0005	0.0540
Subscapular	0.0006	0.0005	0.2082	0.0039	0.0004	0.0005	0.4463	0.0470
Iliac crest	0.0007	0.0003	0.0050	0.0103	0.0005	0.0002	0.0236	0.0500
Medial calf	0.0010	0.0005	0.0338	0.0037	0.0007	0.0004	0.0999	0.0474
Sum of five skinfolds	0.0003	0.0001	0.0062	0.0095	0.0002	0.0001	0.0311	0.0499

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

Table A.12 Linear regression analysis between skinfold measures and residual FEV_1/FVC ratio in women (n=1345)

	Crude				Adjusted*			
	β	SE	*P*	R^2	β	SE	*P*	R^2
Skinfold average thickness (mm)								
Triceps	0.0010	0.0004	0.0041	0.0090	0.0007	0.0004	0.0634	0.0914
Biceps	0.0015	0.0004	0.0005	0.0093	0.0015	0.0005	0.0055	0.0955
Subscapular	0.0007	0.0002	0.0009	0.0082	0.0006	0.0002	0.0061	0.0926
Iliac crest	0.0009	0.0003	0.0006	0.0146	0.0008	0.0003	0.0036	0.0974
Medial calf	0.0008	0.0003	0.0141	0.0075	0.0005	0.0003	0.1175	0.0904
Sum of five skinfolds	0.0003	0.0001	0.0004	0.0143	0.0002	0.0001	0.0077	0.0962

*Adjusted for smoking, physical activity, second-hand smoke, and vitamin D level.
β, regression coefficient; SE, standard error.

The Children Sample

Table A.13 Linear regression analysis for anthropometric measures associated with residual forced vital capacity (FVC (L)) in boys (n=789)

	β	SE	*P*	R^2
Weight (kg)	0.0019	0.0010	0.0725	0.0096
Body mass index (kg/m^2)	0.0137	0.0059	0.0211	0.0260
Waist circumference (cm)	0.0027	0.0014	0.0485	0.0082
Hip circumference (cm)	0.0029	0.0013	0.0275	0.0096
Waist-to-hip ratio	0.2791	0.3426	0.4153	0.0015

β, regression coefficient; SE, standard error.

Table A.14 Linear regression analysis for anthropometric measures associated with residual forced vital capacity (FVC (L)) in girls (n=794)

	β	SE	*P*	R^2
Weight (kg)	0.0044	0.0010	0.0000	0.0453
Body mass index (kg/m^2)	0.0245	0.0042	0.0000	0.0970
Waist circumference (cm)	0.0065	0.0011	0.0000	0.0542
Hip circumference (cm)	0.0050	0.0013	0.0001	0.0376
Waist-to-hip ratio	0.8475	0.1765	0.0000	0.0199

β, regression coefficient; SE, standard error.

Table A.15 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$ (L)) in boys (n=789)

	β	SE	*P*	R^2
Weight (kg)	0.0008	0.0009	0.3496	0.0026
Body mass index (kg/m^2)	0.0057	0.0039	0.1394	0.0064
Waist circumference (cm)	0.0004	0.0012	0.7694	0.0002
Hip circumference (cm)	0.0014	0.0010	0.1926	0.0030
Waist-to-hip ratio	-0.4256	0.3469	0.2199	0.0049

β, regression coefficient; SE, standard error.

Table A.16 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$ (L)) in girls (n=794)

	β	SE	*P*	R^2
Weight (kg)	0.0022	0.0008	0.0070	0.0199
Body mass index (kg/m^2)	0.0125	0.0044	0.0045	0.0442
Waist circumference (cm)	0.0029	0.0014	0.0399	0.0181
Hip circumference (cm)	0.0025	0.0010	0.0144	0.0170
Waist-to-hip ratio	0.2278	0.2660	0.3917	0.0025

β, regression coefficient; SE, standard error.

Table A.17 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1 (L)) in boys (n=789)

	β	SE	*P*	R^2
Weight (kg)	0.0007	0.0009	0.4234	0.0018
Body mass index (kg/m^2)	0.0053	0.0039	0.1738	0.0050
Waist circumference (cm)	0.00005	0.0011	0.9644	0.0000
Hip circumference (cm)	0.0012	0.0010	0.2244	0.0022
Waist-to-hip ratio	-0.5251	0.3381	0.1204	0.0066

β, regression coefficient; SE, standard error.

Table A.18 Linear regression analysis for anthropometric measures associated with residual forced expiratory volume in one second (FEV_1 (L)) in girls (n=794)

	β	SE	*P*	R^2
Weight (kg)	0.0026	0.0008	0.0017	0.0230
Body mass index (kg/m^2)	0.0144	0.0044	0.0012	0.0508
Waist circumference (cm)	0.0033	0.0013	0.0104	0.0209
Hip circumference (cm)	0.0030	0.0010	0.0041	0.0204
Waist-to-hip ratio	0.2325	0.2283	0.3084	0.0023

β, regression coefficient; SE, standard error.

Table A.19 Linear regression analysis for anthropometric measures associated with residual FEV_1/FVC ratio in boys (n=789)

	β	SE	*P*	R^2
Weight (kg)	-0.0002	0.0001	0.1018	0.0055
Body mass index (kg/m^2)	-0.0016	0.0007	0.0280	0.0159
Waist circumference (cm)	-0.0006	0.0002	0.0055	0.0178
Hip circumference (cm)	-0.0003	0.0002	0.1093	0.0053
Waist-to-hip ratio	-0.2049	0.0473	0.0000	0.0361

β, regression coefficient; SE, standard error.

Table A.20 Linear regression analysis for anthropometric measures associated with residual FEV_1/FVC ratio in girls (n=794)

	β	SE	*P*	R^2
Weight (kg)	-0.0004	0.0001	0.0176	0.0115
Body mass index (kg/m^2)	-0.0019	0.0006	0.0020	0.0239
Waist circumference (cm)	-0.0007	0.0002	0.0051	0.0216
Hip circumference (cm)	-0.0004	0.0002	0.0302	0.0095
Waist-to-hip ratio	-0.1293	0.0668	0.0530	0.0186

β, regression coefficient; SE, standard error.

The Children Skinfold Sample

Table A.21 Linear regression analysis for skinfold measures associated with residual forced vital capacity (FVC (L)) in boys (n=762)

	β	SE	*P*	R^2
Skinfold average thickness (mm)				
Triceps	-0.0031	0.0022	0.1591	0.0016
Biceps	-0.0019	0.0038	0.6127	0.0002
Subscapular	0.0062	0.0026	0.0185	0.0062
Iliac crest	0.0011	0.0013	0.4110	0.0006
Medial calf	-0.0018	0.0022	0.4071	0.0007
Sum of five skinfolds	0.0001	0.0005	0.7651	0.0001

β, regression coefficient; SE, standard error.

Table A.22 Linear regression analysis for skinfold measures associated with residual forced vital capacity (FVC (L)) in girls (n=763)

	β	SE	*P*	R^2
Skinfold average thickness (mm)				
Triceps	0.0096	0.0040	0.0161	0.0222
Biceps	0.0140	0.0066	0.0329	0.0165
Subscapular	0.0073	0.0035	0.0341	0.0187
Iliac crest	0.0049	0.0023	0.0297	0.0197
Medial calf	0.0063	0.0043	0.1453	0.0139
Sum of five skinfolds	0.0018	0.0008	0.0319	0.0217

β, regression coefficient; SE, standard error.

Table A.23 Linear regression analysis for skinfold measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$ (L)) in boys (n=762)

	β	SE	*P*	R^2
Skinfold average thickness (mm)				
Triceps	-0.0074	0.0041	0.0680	0.0121
Biceps	-0.0068	0.0056	0.2261	0.0036
Subscapular	-0.0008	0.0027	0.7777	0.0001
Iliac crest	-0.0021	0.0019	0.2754	0.0029
Medial calf	-0.0040	0.0031	0.1978	0.0047
Sum of five skinfolds	-0.0009	0.0007	0.2110	0.0042

β, regression coefficient; SE, standard error.

Table A.24 Linear regression analysis for skinfold measures associated with residual forced expiratory volume at 0.75 seconds ($FEV_{0.75}$ (L)) in girls (n=763)

	β	SE	*P*	R^2
Skinfold average thickness (mm)				
Triceps	0.0063	0.0035	0.0721	0.0164
Biceps	0.0065	0.0063	0.3049	0.0061
Subscapular	0.0052	0.0034	0.1255	0.0163
Iliac crest	0.0032	0.0020	0.1222	0.0139
Medial calf	0.0042	0.0037	0.2473	0.0108
Sum of five skinfolds	0.0011	0.0008	0.1377	0.0157

β, regression coefficient; SE, standard error.

Table A.25 Linear regression analysis for skinfold measures associated with residual forced expiratory volume in one second (FEV_1 (L)) in boys (n=762)

	β	SE	*P*	R^2
Skinfold average thickness (mm)				
Triceps	-0.0083	0.0040	0.0391	0.0135
Biceps	-0.0091	0.0057	0.1103	0.0058
Subscapular	-0.0011	0.0025	0.6565	0.0003
Iliac crest	-0.0027	0.0018	0.1335	0.0045
Medial calf	-0.0053	0.0032	0.1000	0.0074
Sum of five skinfolds	-0.0011	0.0007	0.1051	0.0060

β, regression coefficient; SE, standard error.

Table A.26 Linear regression analysis for skinfold measures associated with residual forced expiratory volume in one second (FEV_1 (L)) in girls (n=763)

	β	SE	*P*	R^2
Skinfold average thickness (mm)				
Triceps	0.0071	0.0036	0.0490	0.0181
Biceps	0.0078	0.0065	0.2355	0.0076
Subscapular	0.0057	0.0035	0.1020	0.0169
Iliac crest	0.0036	0.0021	0.0855	0.0153
Medial calf	0.0047	0.0038	0.2120	0.0117
Sum of five skinfolds	0.0013	0.0008	0.1022	0.0171

β, regression coefficient; SE, standard error.

Table A.27 Linear regression analysis for skinfold measures associated with residual FEV_1/FVC ratio in boys (n=762)

	β	SE	*P*	R^2
Skinfold average thickness (mm)				
Triceps	-0.0017	0.0008	0.0321	0.0212
Biceps	-0.0025	0.0011	0.0273	0.0161
Subscapular	-0.0019	0.0006	0.0025	0.0249
Iliac crest	-0.0011	0.0004	0.0044	0.0261
Medial calf	-0.0013	0.0005	0.0216	0.0150
Sum of five skinfolds	-0.0004	0.0001	0.0085	0.0250

β, regression coefficient; SE, standard error.

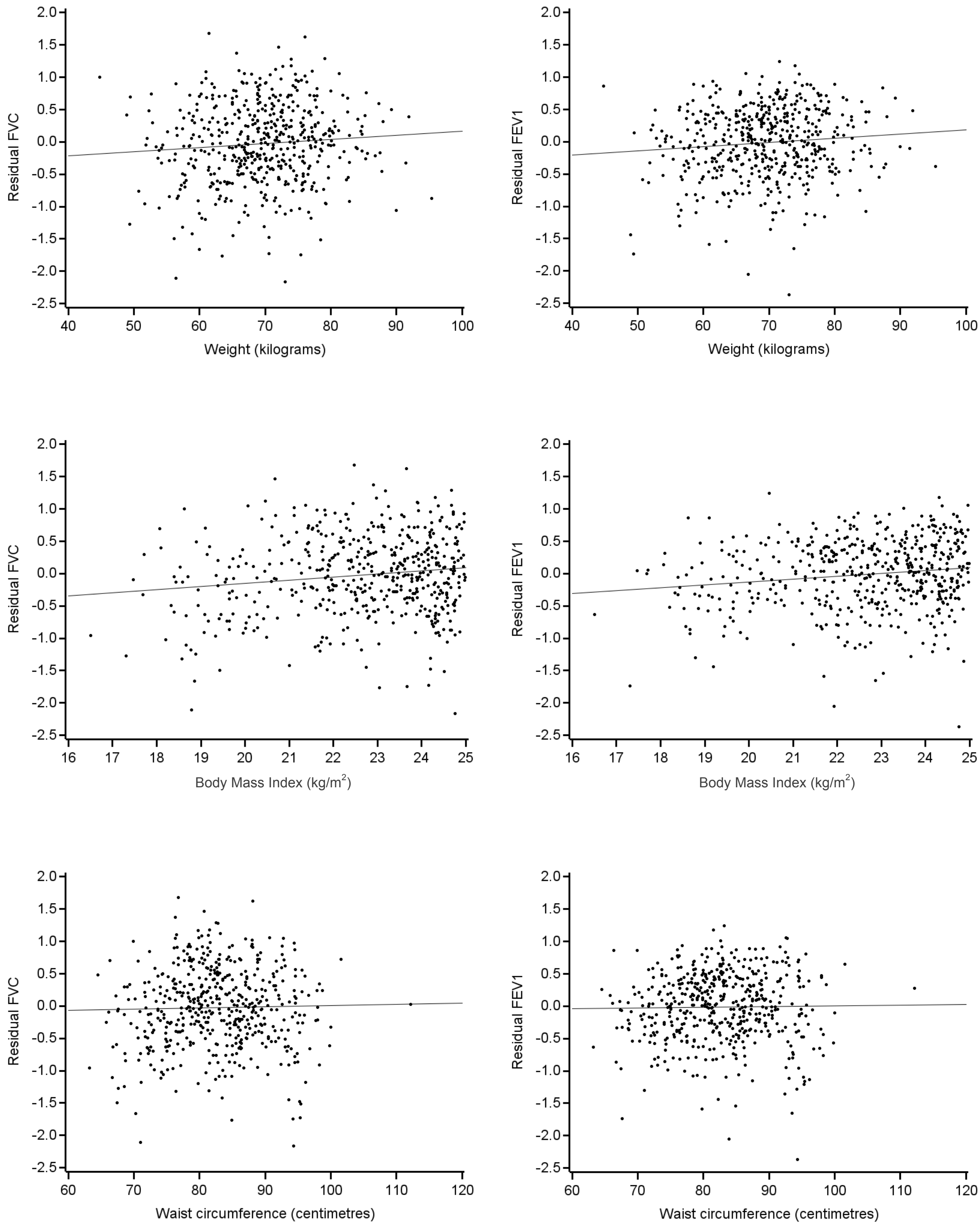
Table A.28 Linear regression analysis for skinfold measures associated with residual FEV_1/FVC ratio in girls (n=763)

	β	SE	*P*	R^2
Skinfold average thickness (mm)				
Triceps	-0.0003	0.0007	0.6434	0.0010
Biceps	-0.0013	0.0013	0.3384	0.0054
Subscapular	-0.0002	0.0006	0.7210	0.0007
Iliac crest	-0.0002	0.0004	0.5786	0.0019
Medial calf	-0.0002	0.0007	0.7262	0.0008
Sum of five skinfolds	-0.0001	0.0002	0.6068	0.0017

β, regression coefficient; SE, standard error.

APPENDIX III

Figures


Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m2)
Residual FEV1
Body Mass Index (kg/m2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

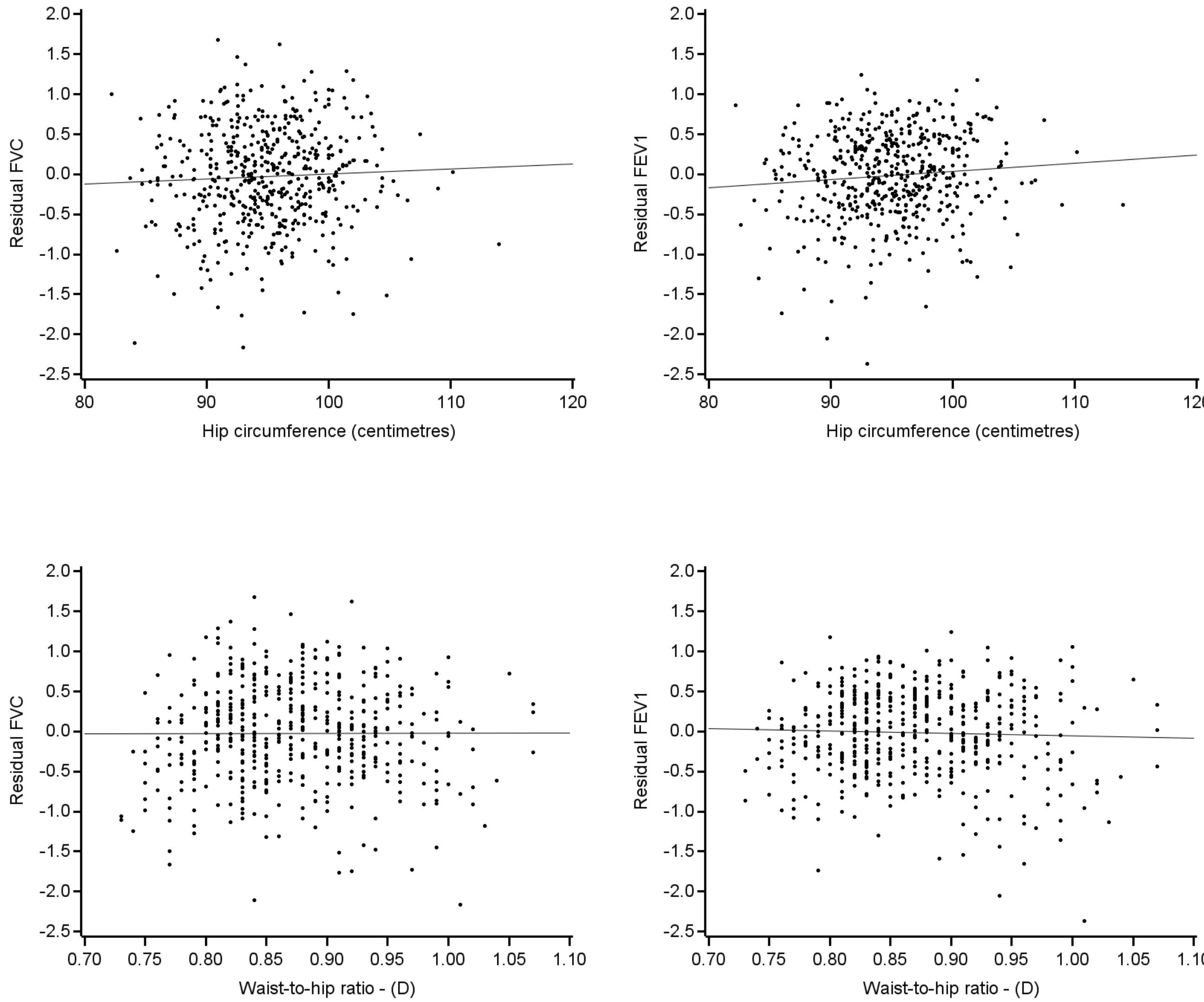
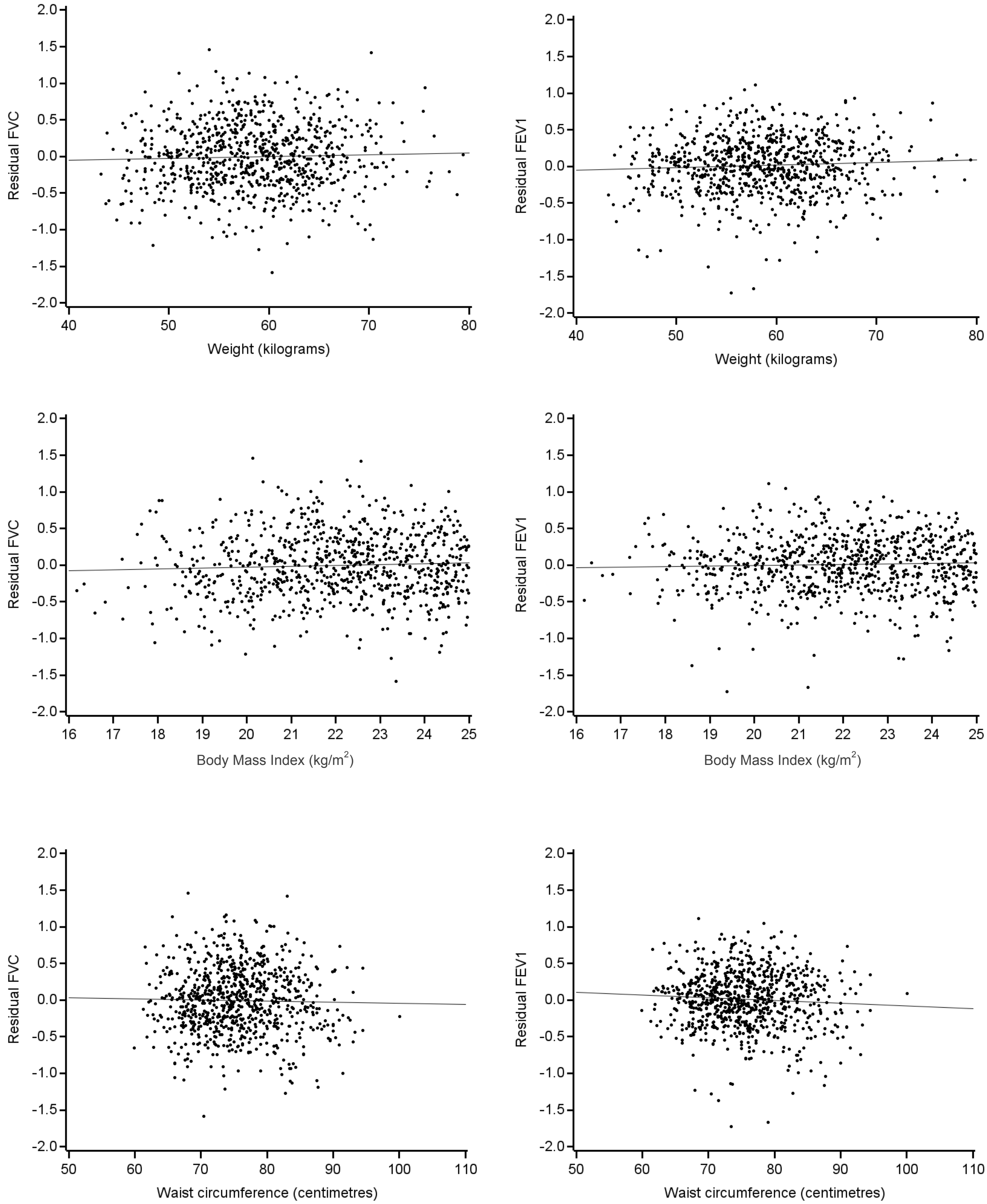


Figure 7.1 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV_1 in normal weight men.


Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m2)
Residual FEV1
Body Mass Index (kg/m2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

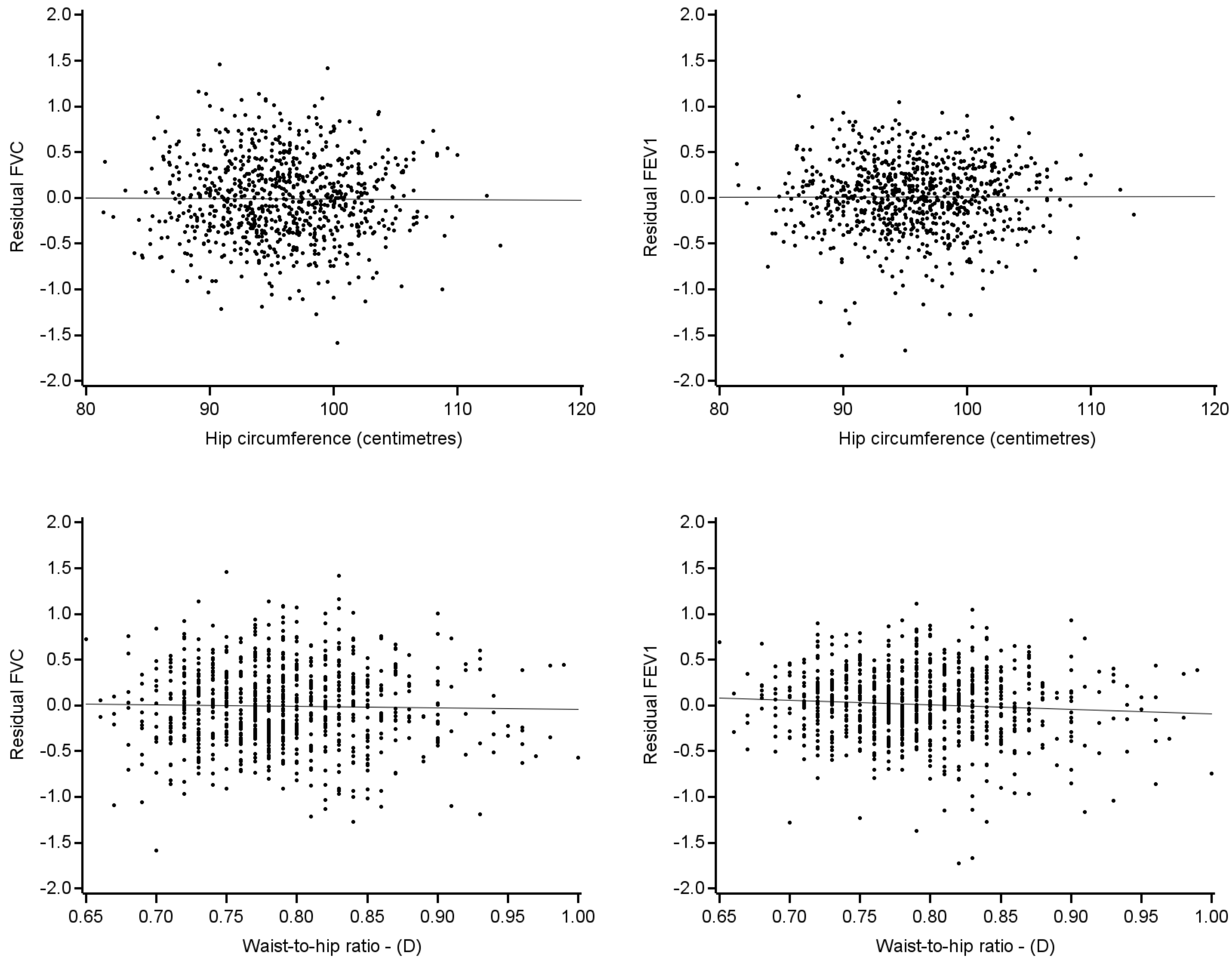
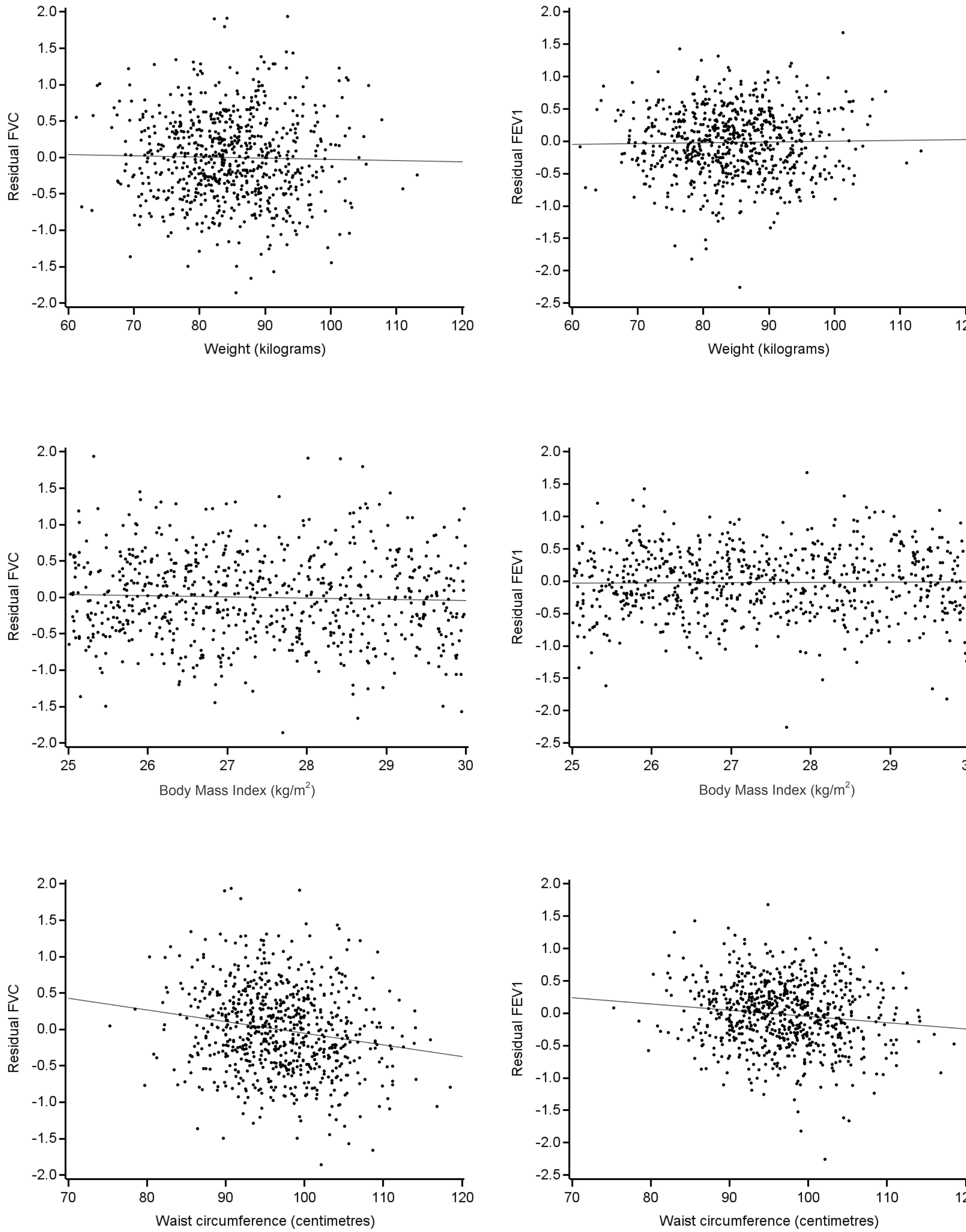


Figure 7.2 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV_1 in normal weight women.



Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m2)
Residual FEV1
Body Mass Index (kg/m2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

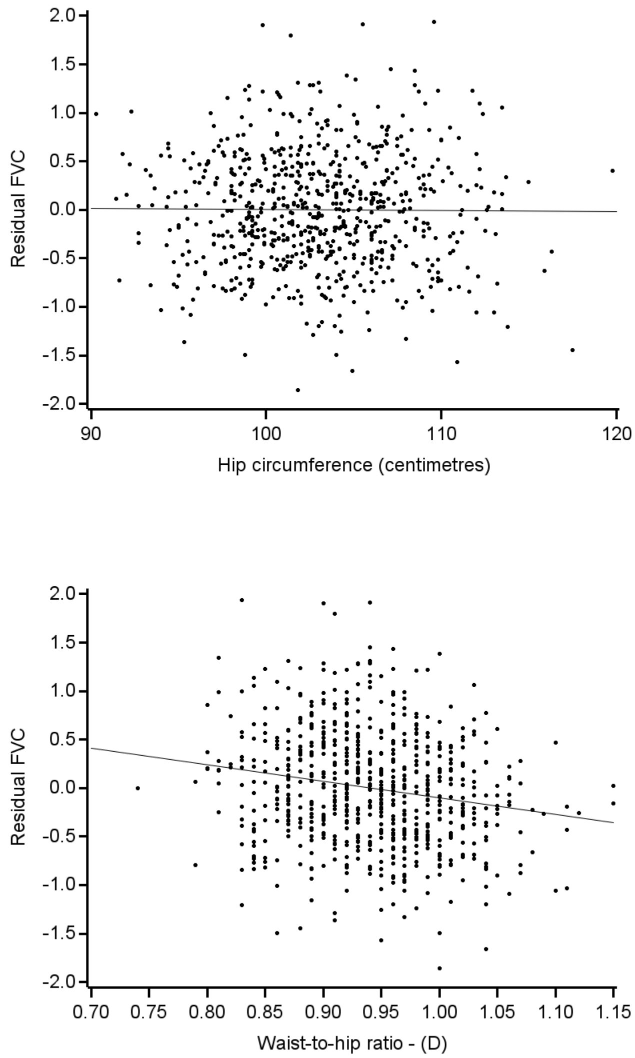
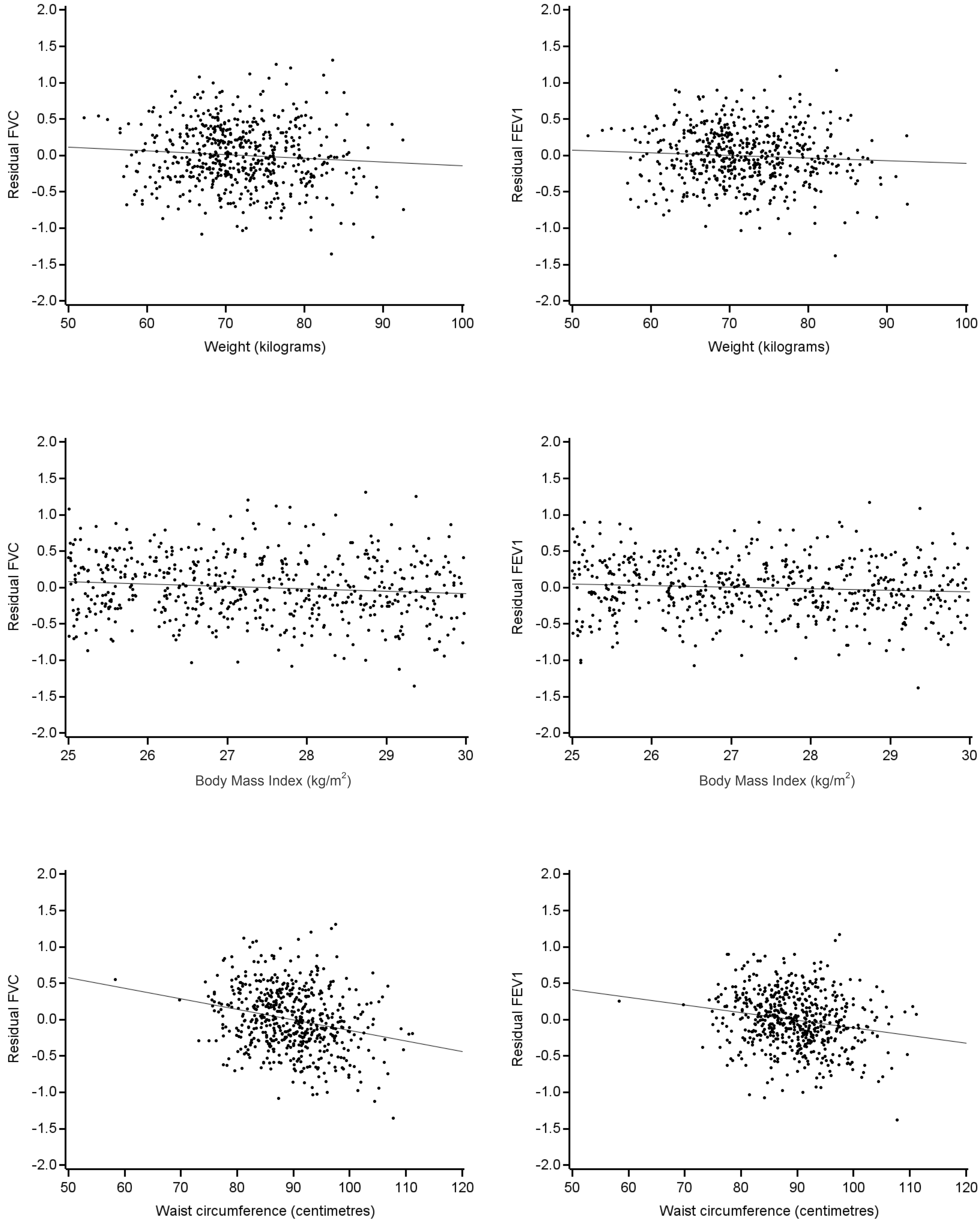


Figure 7.3 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV$_1$ in overweight men.


Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m2)
Residual FEV1
Body Mass Index (kg/m2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

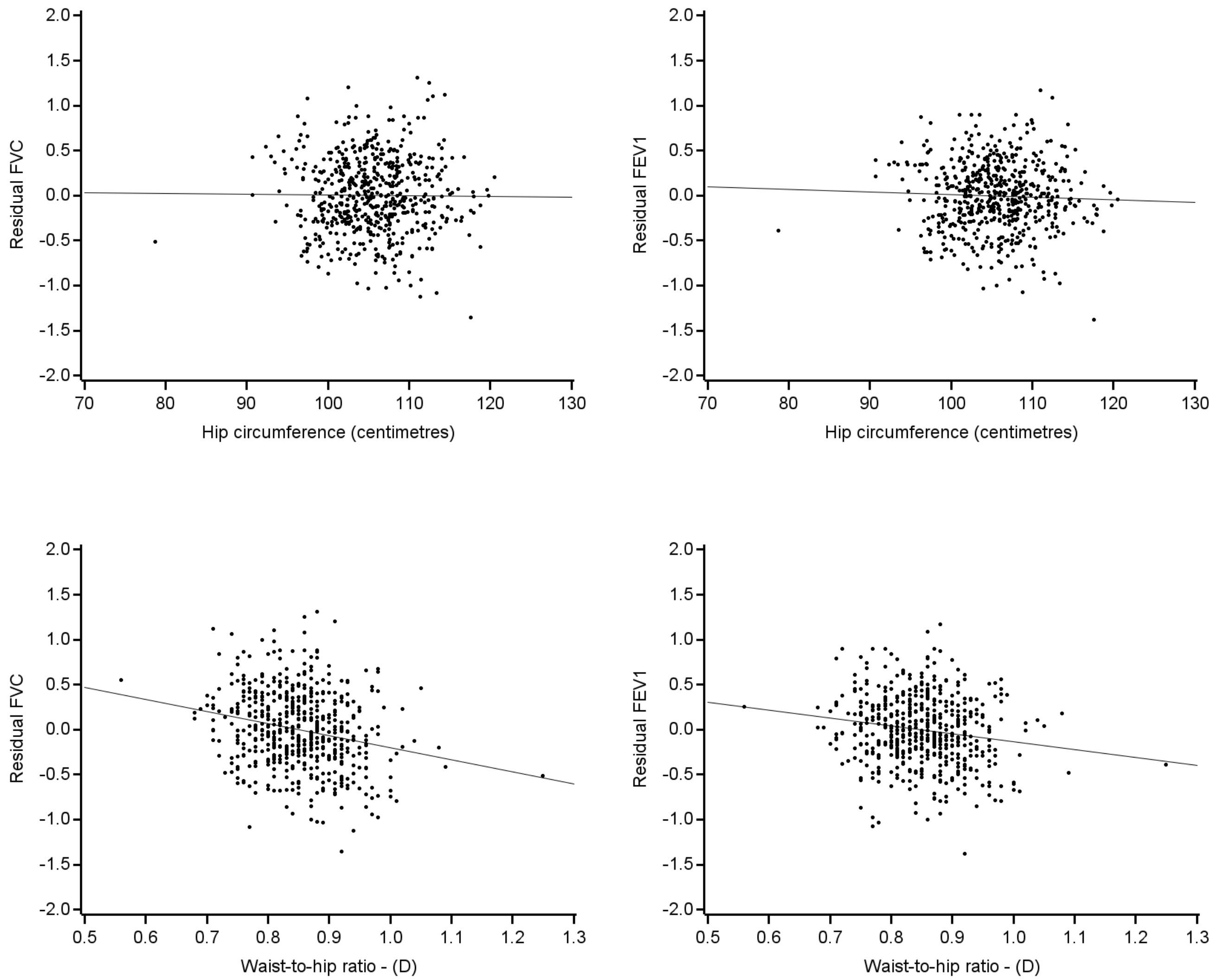
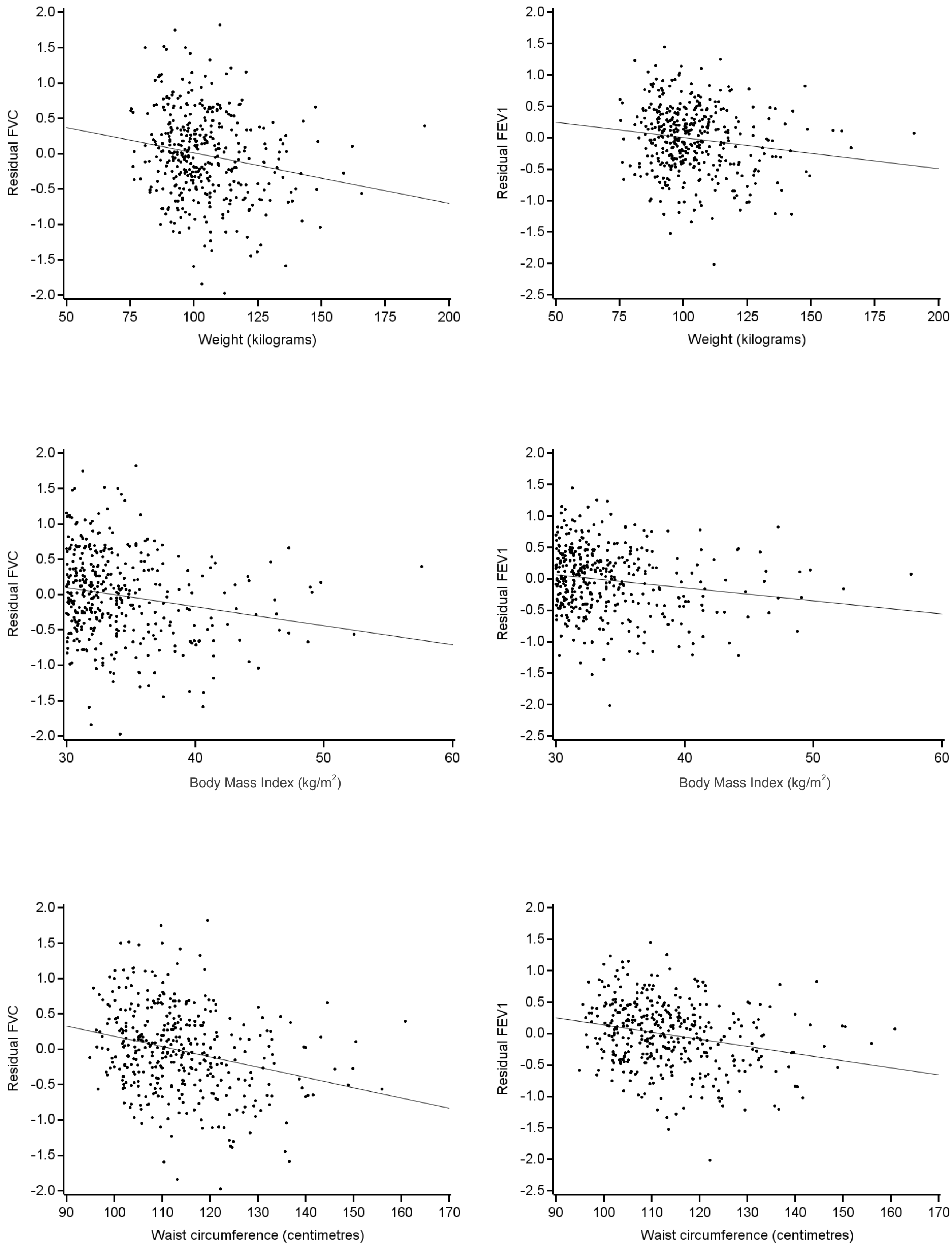


Figure 7.4 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV_1 in overweight women.


Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m2)
Residual FEV1
Body Mass Index (kg/m2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

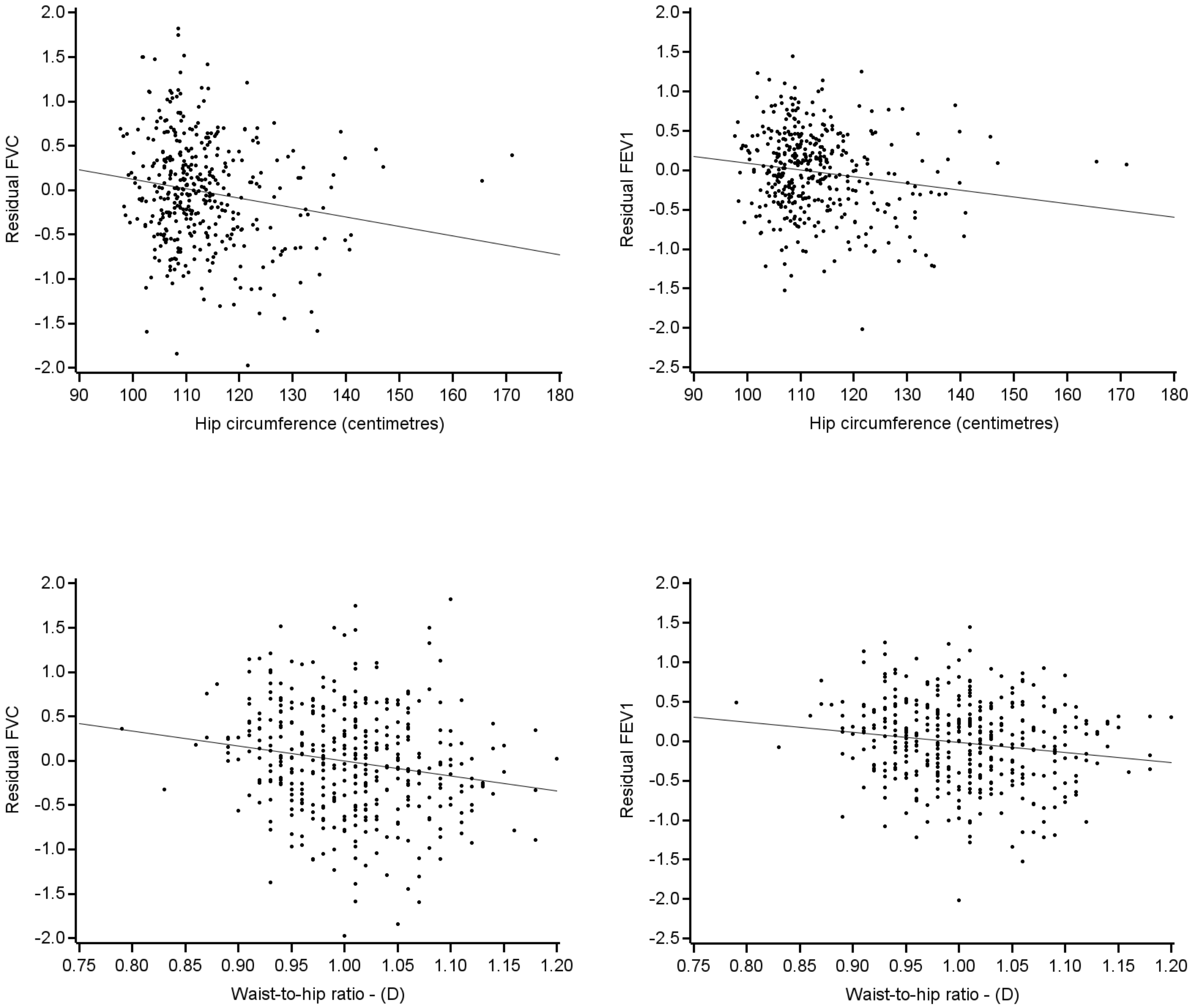
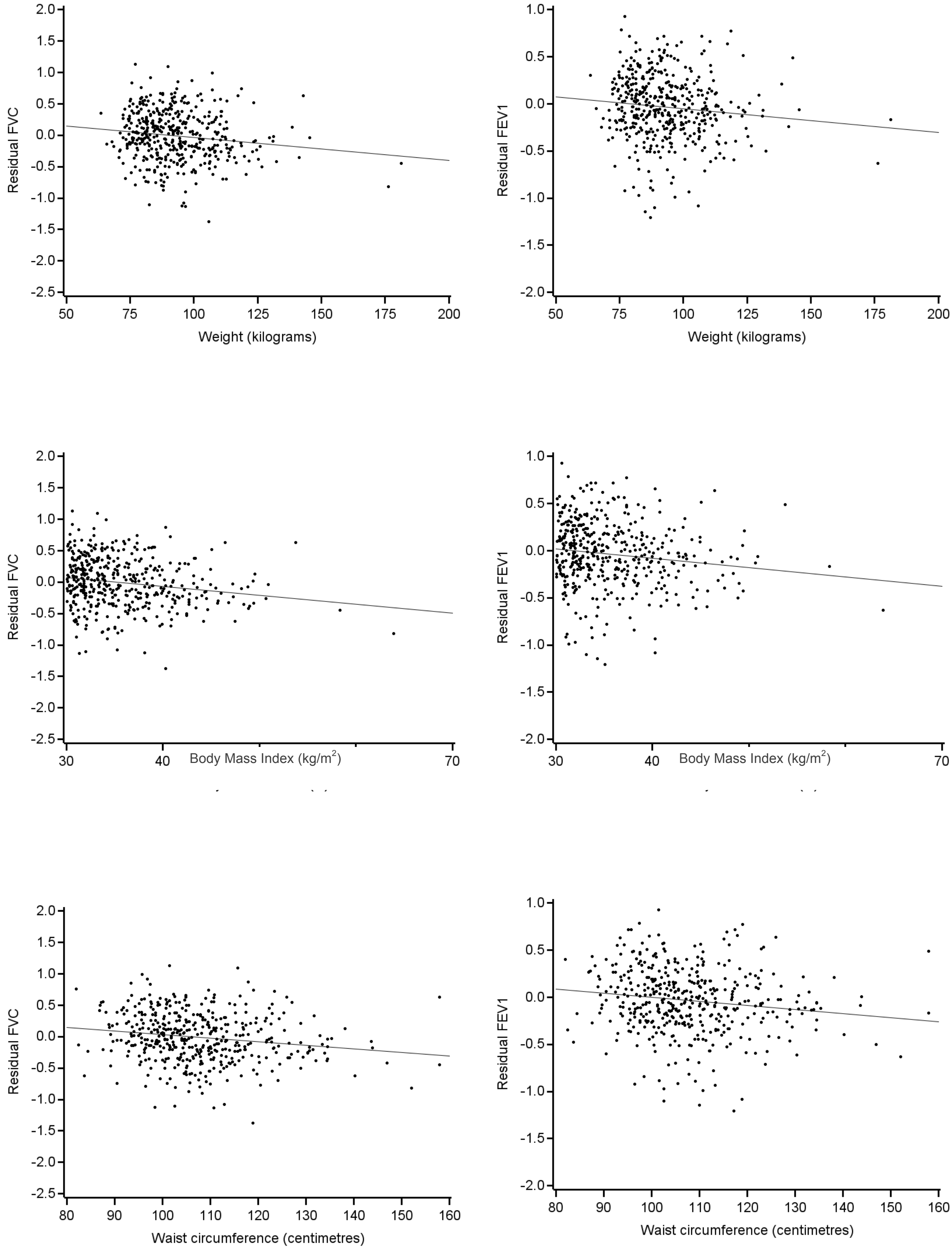


Figure 7.5 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV_1 in obese men.


Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m^2)
Residual FEV1
Body Mass Index (kg/m^2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

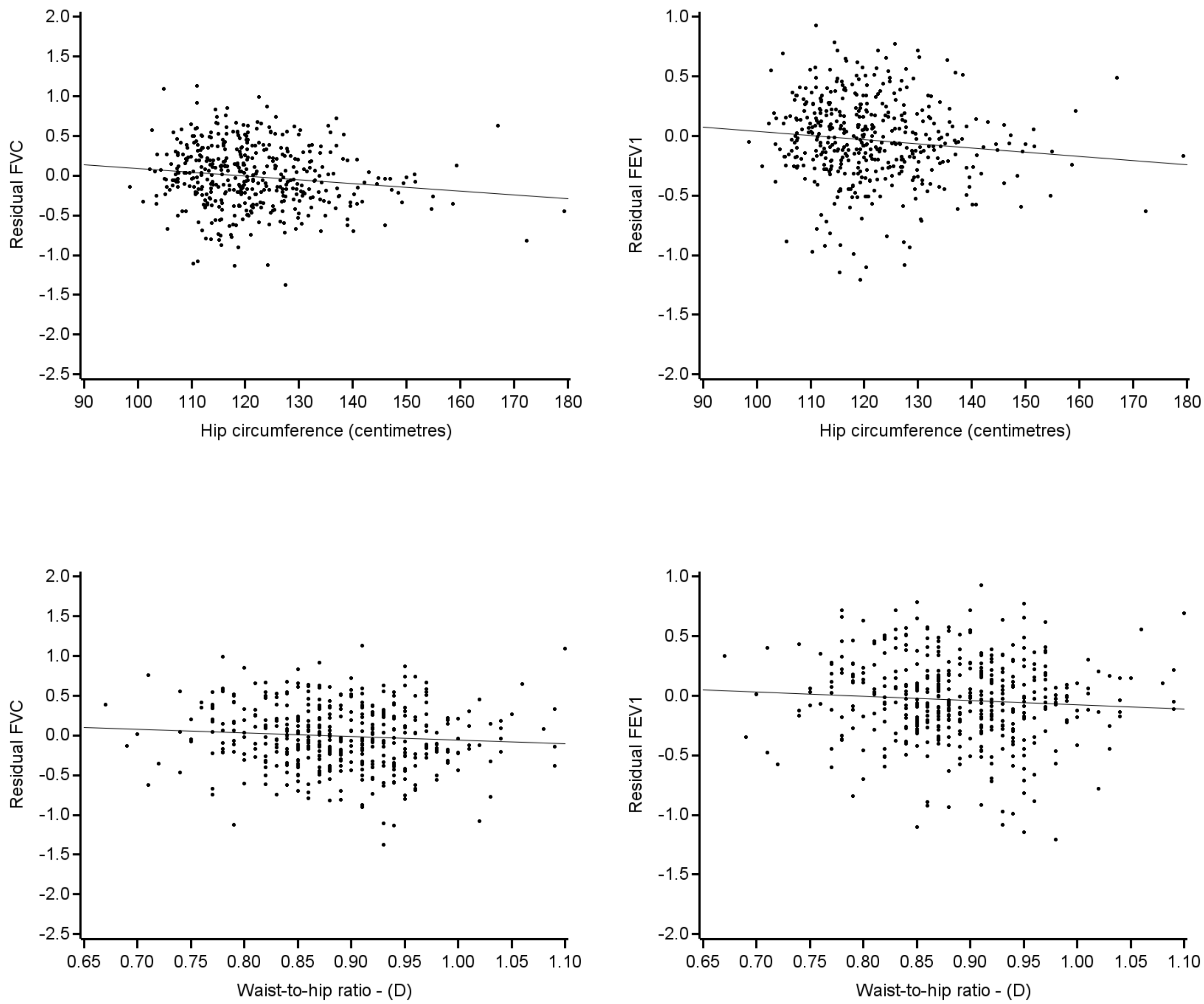
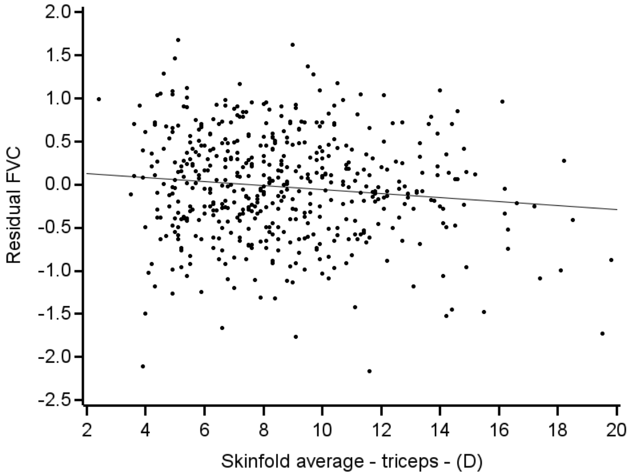
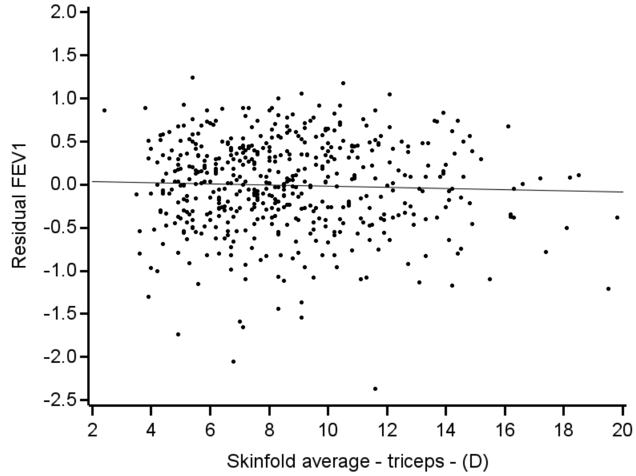
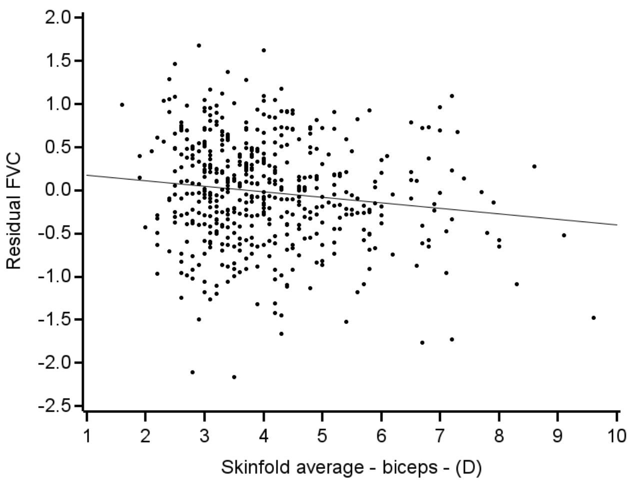
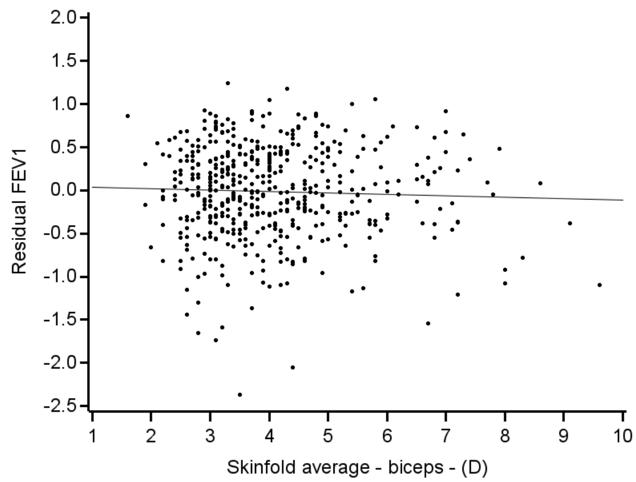


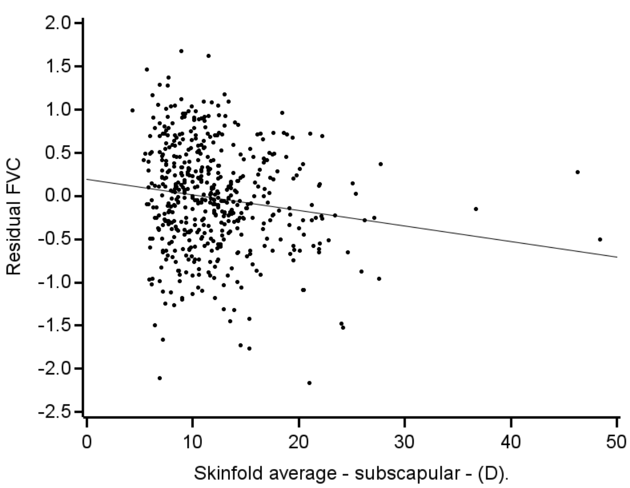
Figure 7.6 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV_1 in obese women.

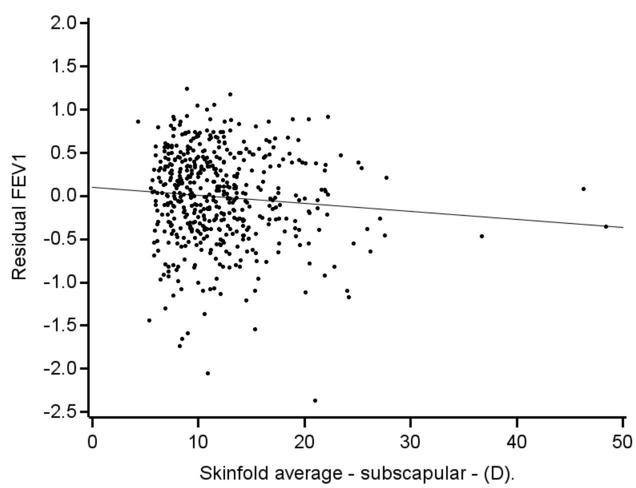

Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
2 4 6 8 10 12 14 16 18 20
Skinfold average - triceps - (D)


Residual FEV1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
2 4 6 8 10 12 14 16 18 20
Skinfold average - triceps - (D)


Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
1 2 3 4 5 6 7 8 9 10
Skinfold average - biceps - (D)


Residual FEV1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
1 2 3 4 5 6 7 8 9 10
Skinfold average - biceps - (D)


Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
0 10 20 30 40 50
Skinfold average - subscapular - (D).


Residual FEV1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
0 10 20 30 40 50
Skinfold average - subscapular - (D).

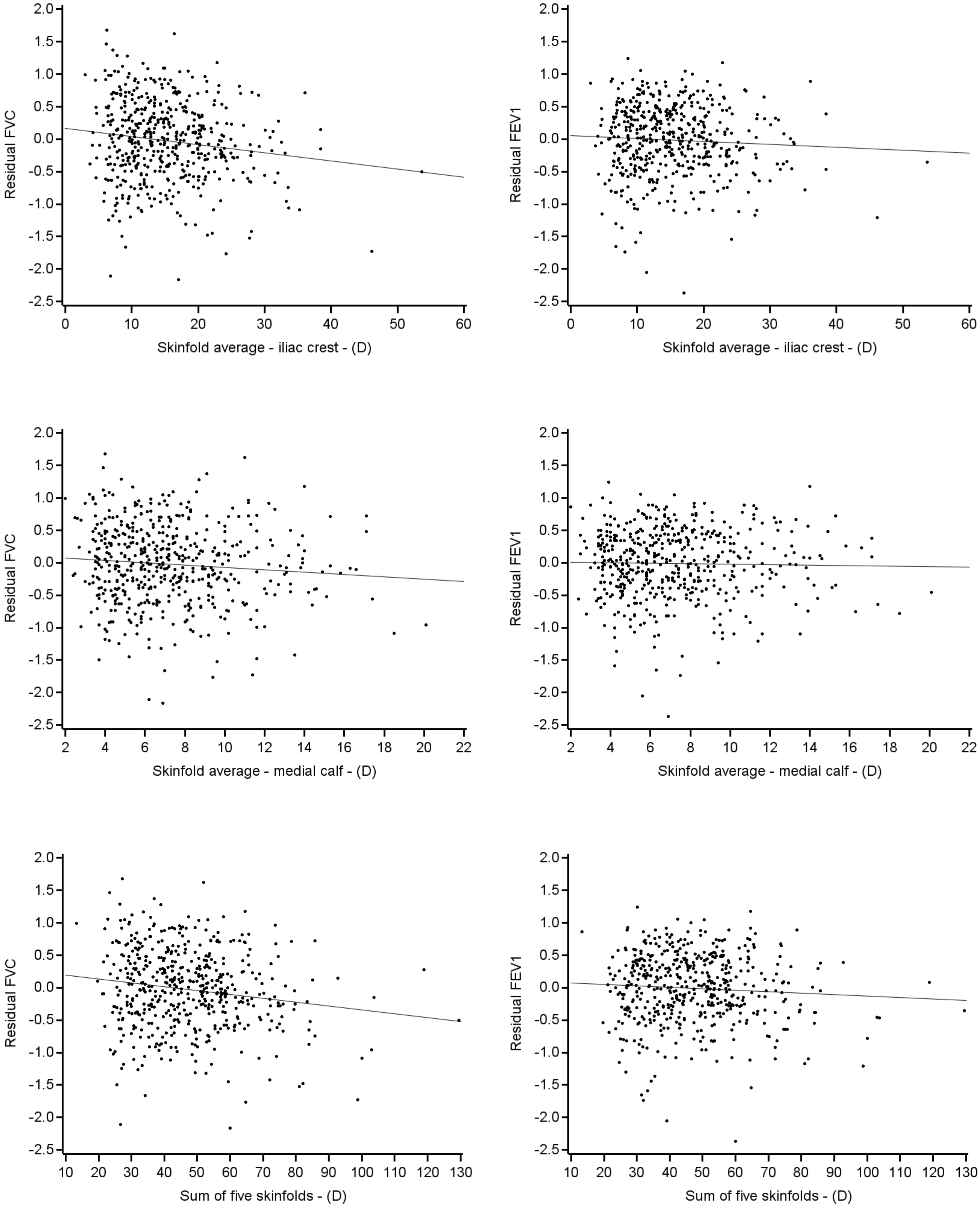
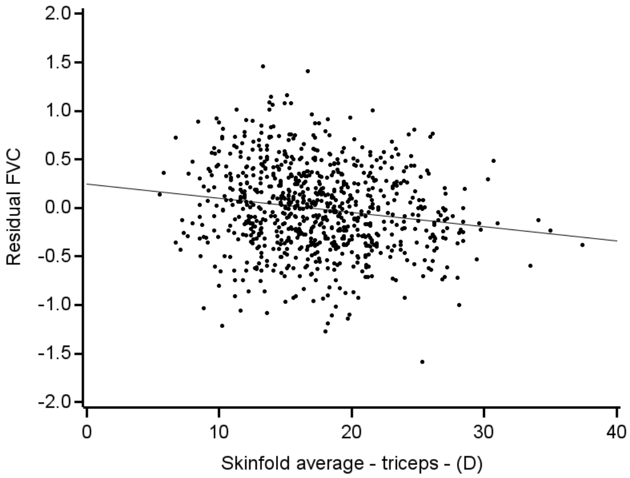
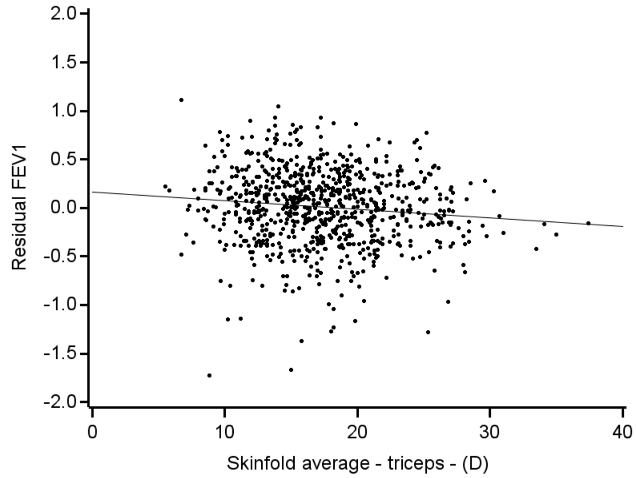
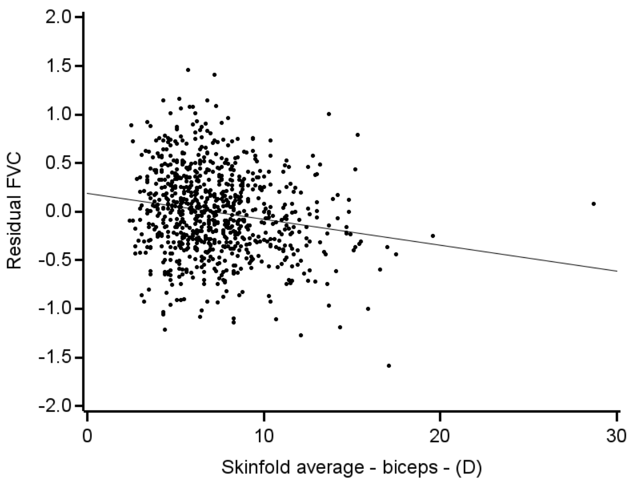
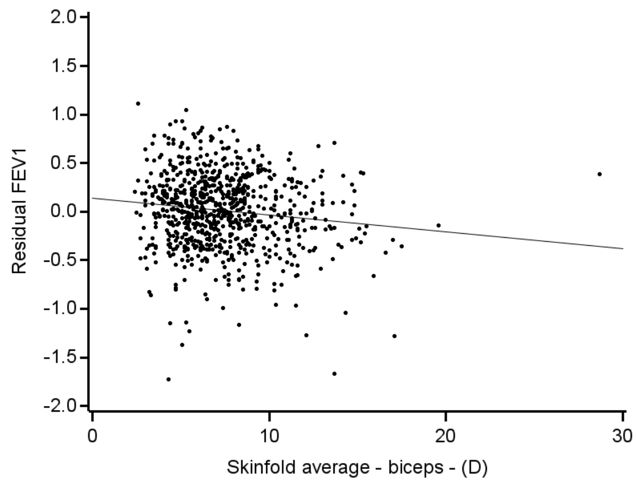


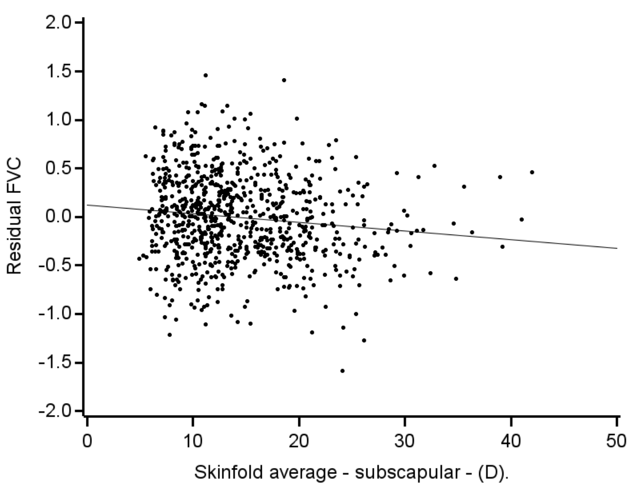
Figure 7.7 Various skinfold measures in association with residual FVC and FEV_1 in normal weight men. All skinfold measurements are in millimeters.

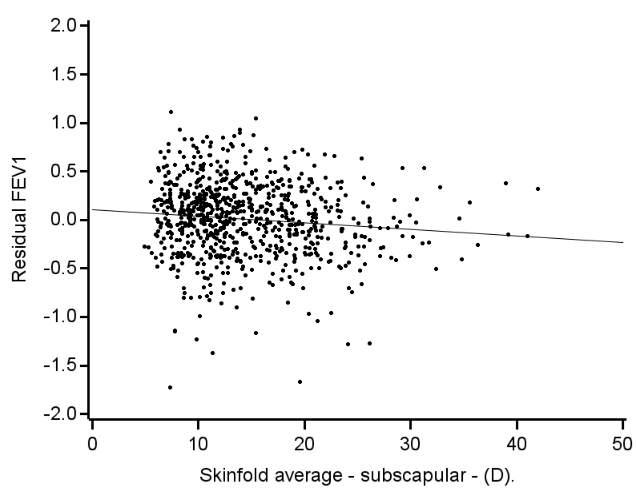

Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
10
20
30
40
Skinfold average - triceps - (D)


Residual FEV1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
10
20
30
40
Skinfold average - triceps - (D)


Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
10
20
30
Skinfold average - biceps - (D)


Residual FEV1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
10
20
30
Skinfold average - biceps - (D)


Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
10
20
30
40
50
Skinfold average - subscapular - (D).


Residual FEV1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
10
20
30
40
50
Skinfold average - subscapular - (D).

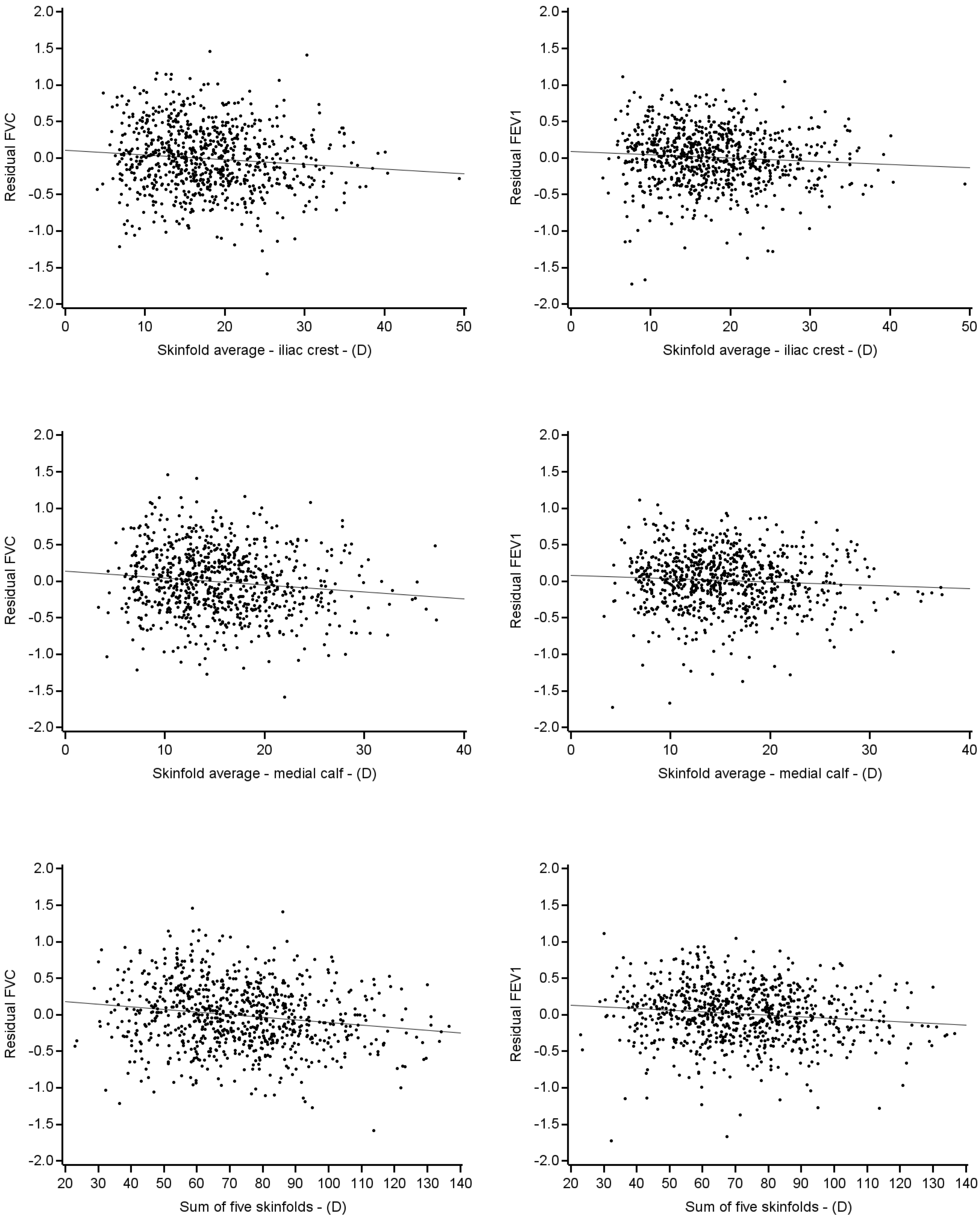
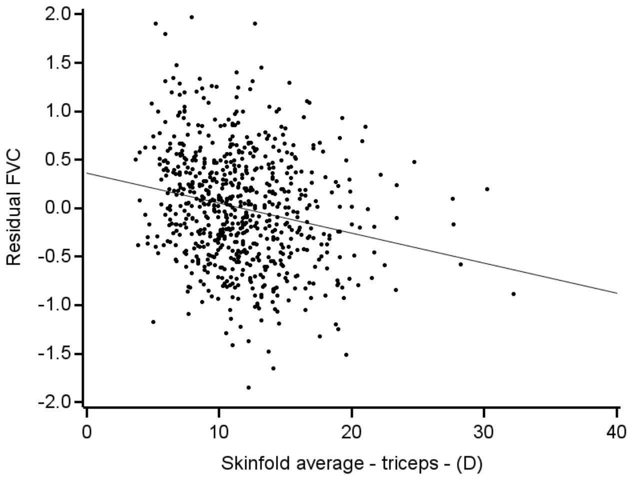
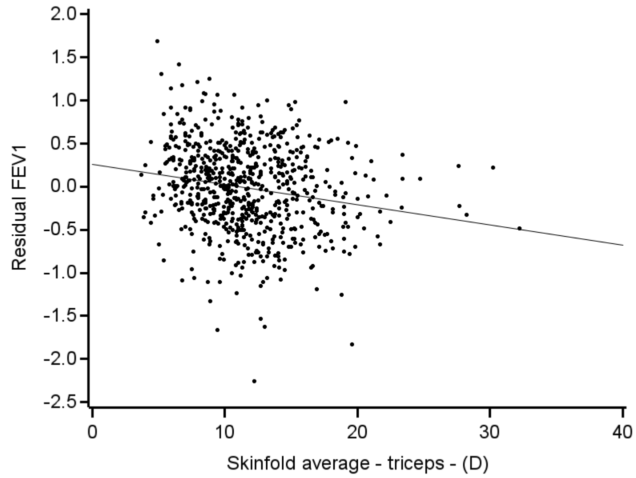
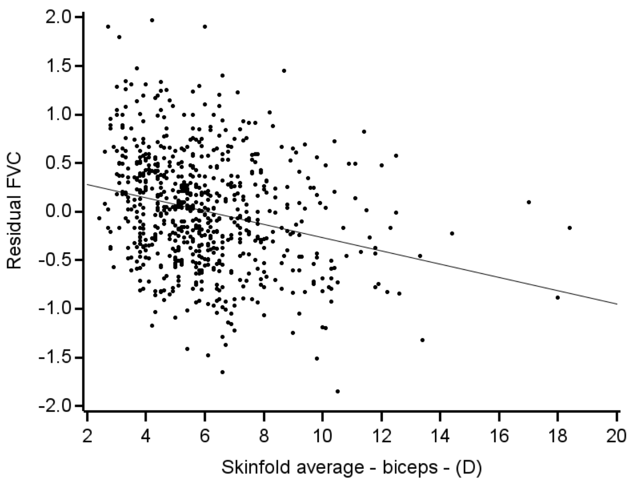
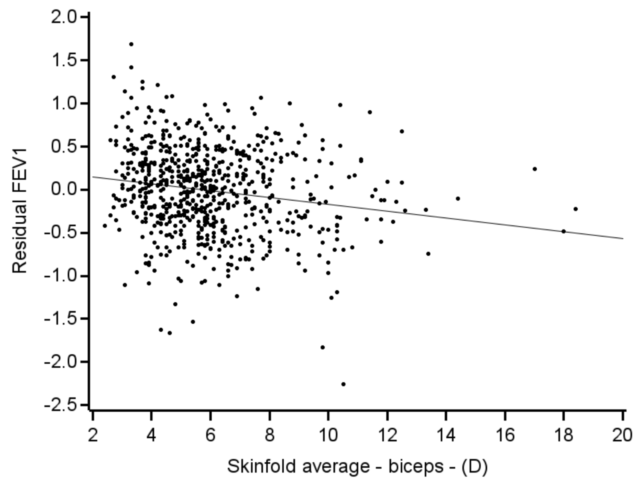


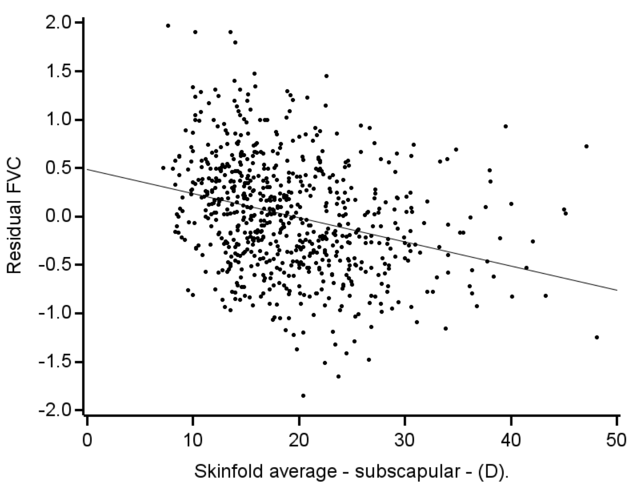
Figure 7.8 Various skinfold measures in association with residual FVC and FEV_1 in normal weight women. All skinfold measurements are in millimeters.

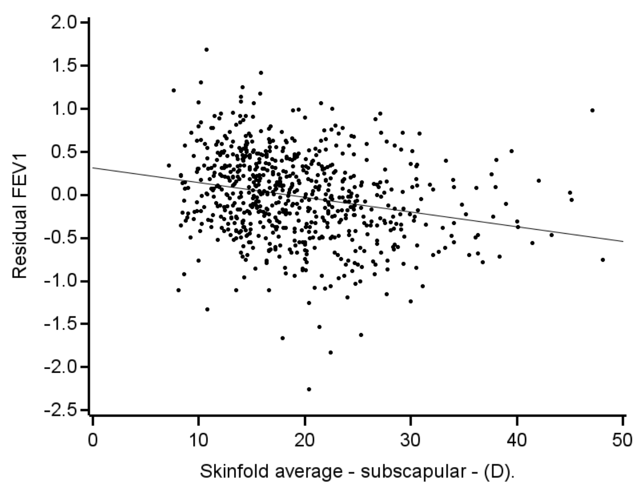

Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
10
20
30
40
Skinfold average - triceps - (D)


Residual FEV1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
0
10
20
30
40
Skinfold average - triceps - (D)


Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
2
4
6
8
10
12
14
16
18
20
Skinfold average - biceps - (D)


Residual FEV1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
2
4
6
8
10
12
14
16
18
20
Skinfold average - biceps - (D)


Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
10
20
30
40
50
Skinfold average - subscapular - (D).


Residual FEV1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
0
10
20
30
40
50
Skinfold average - subscapular - (D).

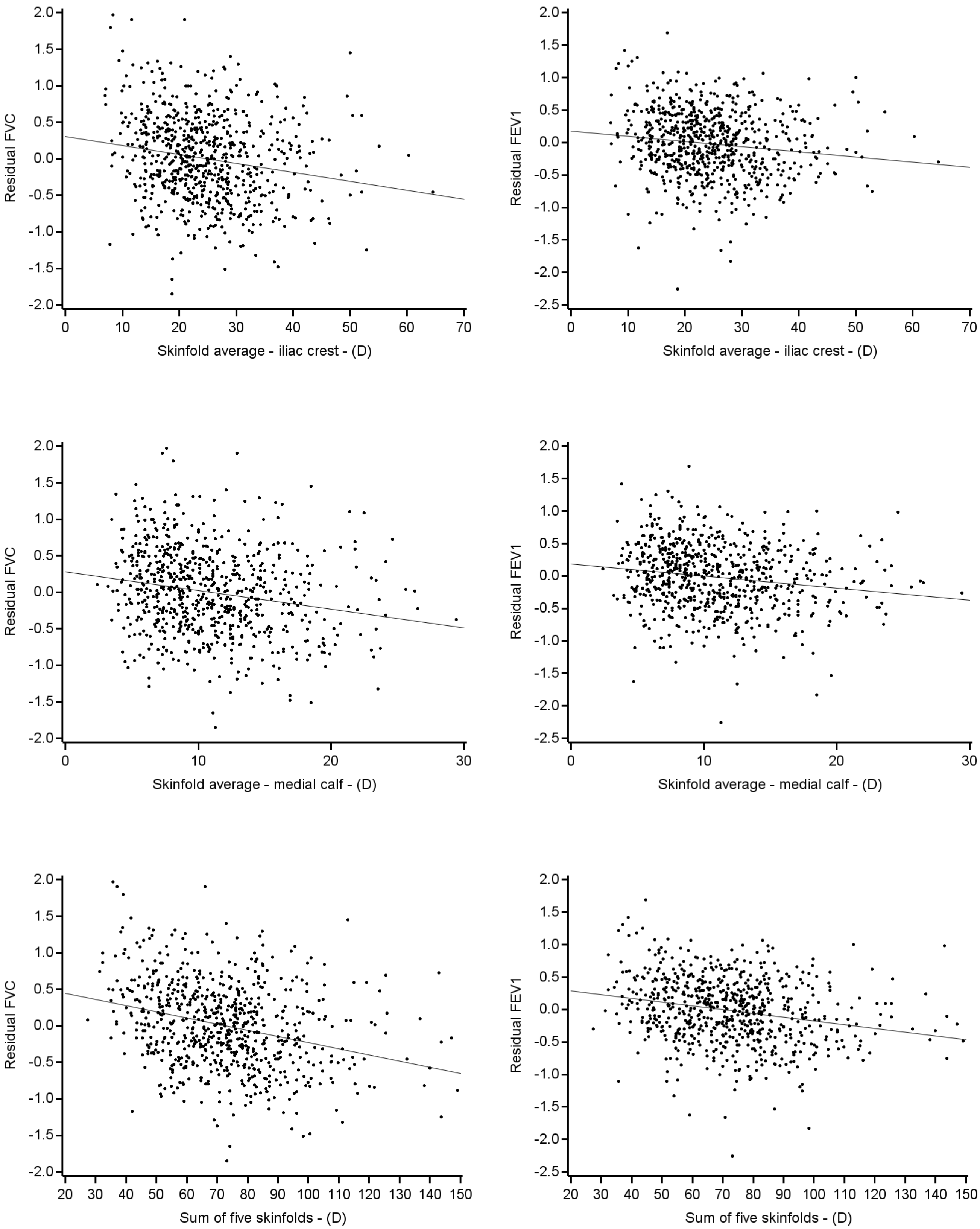
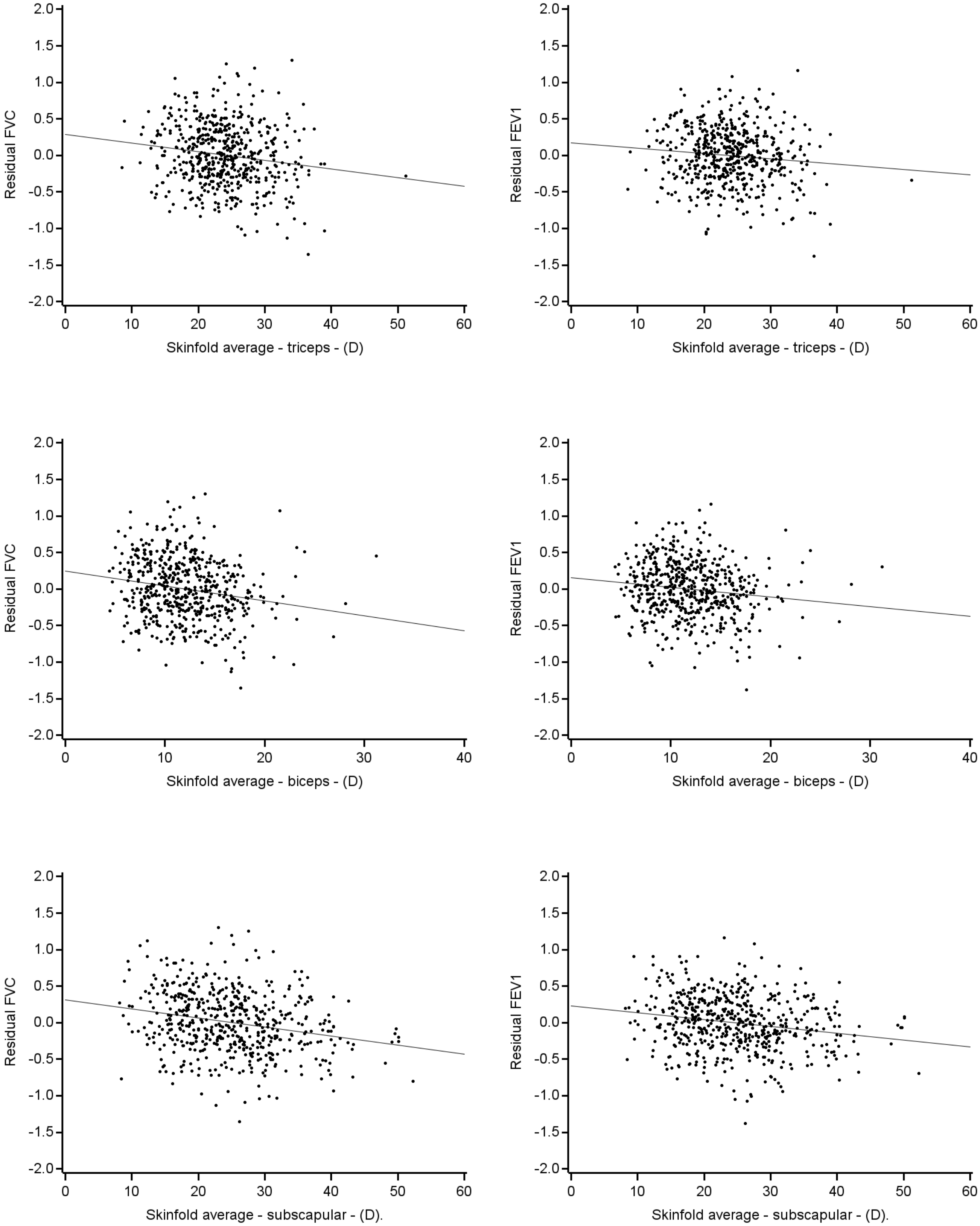


Figure 7.9 Various skinfold measures in association with residual FVC and FEV_1 in overweight men. All skinfold measurements are in millimeters.


Residual FVC
Skinfold average - triceps - (D)
Residual FEV1
Skinfold average - triceps - (D)
Residual FVC
Skinfold average - biceps - (D)
Residual FEV1
Skinfold average - biceps - (D)
Residual FVC
Skinfold average - subscapular - (D).
Residual FEV1
Skinfold average - subscapular - (D).

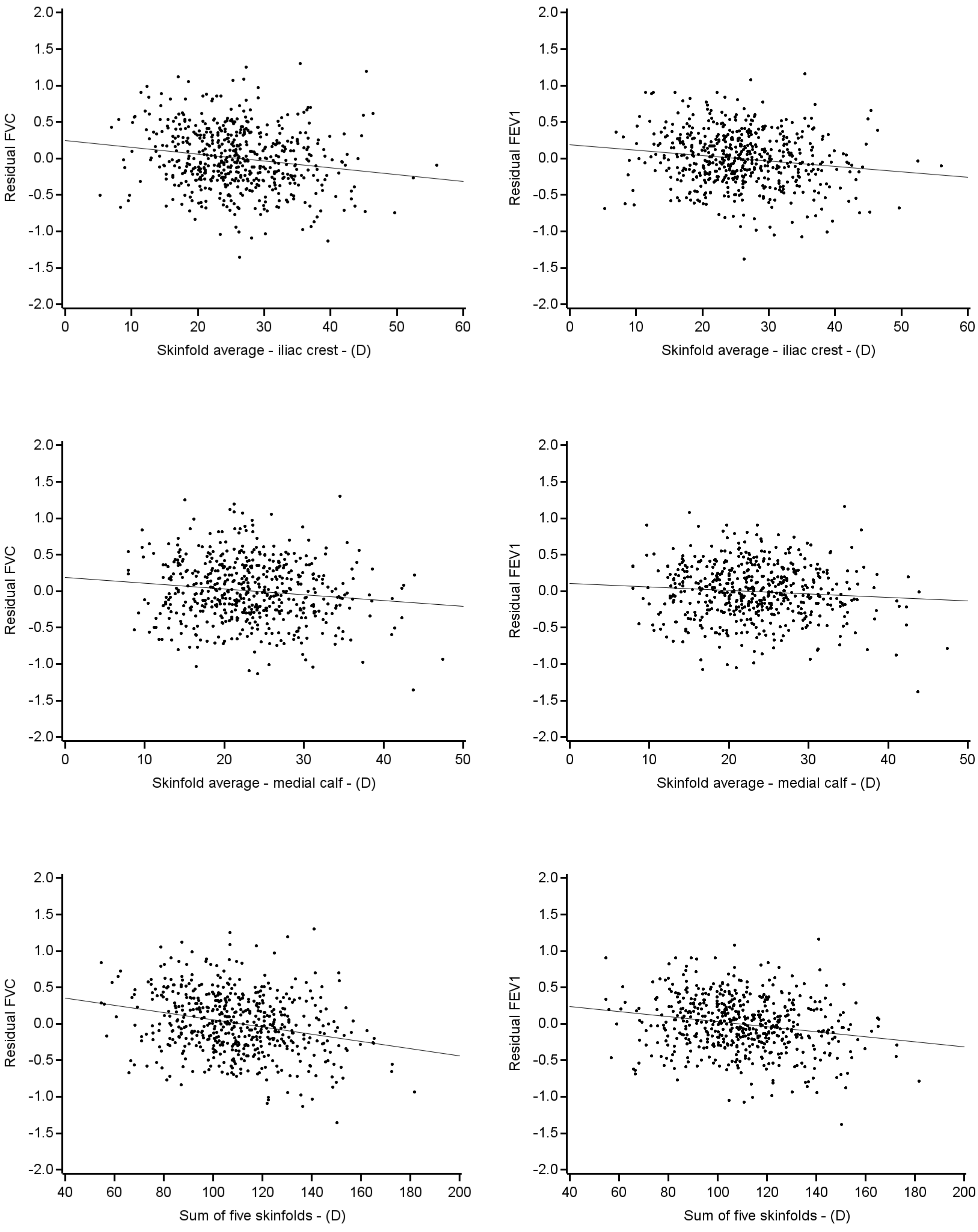
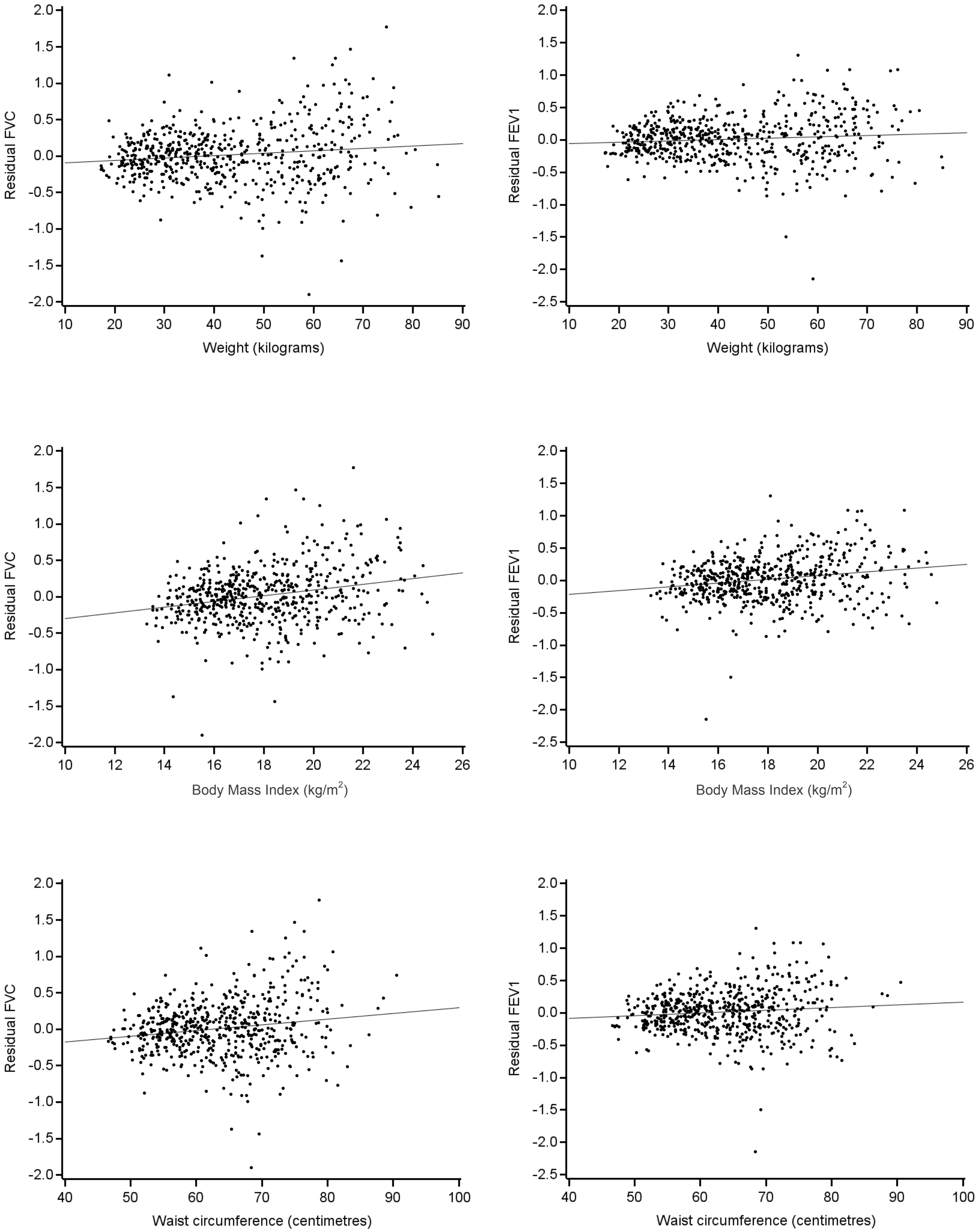


Figure 7.10 Various skinfold measures in association with residual FVC and FEV_1 in overweight women. All skinfold measurements are in millimeters.


Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m2)
Residual FEV1
Body Mass Index (kg/m2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

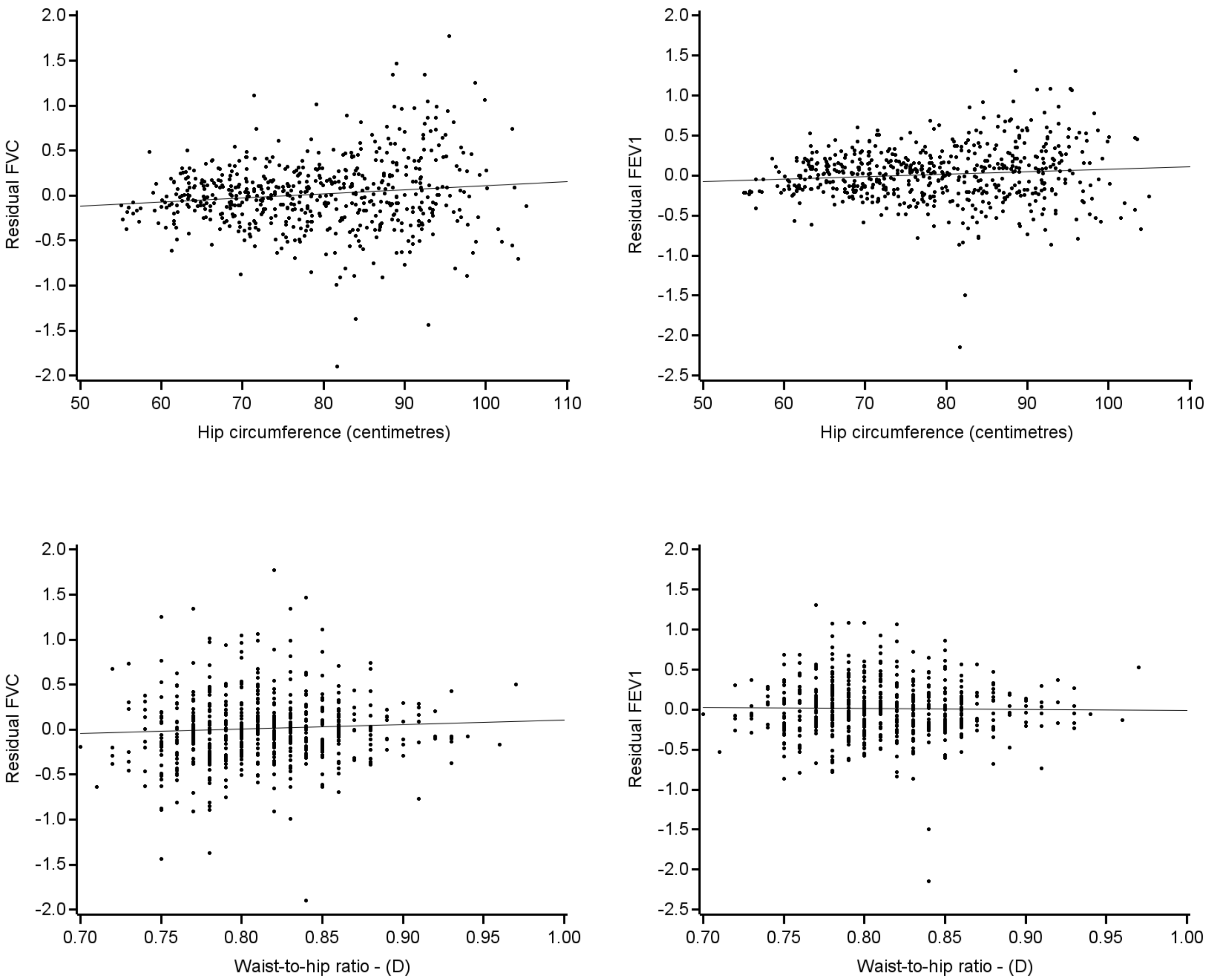
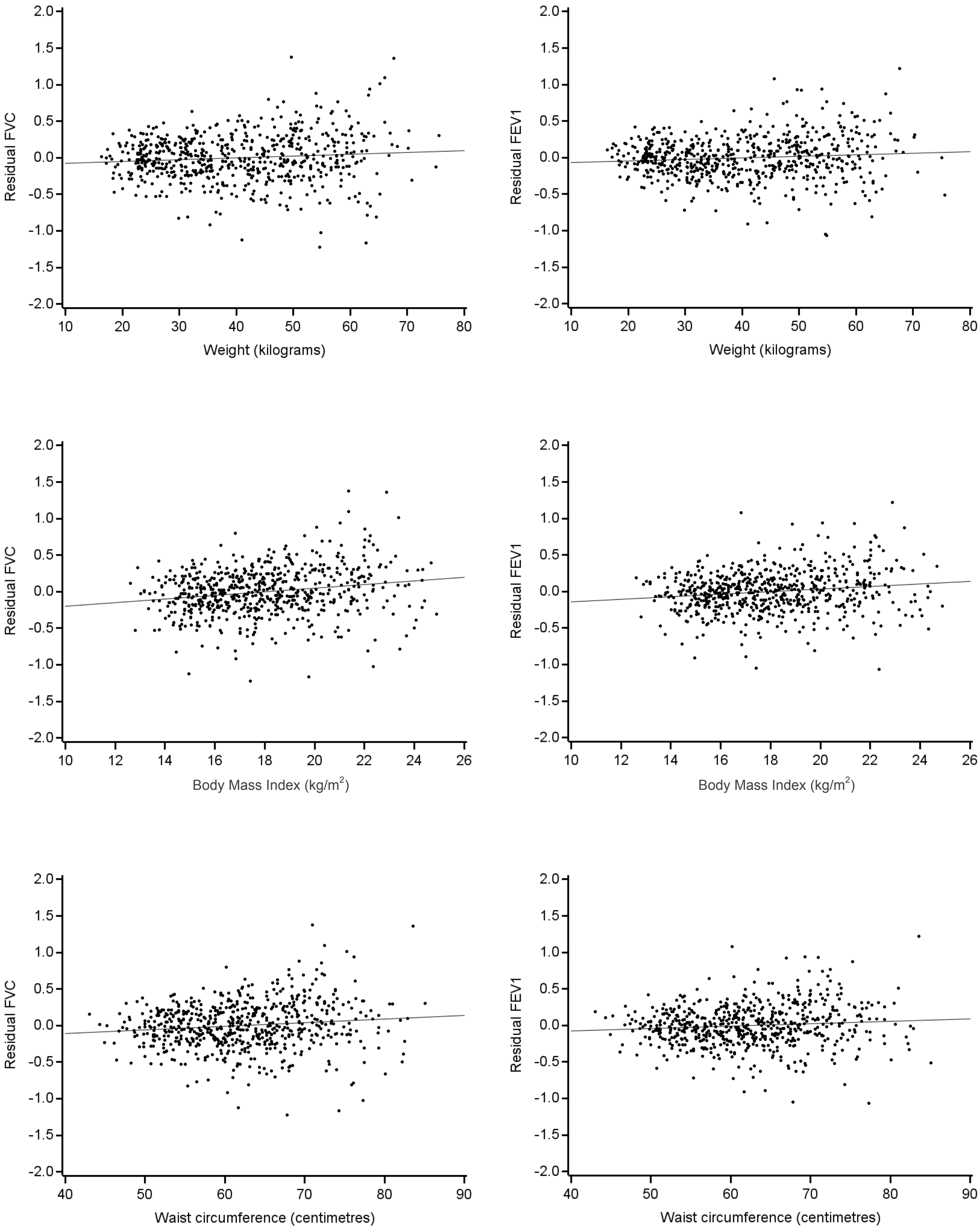


Figure 7.11 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV_1 in normal weight boys.


Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m2)
Residual FEV1
Body Mass Index (kg/m2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

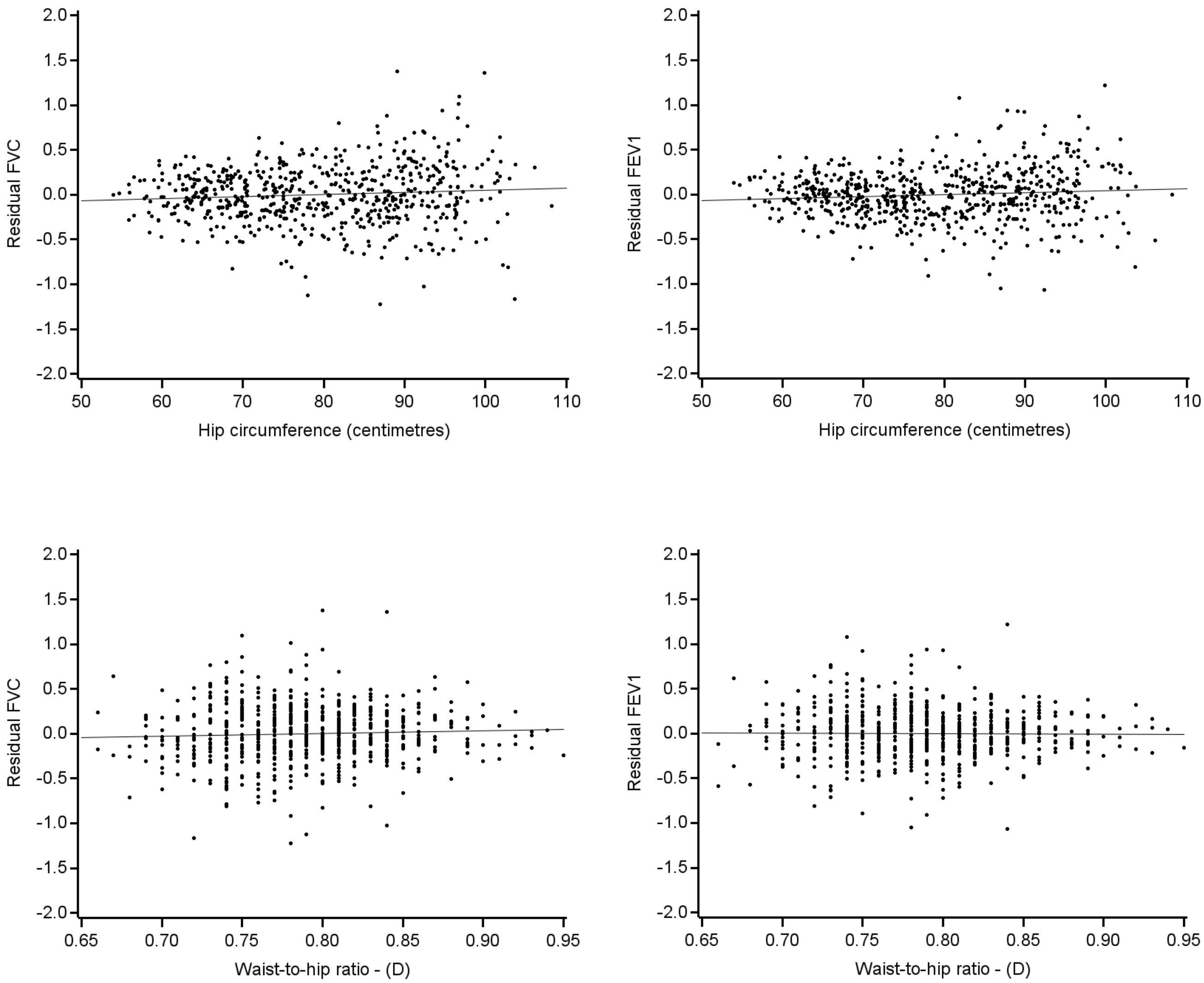
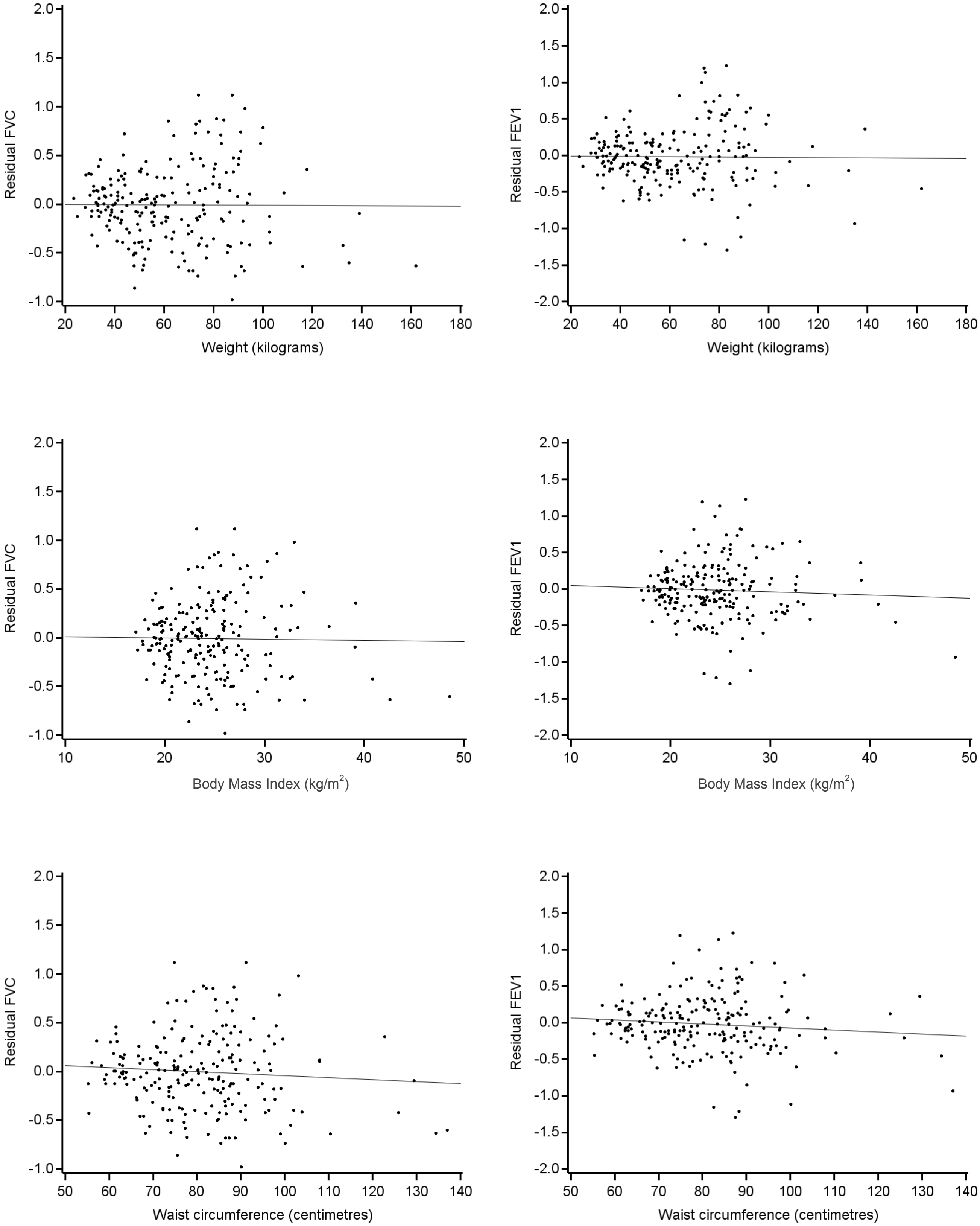


Figure 7.12 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV_1 in normal weight girls.


Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m2)
Residual FEV1
Body Mass Index (kg/m2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

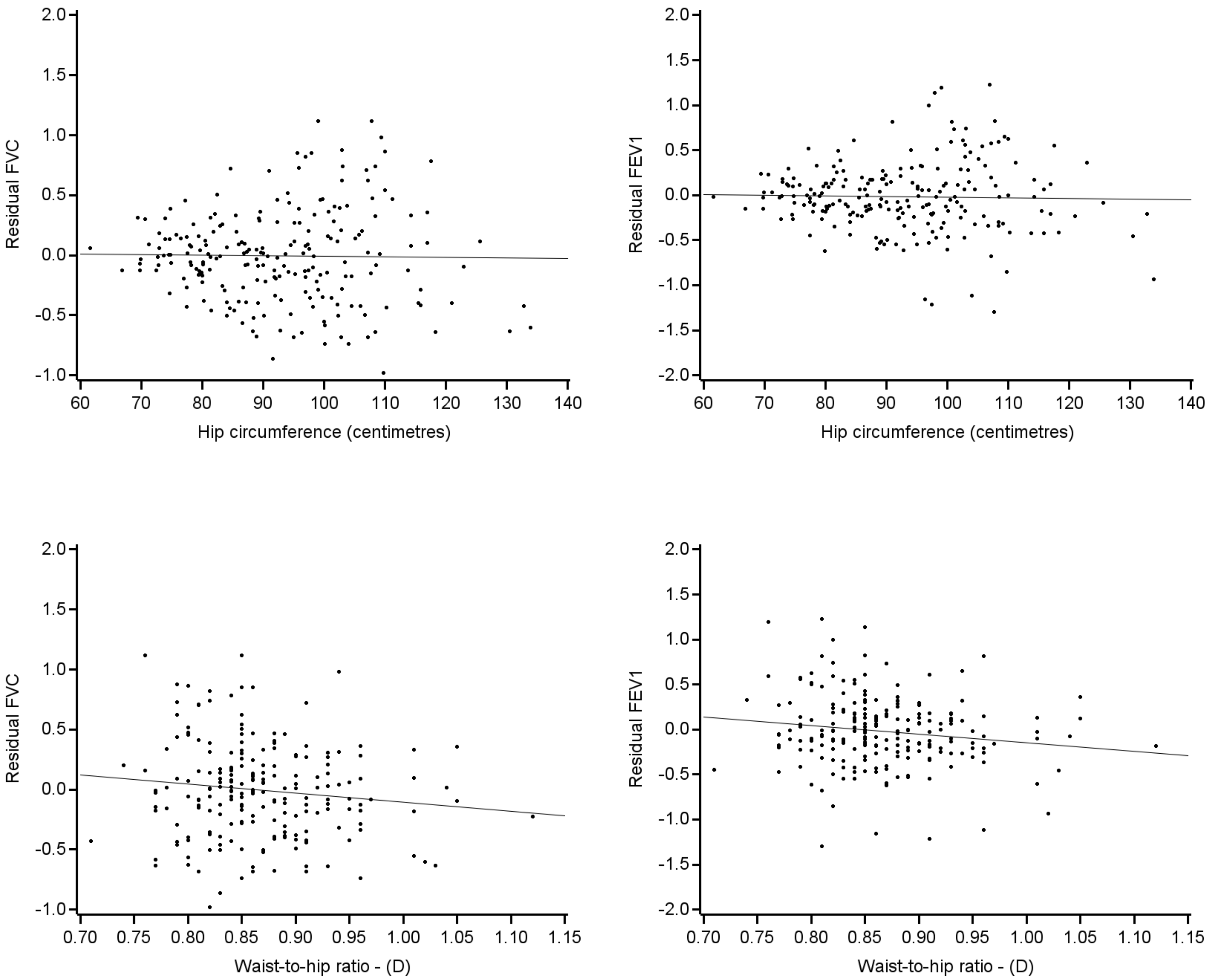
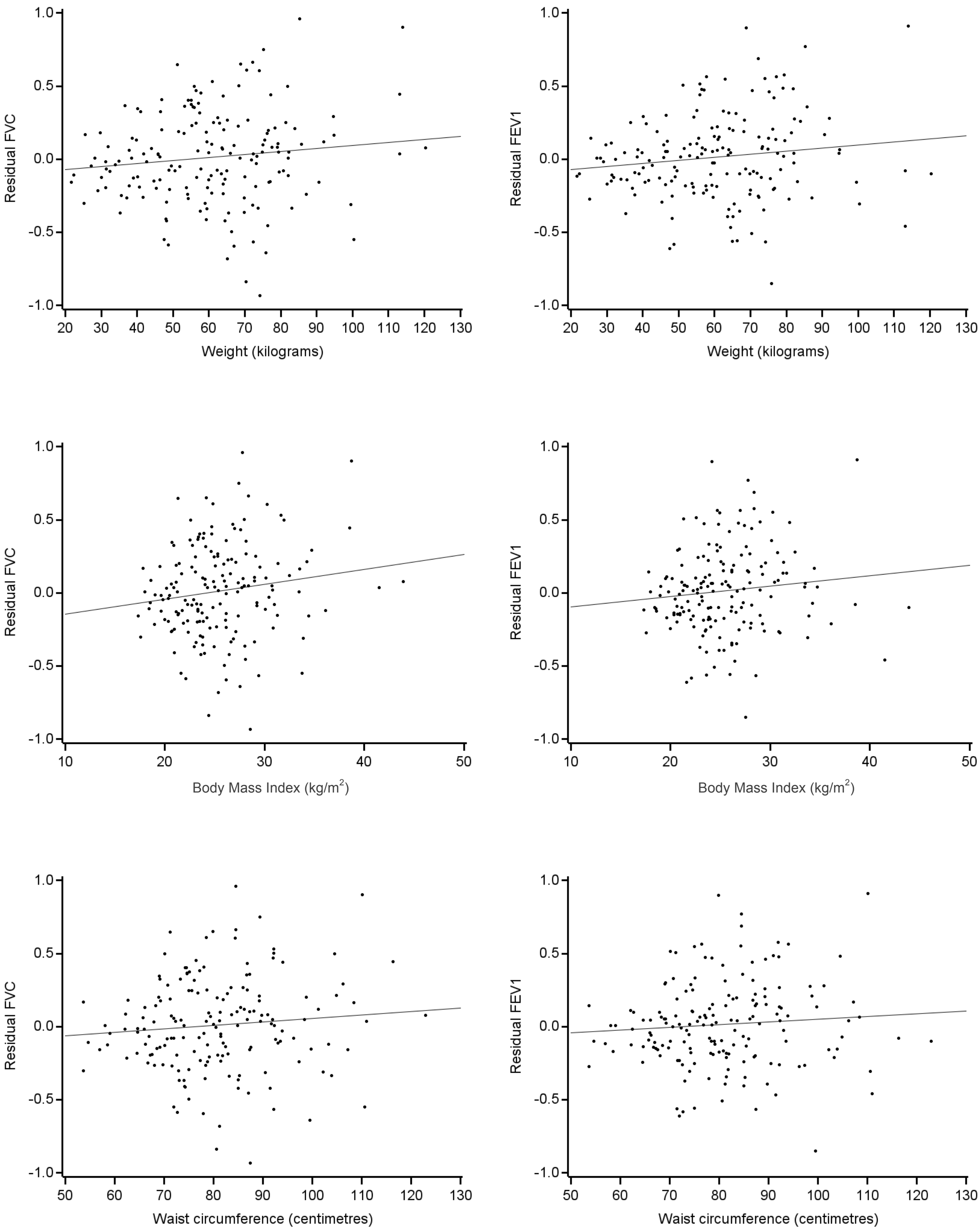


Figure 7.13 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV_1 in overweight or obese boys.


Residual FVC
Weight (kilograms)
Residual FEV1
Weight (kilograms)
Residual FVC
Body Mass Index (kg/m2)
Residual FEV1
Body Mass Index (kg/m2)
Residual FVC
Waist circumference (centimetres)
Residual FEV1
Waist circumference (centimetres)

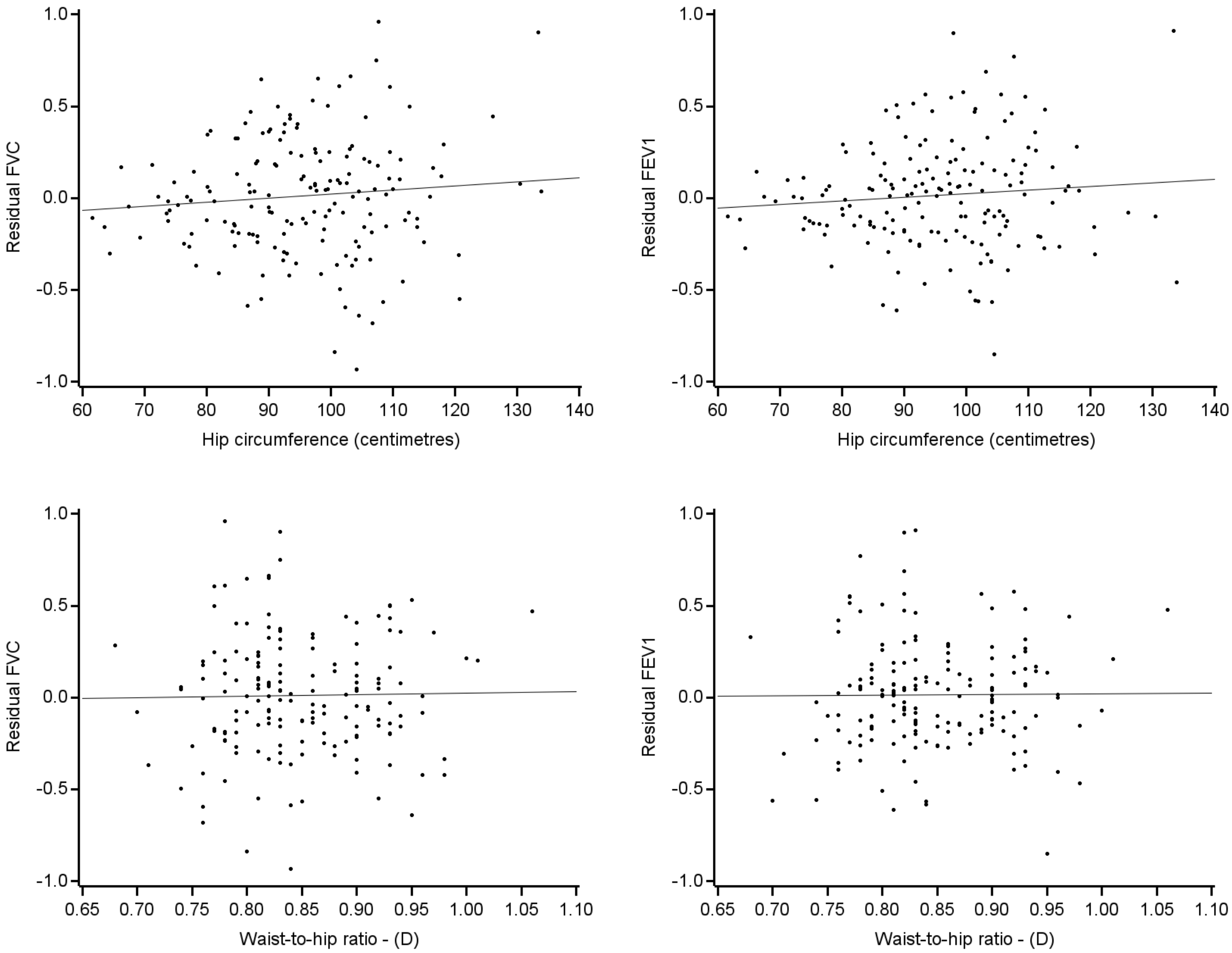
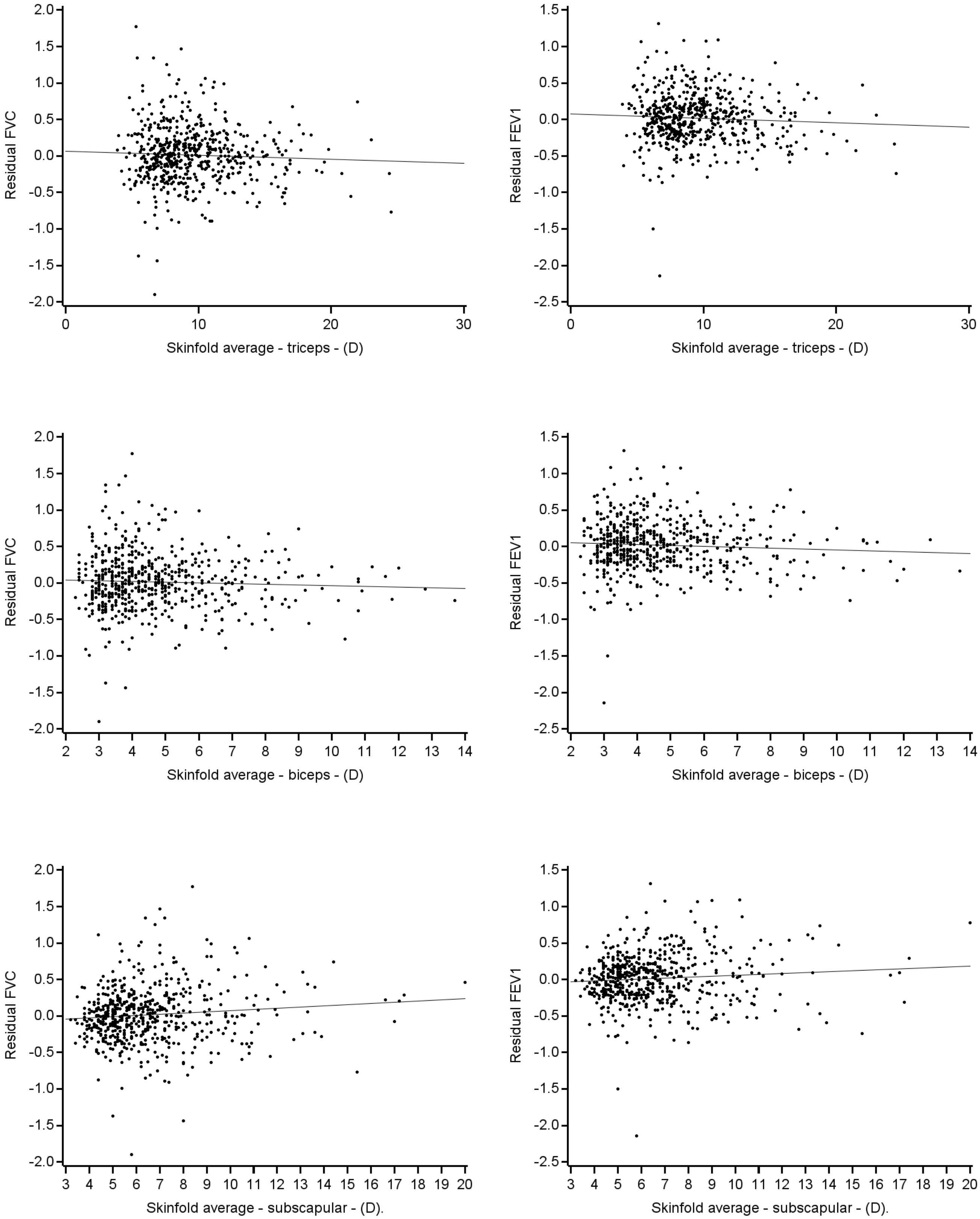


Figure 7.14 Weight, BMI, waist circumference, hip circumference and waist-to-hip ratio in association with residual FVC and FEV_1 in overweight or obese girls.


Residual FVC
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
10
20
30
Skinfold average - triceps - (D)
Residual FEV1
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
0
10
20
30
Skinfold average - triceps - (D)
Residual FVC
2 3 4 5 6 7 8 9 10 11 12 13 14
Skinfold average - biceps - (D)
Residual FEV1
2 3 4 5 6 7 8 9 10 11 12 13 14
Skinfold average - biceps - (D)
Residual FVC
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Skinfold average - subscapular - (D).
Residual FEV1
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Skinfold average - subscapular - (D).

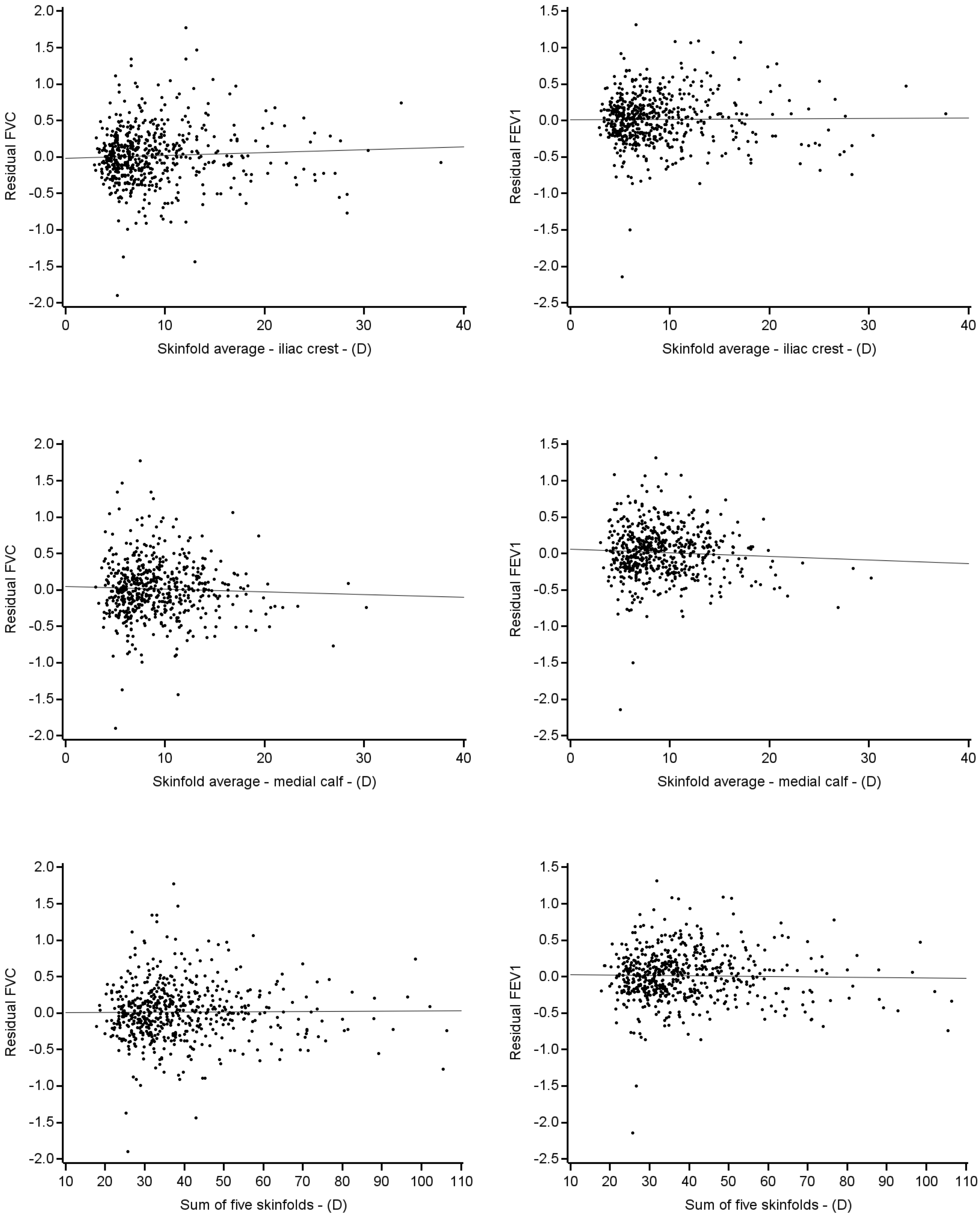
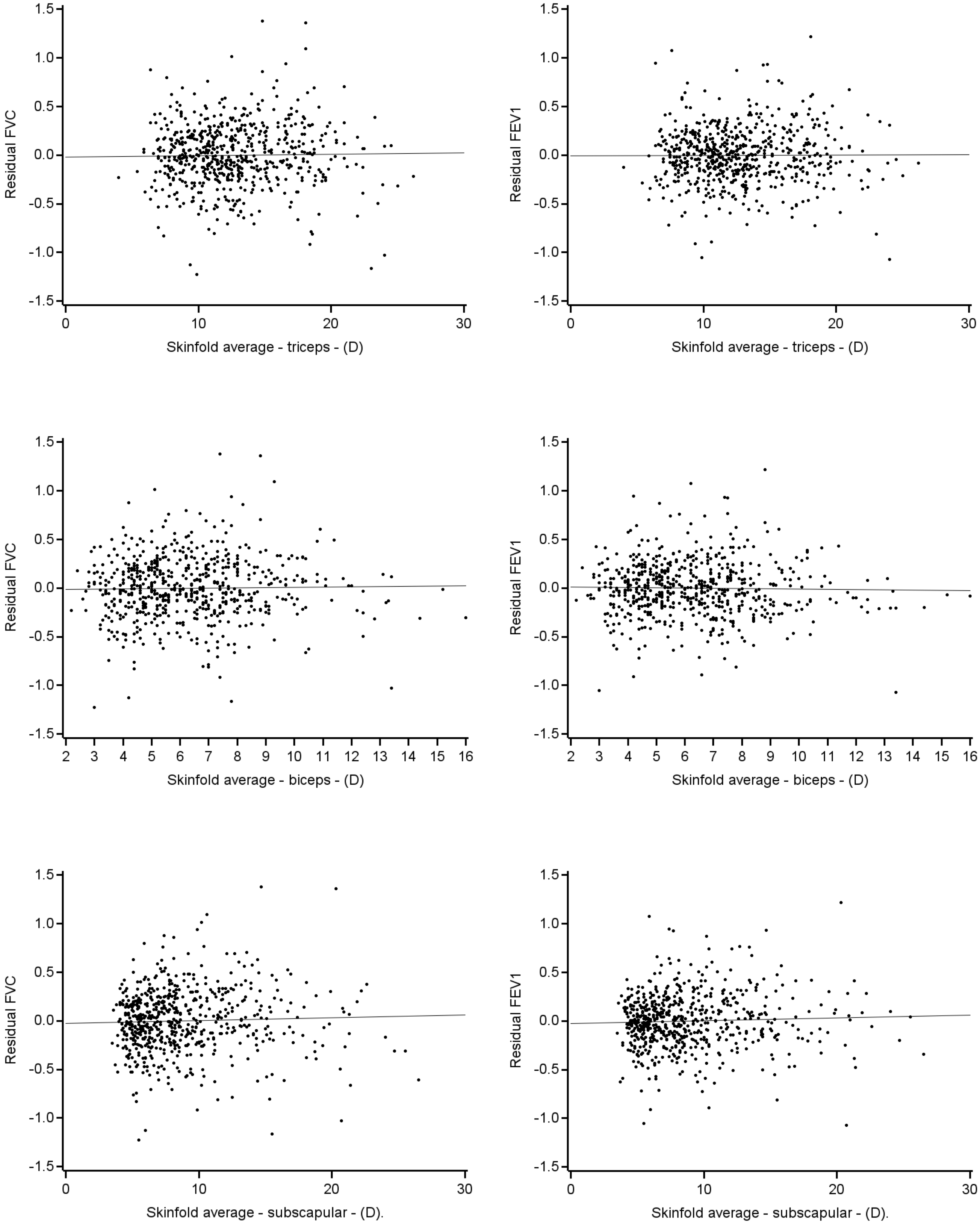


Figure 7.15 Various skinfold measures in association with residual FVC and FEV_1 in normal weight boys. All skinfold measurements are in millimeters.


Residual FVC
Skinfold average - triceps - (D)
Residual FEV1
Skinfold average - triceps - (D)
Residual FVC
Skinfold average - biceps - (D)
Residual FEV1
Skinfold average - biceps - (D)
Residual FVC
Skinfold average - subscapular - (D).
Residual FEV1
Skinfold average - subscapular - (D).

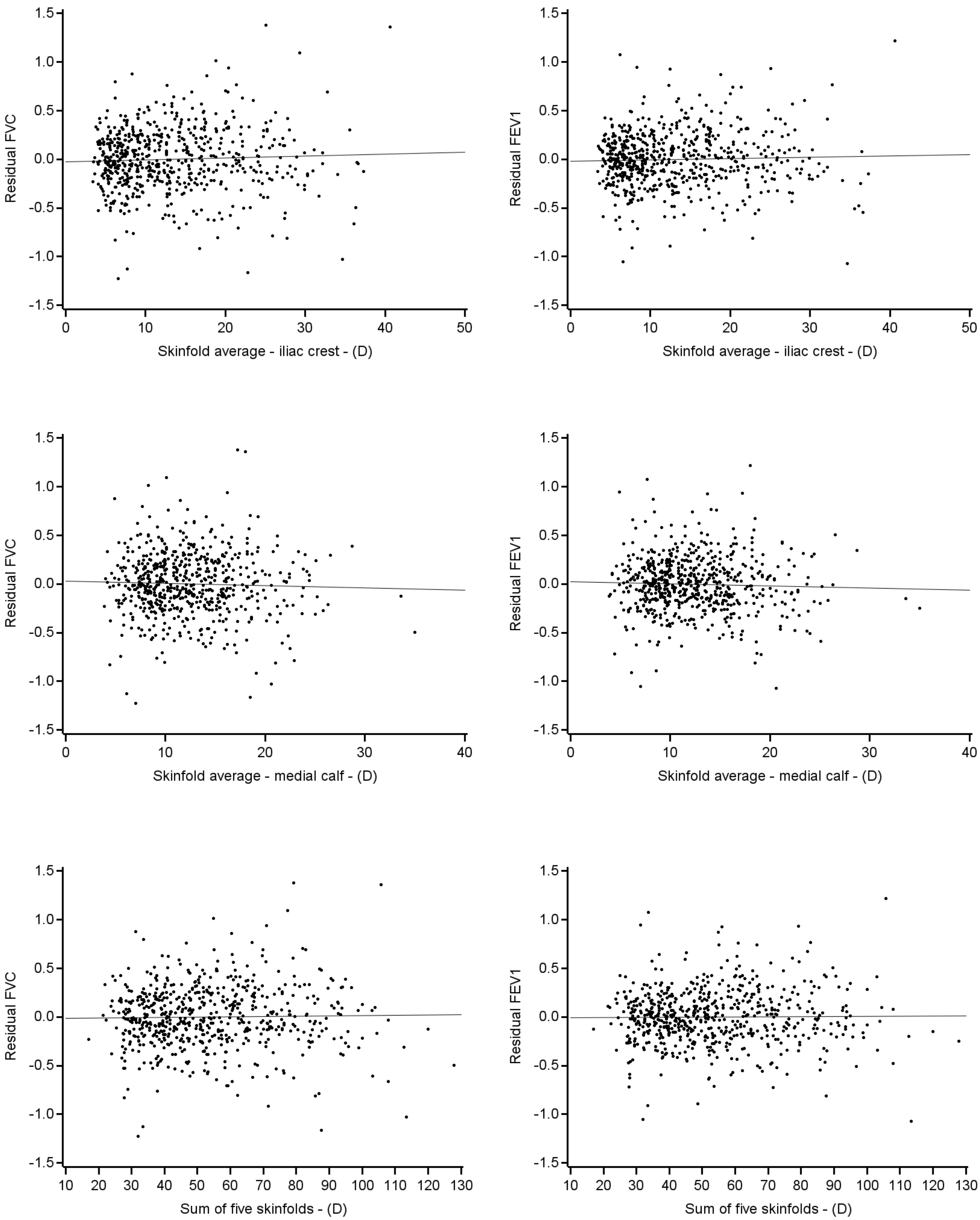
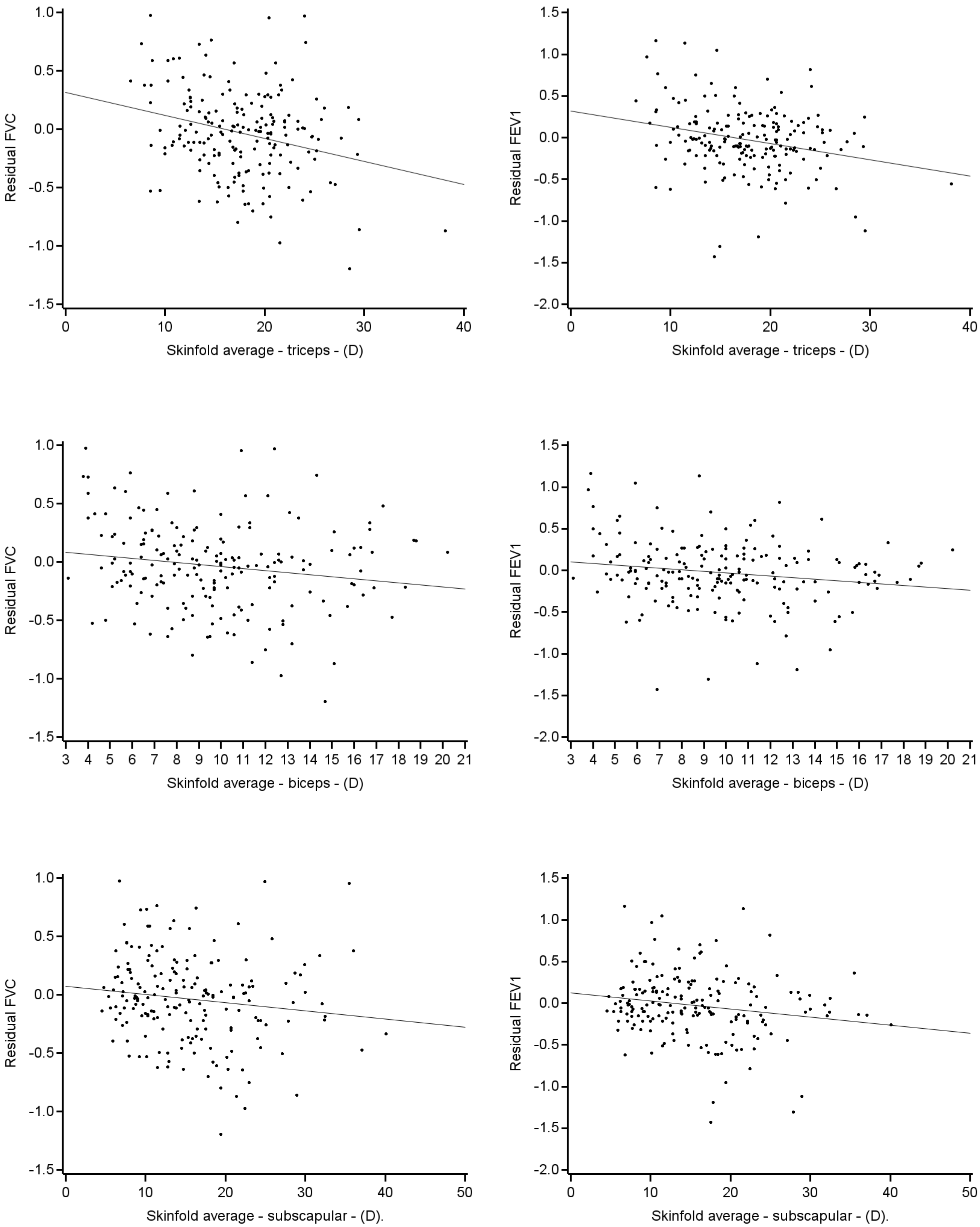


Figure 7.16 Various skinfold measures in association with residual FVC and FEV_1 in normal weight girls. All skinfold measurements are in millimeters.


Residual FVC
Skinfold average - triceps - (D)
Residual FEV1
Skinfold average - triceps - (D)
Residual FVC
Skinfold average - biceps - (D)
Residual FEV1
Skinfold average - biceps - (D)
Residual FVC
Skinfold average - subscapular - (D).
Residual FEV1
Skinfold average - subscapular - (D).

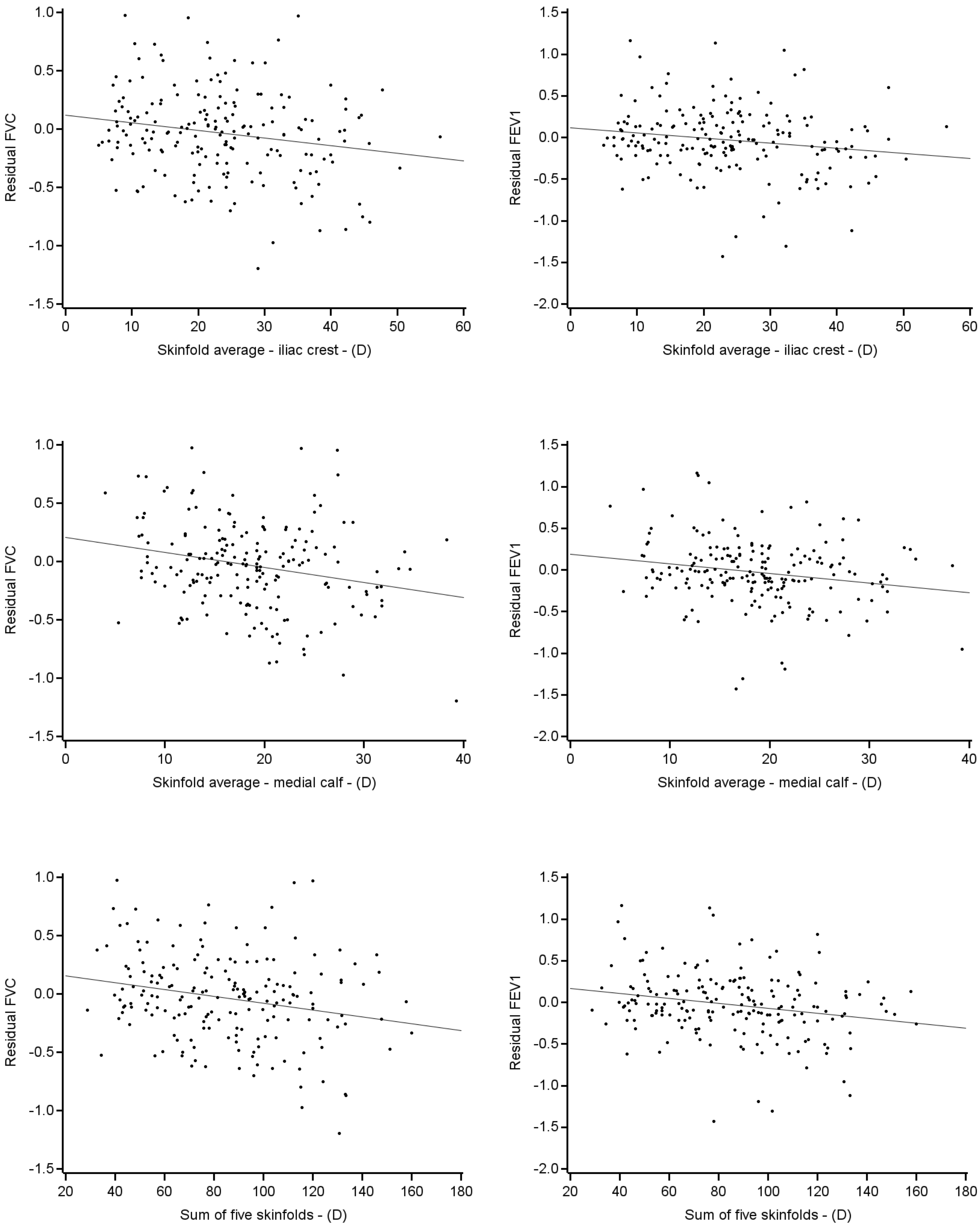
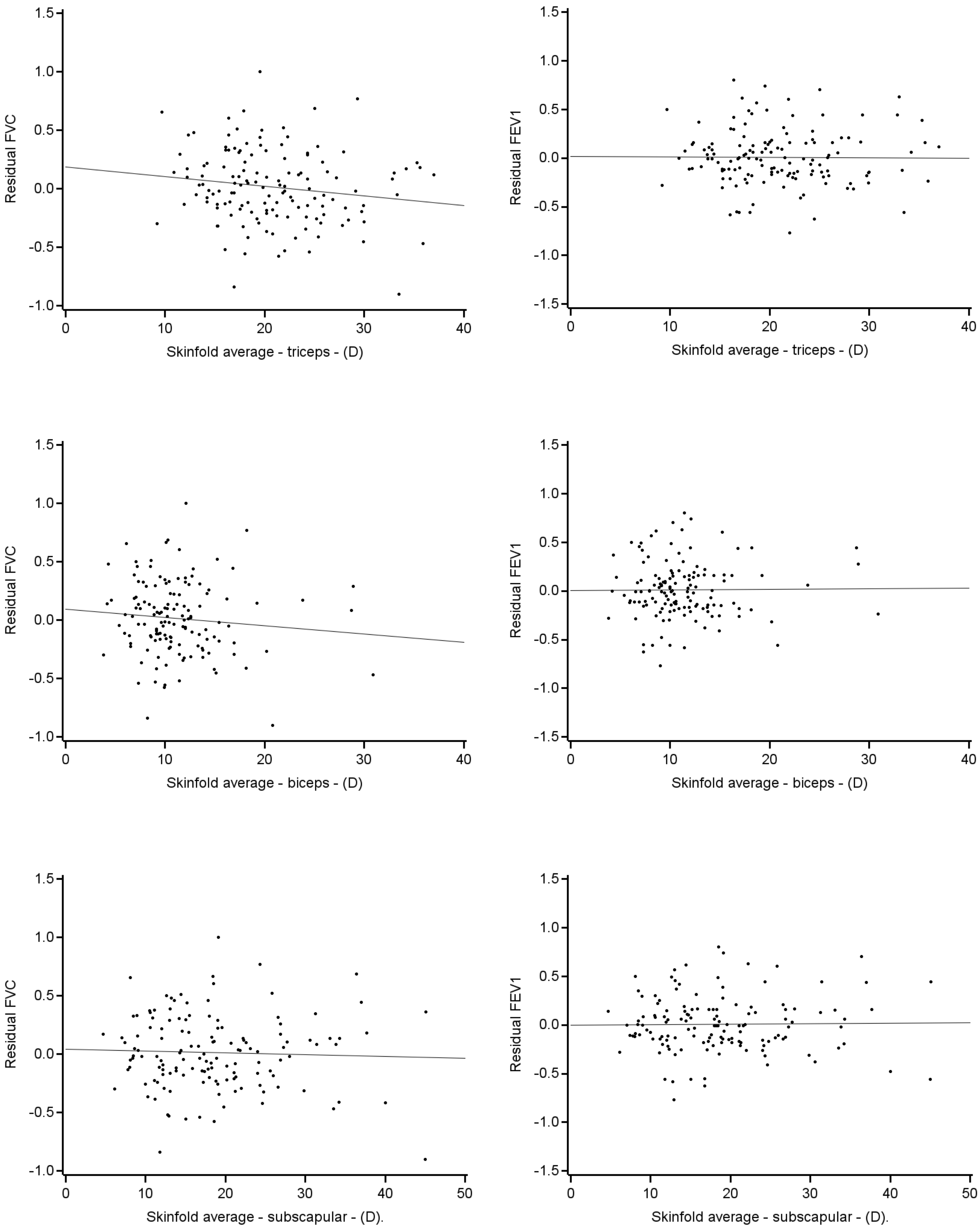


Figure 7.17 Various skinfold measures in association with residual FVC and FEV_1 in overweight or obese boys. All skinfold measurements are in millimeters.


Residual FVC
Skinfold average - triceps - (D)
Residual FEV1
Skinfold average - triceps - (D)
Residual FVC
Skinfold average - biceps - (D)
Residual FEV1
Skinfold average - biceps - (D)
Residual FVC
Skinfold average - subscapular - (D).
Residual FEV1
Skinfold average - subscapular - (D).

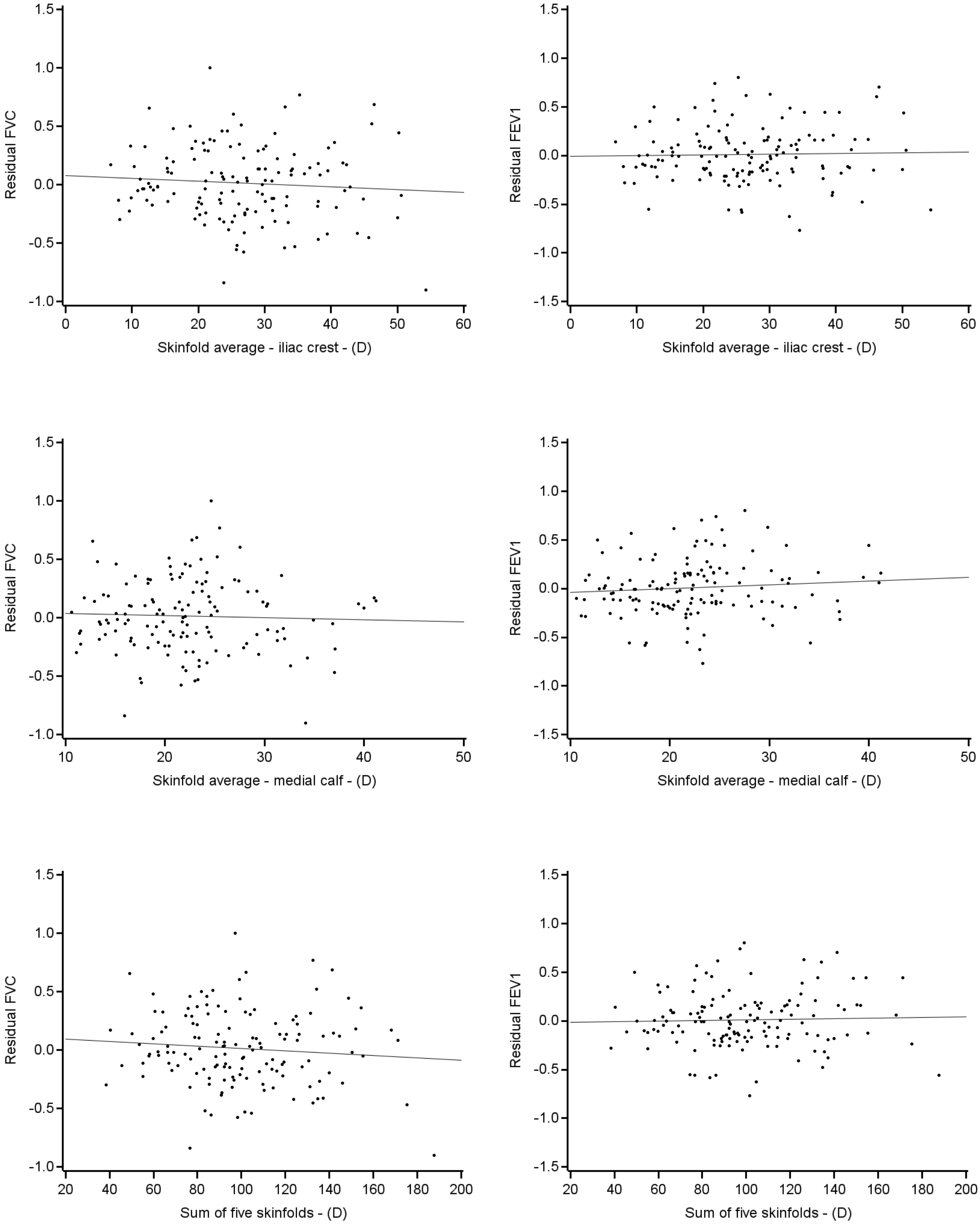


Figure 7.18 Various skinfold measures in association with residual FVC and FEV_1 in overweight or obese girls. All skinfold measurements are in millimeters.