CHEST

Original Research

OBESITY

The Effects of Body Mass Index on Lung Volumes*

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Background: **Obesity is a major health issue in North America, and the trend is for obesity to be a more important medical issue in the future. Since obesity can cause respiratory symptoms, many obese people are referred for pulmonary function tests (PFTs). It is well known that obesity causes decreases in lung volumes, but there has never been a large study showing the correlation between body mass index (BMI) and the various lung volumes.**

Design: **We collected PFT results from 373 patients sent for lung function testing who had normal values for airway function but a wide range of BMIs.**

Setting: **The PFTs were done in two accredited outpatient laboratories.**

Results: **There were significant linear relationships between BMI and vital capacity and total lung capacity, but the group mean values remained within the normal ranges even for morbidly obese patients. However, functional residual capacity (FRC) and expiratory reserve volume (ERV) decreased exponentially with increasing BMI, such that morbid obesity resulted in patients breathing near their residual volume. An important finding was that the greatest rates of change in FRC and ERV occurred in the overweight condition and in mild obesity. At a BMI of 30 kg/m², FRC and ERV were only 75% and 47%, respectively, of the values for a lean person with a BMI of 20 kg/m².**

Conclusions: **We showed that BMI has significant effects on all of the lung volumes, and the greatest effects were on FRC and ERV, which occurred at BMI values < 30 kg/m². Our results will assist clinicians when interpreting PFT results in patients with normal airway function.**

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Key words: body mass index; lung volumes; obesity; pulmonary function testing

Abbreviations: ANOVA = analysis of variance; BMI = body mass index; DLCO = diffusion capacity of the lung for carbon monoxide; ERV = expiratory reserve volume; FRC = functional residual capacity; LLN = lower limit of normal; PFT = pulmonary function test; RV = residual volume; TLC = total lung capacity; ULN = upper limit of normal; VC = vital capacity

Obesity is a major health issue for North Americans. There has been a steady trend of increasing obesity over the past several decades,[1] with the prediction of 20% of the US population being morbidly obese by the year 2010.[2] A similar trend exists in Canada.[3] Obesity impacts on many areas of clinical medicine, including pulmonary medicine, where it is debated if obesity is linked to asthma,[4–5] or whether the obesity, due to its effect of decreasing lung volumes and increasing airway resistance,[6–10] causes symptoms that simply mimic asthma.[11,12] The purpose of this study was not to enter the obesity/asthma debate, but many obese people do have symptoms suggestive of lung disease,[11,12] so many of them are sent by their doctors for pulmonary function tests (PFTs). Therefore, it is important to understand the relationship between body mass index (BMI) and lung function to properly interpret PFTs. Our study is unique in that we show for the first time the correlation between BMI and lung volumes.

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Several previous studies[7,10,13–16] have reported that increased body weight decreases lung volumes, but many of the previous studies have been small; they included subjects with coexisting morbidities such as cardiovascular disease,[17] or they were conducted with the subjects in the supine position.[7] Also, some studies[12,16–19] reported only spirometry results or they included only two groups of subjects: those with lower BMI and those with high BMI.[13,14,20,21] Despite the different study populations, there is general agreement that obesity, even morbid obesity, has relatively little effect on vital capacity (VC) or total lung capacity (TLC). However, functional residual capacity (FRC) and expiratory reserve volume (ERV) can be severely decreased[14,15,17,20,22] as a result of the altered chest wall mechanics in obesity.[21,23–26] One study showed that mild obesity decreases FRC and ERV in patients with cardiovascular disease,[17] but others[13,15,27] reported that much more severe obesity is required to decrease FRC and ERV. Others[28] studied obese subjects before and after surgery-induced decreases in body weight, and showed that decreasing body weight has the expected positive impact on lung mechanics.

We have had much experience interpreting PFTs, and we noticed that FRC is often decreased in patients who have only a modest increase in BMI. We have also observed a high frequency of normal airway function in many obese patients with asthma receiving bronchodilators. This is not unexpected, since a previous report[11] from our institution showed that obesity is associated with a higher ratio of FEV_1 to FVC, while at the same time it is, parenthetically, associated with a higher incidence of bronchodilator use. We hypothesized that in patients with normal FEV_1/FVC ratio, there would be a significant decrease in lung volumes as BMI increased, and that some of the lung volumes would be decreased at modest values for BMI.

Materials and Methods

This was a retrospective study conducted between October 2004 and March 2005, and ethics approval was previously obtained to review the results of lung function. Data were collected from two laboratories with identical body plethysmograph systems. Three hundred seventy-three PFT results were selected for both male and female patients > 18 years old with normal forced expired flow rates and a smoking history of < 10 pack-years. The majority of the patient results that were reviewed but not selected for this study had significant airway obstruction, but others had evidence for interstitial lung disease or cardiovascular disease and some gave nonreproducible effort. Specifically, patients comprising this study had the following characteristics: (1) BMI > 20 kg/m^2; (2) white race; (3) no diagnosis of cardiopulmonary or chest wall disease, but a working diagnosis of asthma was permitted; (4) normal FEV_1/FVC ratio (90% of predicted)[29]; (5) normal forced expired flow at 75% of the FVC as derived from the data of Knudson et al.[30] The lower limit of normal (LLN) was taken as 25% of the FVC per second (the LLN for forced expired flow at 75% of FVC for a person with an FVC of 2 L would be 0.5 L/s); (6) residual volume (RV) below the upper limit of normal (ULN)[29]; and (7) single-breath diffusing capacity of the lung for carbon monoxide (DLCO) above the LLN[29] after adjusting for the patient's alveolar volume according to the method of Johnson.[31] Values for DLCO above the ULN were included.

The two laboratories from which the PFTs were reviewed and selected for this study are accredited by the Alberta College of Physicians and Surgeons. Prior to the study, both laboratories were inspected by a committee of the College composed of experts in lung function testing. The inspections included assessment of testing procedures, technician knowledge, infection control, safety, record keeping, and accuracy of data interpretation. Both laboratories use SensorMedics (Northridge, CA) Vmax 22 systems including a 6200 Autobox for measuring lung volumes. The plethysmograph software was Vmax version 06-1B (Viasys; Yorba Linda, CA), which adjusts the volume calibration for the size of the patient being tested. All patients tested were referred to these laboratories primarily by family physicians and internists for lung function testing. All patients arrived for testing with a PFT requisition stating the diagnosis or working diagnosis, symptoms, and medications. During the 5 months of selection for this study, approximately 1,700 tests were reviewed; and it was from this sample that the 373 patients were selected. We selected patients according to the criteria listed above and subdivided the patient results into BMI categories of 20 to 25 kg/m^2 (normal weight), $>$25 to 30 kg/m^2 (overweight), $>$30 to 35 kg/m^2 (mild obesity), $>$35 to 40 kg/m^2 (moderate obesity), and $>$ 40 kg/m^2 (morbid obesity).[32]

The lung volumes and FEV_1/FVC ratio are represented as percentage of the predicted value with the predicted values coming from a study by Gutierrez et al.[29] Predicted ERV was obtained by subtracting the predicted RV from the predicted FRC.[29] TLC was determined by FRC plus inspiratory capacity, and RV was determined by TLC minus VC.

The results were analyzed using linear or nonlinear exponential regression to assess the effects of BMI on lung volumes. Differences between BMI groups were analyzed using analysis of variance (ANOVA) with a Tukey *post hoc* analysis. Significance was taken as $p < 0.05$ for all tests.

Results

The numbers of female and male patients in each BMI group are shown in Table 1. There were fewer men in both the lowest and the two highest BMI groups. However, there were no significant differences in the best-fit regression lines between men and women for the effects of BMI on TLC, VC, RV, FRC, ERV, or DLCO. Therefore, we grouped the data from men and women together.

Figure 1 shows the effects of BMI on TLC, VC, and RV. The 20 to 25 kg/m^2 BMI group was not significantly different from the 25 to 30 kg/m^2 BMI group for any of these measurements. However, in all cases, the 20 to 25 kg/m^2 BMI group had significantly higher lung volumes than those in the $>$ 30 kg/m^2 BMI groups. The 25 to 30 kg/m^2 BMI group had a higher TLC than patients $>$ 35 kg/m^2

Table 1—*Pulmonary Function Results for the Different BMI Groups**

Variables	BMI Groups, kg/m^2 20–25	25–30	30–35	35–40	> 40
Gender					
Female	58	38	50	41	28
Male	35	40	42	26	15
FEV_1/FVC ratio	100.7 (5.6)	101.4 (5.5)	102.8 (4.9)	102.2 (5.9)	101.5 (4.2)
VC	97.6 (10.0)	97.2 (10.5)	92.2 (11.2)	91.1 (10.9)	87.9 (11.4)
TLC	98.7 (8.7)	96.9 (9.0)	93.1 (9.1)	92.0 (8.3)	88.1 (10.7)
RV	102.7 (15.9)	96.7 (18.3)	95.5 (16.4)	94.6 (16.3)	90.5 (17.2)
RV/TLC	29.6 (7.2)	30.5 (7.9)	32.1 (8.5)	32.6 (8.2)	31.0 (6.2)
FRC	103.1 (15.5)	89.2 (14.1)	78.3 (13.1)	72.2 (12.9)	66.6 (12.3)
FRC/TLC	52.9† (6.5)	46.2‡ (6.1)	42.6 (6.0)	44.4 (5.3)	42.2 (6.0)
ERV	95.6 (29.8)	72.3 (30.6)	42.4 (29.3)	29.3 (18.7)	24.6 (18.8)
Dlco	99.3 (10.9)	101.3 (10.7)	101.2 (11.3)	103.2 (12.4)	108.1† (8.5)

*Values are expressed as No. or mean percentage of predicted (SD), except for RV/TLC and FRC/TLC, which are absolute ratios. Comparisons between BMI groups for VC, TLC, RV, FRC, and ERV are illustrated in Figures 1, 2.
†For RV/TLC, FRC/TLC, and Dlco, $p < 0.05$ compared to all other BMI groups.
‡For RV/TLC, FRC/TLC, and Dlco, $p < 0.05$ compared to adjacent BMI groups.

and a higher VC than those patients > 30 kg/m^2, but there were no differences in RV between any of the adjacent BMI groups. The most dramatic effects of BMI were seen for FRC and ERV (Fig 2). For both FRC and ERV, there were significant differences between the 20 to 25 kg/m^2 BMI group and all other groups having higher BMI, including the 25 to 30 kg/m^2 BMI group. The latter also had significantly higher FRC and ERV than the groups with a BMI > 30 kg/m^2. However, FRC in the 30 to 35 kg/m^2 BMI group was not significantly higher than that for the 35 to 40 kg/m^2 BMI group, and the latter was not different from the > 40 kg/m^2 BMI group. There was, however, a significantly higher FRC in the 30 to 35 kg/m^2 BMI group compared to those patients with a BMI > 40 kg/m^2. The results were similar for ERV.

Figure 3 shows the linear regressions for Dlco, VC, TLC, and RV. In all cases, there was a significant linear relationship with BMI, but there were few individual patients whose values for any of these lung volumes were below the LLN. This was true even for the patients with morbid obesity. There was a slight and significant increase in Dlco with increasing BMI, but there were few values above the ULN.

The best-fit regressions for FRC and ERV were exponential, and both regressions were highly significant (Fig 4). The results show that both FRC and ERV decrease sharply at modest values for BMI. Subjects with a BMI of 30 have an FRC that is 84% of predicted and an ERV that is 55% of predicted. Those with a BMI of 40 kg/m^2 breathe close to their RV (ERV is only 28% of the predicted value).

Table 1 shows the combined male and female averages for FEV_1/FVC ratio, lung volumes, and Dlco for each BMI group. The RV/TLC ratio did not change significantly between any of the BMI groups, but the FRC/TLC ratio decreased sharply between the 20 to 25 kg/m^2 BMI group and the 25 to 30 kg/m^2 BMI group. Compared to the 20 to 25 kg/m^2 BMI group, the FRC/TLC ratio was significantly lower in all other groups, and the 25 to 30 kg/m^2 BMI group had a higher FRC/TLC ratio than the 30 to 35 kg/m^2 BMI group. The three highest BMI groups were not significantly different. For Dlco, the 20 to 25 kg/m^2, 25 to 30 kg/m^2, and 30 to 35 kg/m^2 BMI groups had slight but significantly lower mean values compared to the > 40 kg/m^2 BMI group.

Discussion

Our results confirm the findings of many others[14,15,17,20,22] who have shown that lung volumes, especially FRC and ERV, decrease as body weight increases. However, our study is unique in that it clearly shows the effects of BMI on lung volumes. This information is not available from other studies[7,10,13–16,20] that included small numbers or limited BMI groups. An interesting finding from the regression analyses is that FRC decreased from 112% of predicted at a BMI of 20 kg/m^2 to 84% of predicted at a BMI of 30 kg/m^2. The ERV decreased from 118% of predicted to 55% of predicted when BMI increased from 20 to 30 kg/m^2. Therefore, the FRC of a person with a BMI of 30 kg/m^2, who is on the borderline between overweight and mild obesity,[32] is only 75%; and ERV is only 47% of the values for a person with a BMI of 20 kg/m^2. Put another way,

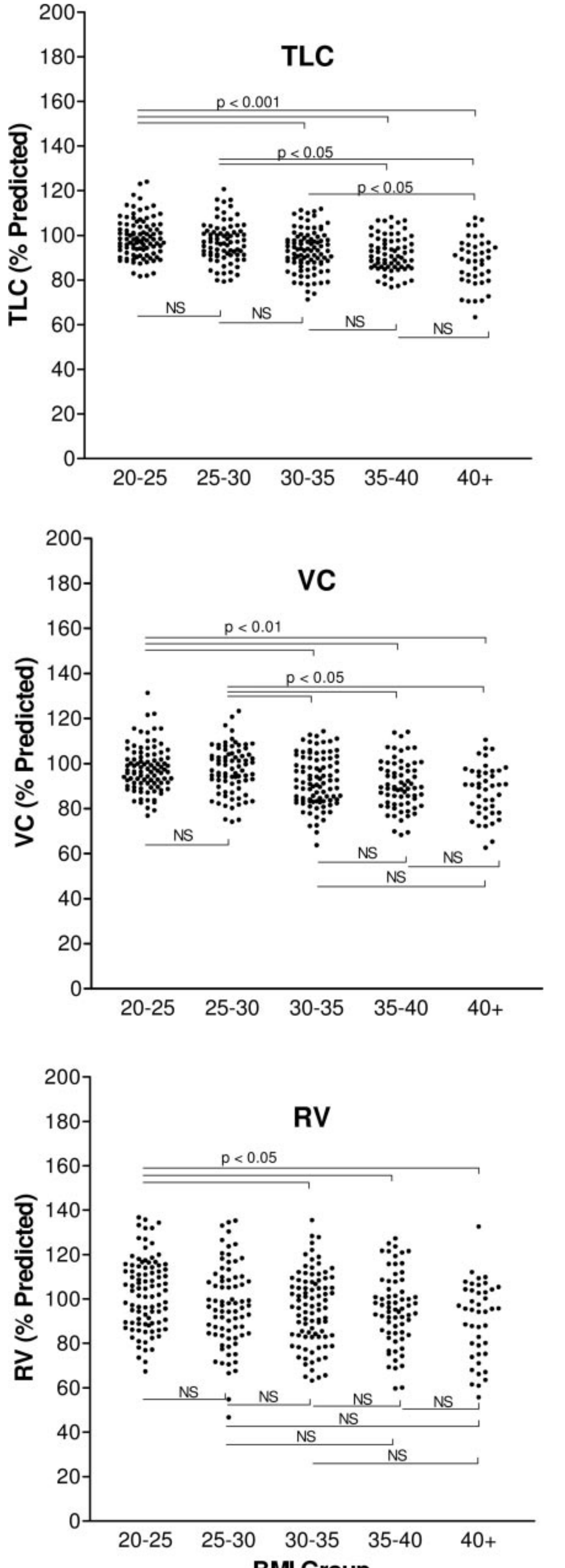

FIGURE 1. Effects of BMI on TLC (*top*), VC (*center*), and RV (*bottom*). The horizontal solid lines are the between-group comparisons from ANOVA and *post hoc* test. NS = not significant ($p > 0.05$).

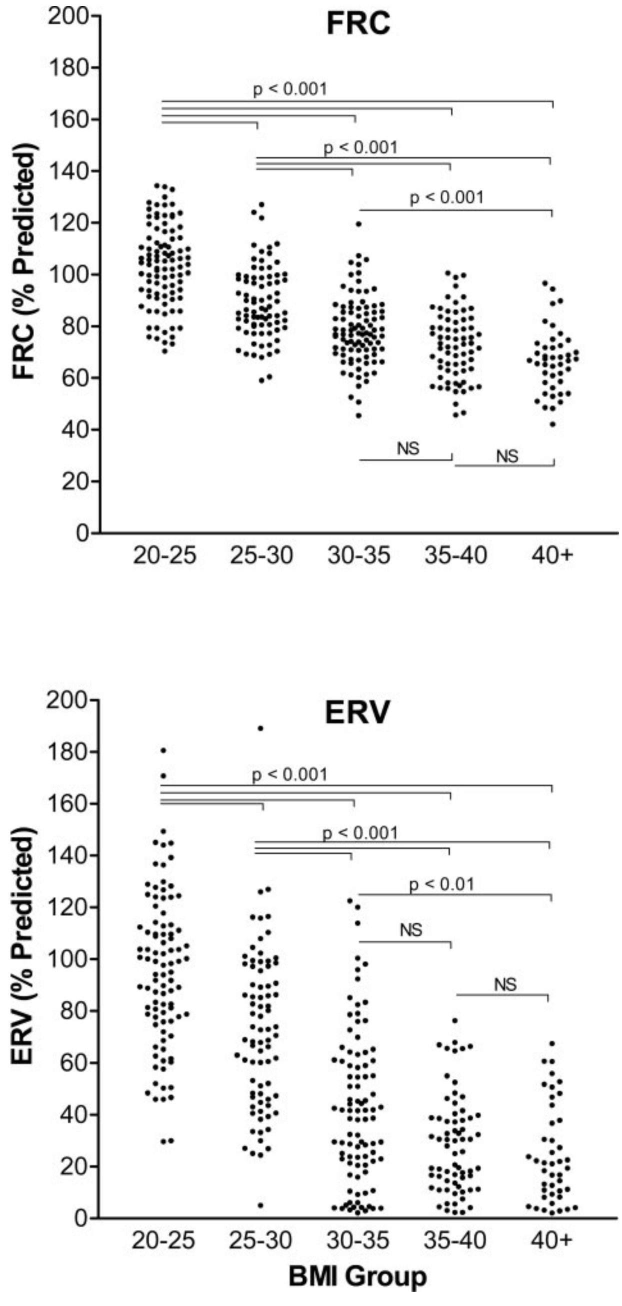

FIGURE 2. Effects of BMI on FRC (*top*) and ERV (*bottom*). The horizontal solid lines are the between-group comparisons from ANOVA and *post hoc* test. See Figure 1 legend for expansion of abbreviation.

compared to a person with a BMI of 20 kg/m^2, a person with a BMI of 30 kg/m^2 has already lost 66% of the FRC and 70% of the ERV of a person with a BMI of 40 kg/m^2. A person with a BMI of 35 kg/m^2 has lost 86% of the FRC and 88% of the ERV of a person with a BMI of 40 kg/m^2. Therefore, there is a rapid loss of FRC and ERV with modest weight gain. The exponential decrease in FRC with increasing BMI is similar to the finding of Pelosi et al,[7] who

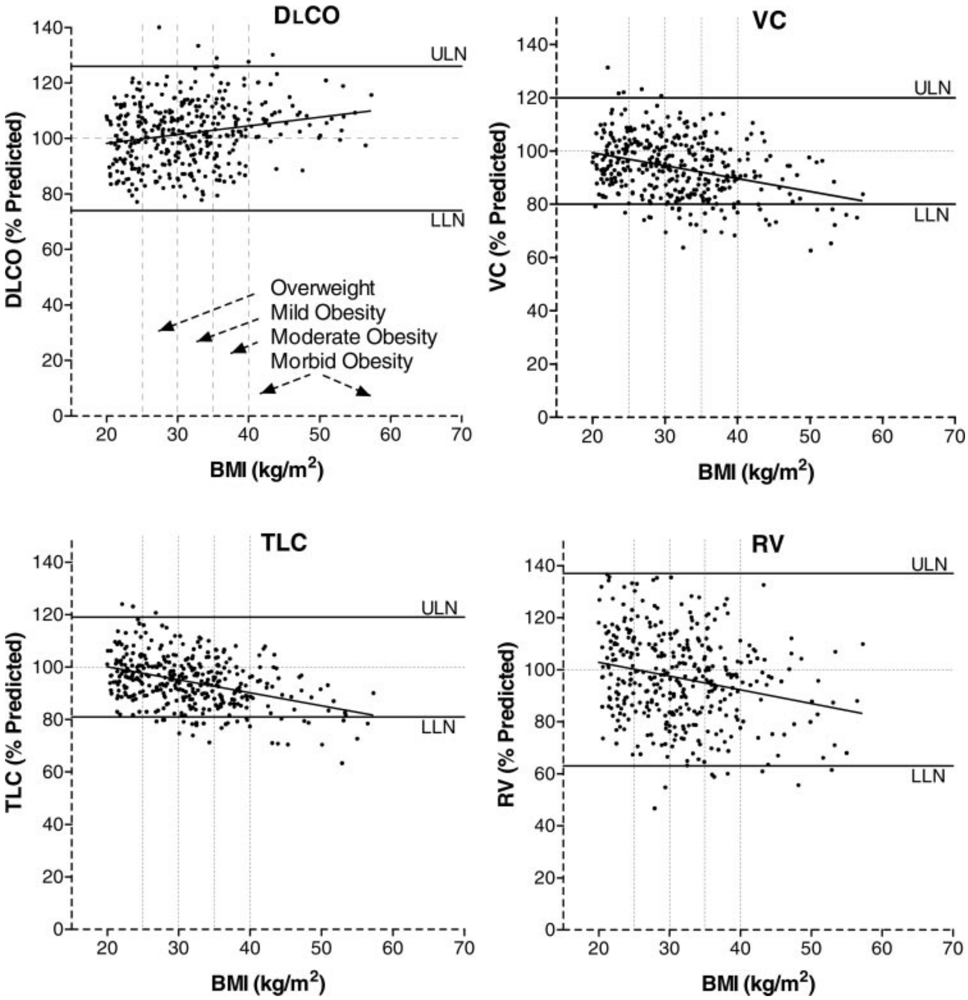

FIGURE 3. The linear regression between BMI and DLCO (*top left*), VC (*top right*), TLC (*bottom left*), and RV (*bottom right*). In all cases, the regressions were significant ($p < 0.0001$). The horizontal solid lines indicate the ULN and LLN.[29] The vertical dashed lines separate the various BMI classifications, which are defined in the DLCO graph. The slopes of the linear regression lines (percentage of predicted/BMI unit) were 0.31, − 0.48, − 0.50, and − 0.53 for DLCO, VC, TLC, and RV, respectively.

also showed that increasing BMI decreases FRC exponentially. However, Pelosi et al[7] performed their studies on supine and anesthetized patients, and the absolute effect of BMI on FRC in their study was greater than in our patients who were studied in the seated posture.

The lack of a significant effect of increasing BMI on RV/TLC ratio indicates that RV and TLC decrease proportionately with increasing body weight. However, the FRC/TLC ratio decreased from the 20 to 25 kg/m^2 BMI group to the 25 to 30 kg/m^2 and 30 to 35 kg/m^2 BMI groups, indicating that FRC is more affected by BMI than is TLC until BMI exceeds 35 kg/m^2, after which FRC and TLC decrease proportionately.

There is a relationship between FRC and airway resistance in obesity,[7–10] and airway conductance is linearly related to FRC in obesity.[6] Based on the changes in FRC observed in our study and compared to a person with a BMI of 20 kg/m^2, airway resistance would increase by approximately 33%, 49%, and 62% for people with BMI values of 30, 35, and 40 kg/m^2, respectively; and this might contribute to previous reports[11,12] of obesity-related breathing symptoms.

Our finding of an increasing DLCO with BMI has been reported previously.[33] However, the increases in DLCO were minimal, and our highest BMI group had an average DLCO of only 108% of predicted, which is well within the normal range.

Our regression analyses fit nicely with the normal reference values used.[29] For all the lung volumes (except ERV, which was predicted by subtracting the predicted RV from the predicted FRC and for which the normal range is not available) our subjects had near 100% of predicted values at a BMI of 25 kg/m^2, which was near that of the population comprising the reference set.[29]

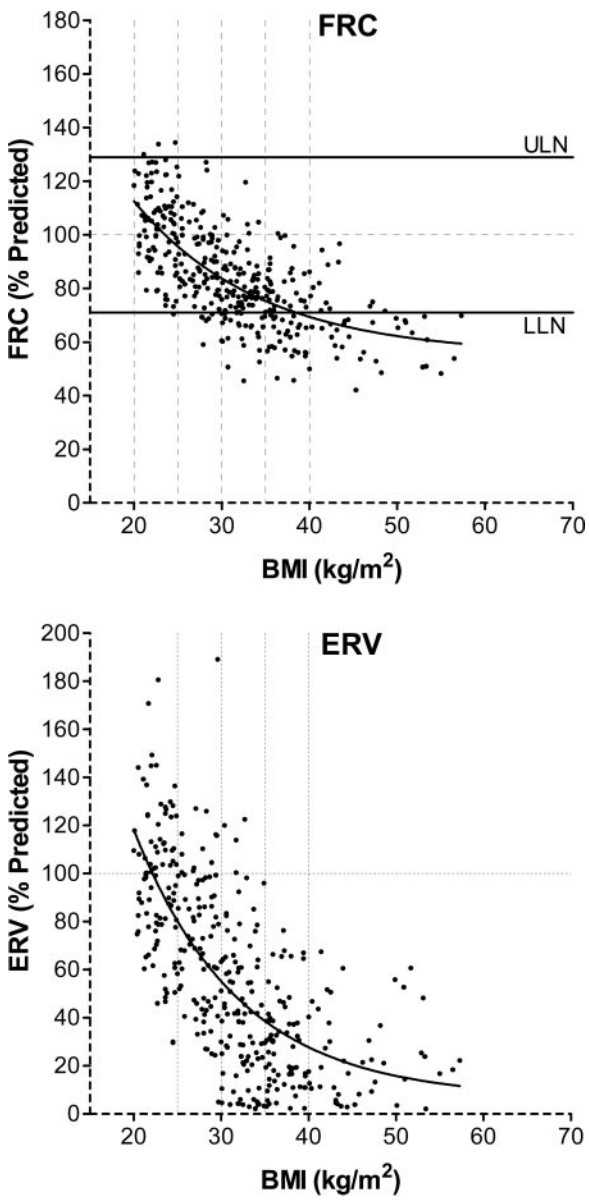

FIGURE 4. The exponential regressions for FRC (*top*) and ERV (*bottom*). The horizontal solid lines for FRC are the average ULN and LLN for men and women.[29] The normal range for ERV is not available. The r^2 values for both FRC and ERV were 0.49 ($p < 0.0001$), and the best-fit equations were as follows: $FRC = 231.9 \exp(-0.070 \times BMI) + 55.2$; and $ERV = 587.8 \exp(-0.083 \times BMI) + 6.5$. The BMI classifications are the same as those in Figure 3.

In summary, we showed the effects of increasing BMI on lung volumes, and our findings will assist clinicians when interpreting PFT results from patients with normal airway function. Using a rule of thumb, physicians can expect an approximate 0.5% decrease in VC, TLC, and RV with each unit increase in BMI. DLCO increases approximately 0.3% for each unit increase in BMI. For FRC and ERV, the changes are more dramatic. Although the linear regressions between BMI and FRC and ERV were significant ($p < 0.0001$), the exponential relationship was more accurate in showing the relatively rapid decrease in FRC and ERV in the overweight and mild obesity states. However, using the linear regressions, FRC and ERV decrease approximately 3% and 5%, respectively, for each unit increase in BMI from 20 to 30 kg/m^2. Above a BMI of 30 kg/m^2, both FRC and ERV decrease approximately 1% for each unit increase in BMI. With body weight increasing in North America,[1–3] and the reported relationship between FRC and airway resistance,[6] physicians can expect an increasing frequency of complaints of shortness of breath.

The potential impact on pulmonary function laboratories should be large since currently 35% of the US population is overweight (BMI 25 to 30 kg/m^2), 26% have mild-to-moderate obesity (BMI 30 to 40 kg/m^2), and 5% are morbidly obese with BMI > 40 kg/m^2 (derived from the data of Hedley et al[34]). Therefore, two thirds of the US population currently has a decreased FRC.

Limitations of the Study

Our selection criteria were based primarily on patients having a normal FEV_1/FVC ratio, a DLCO above the LLN, and no documented history of any disease. It is possible that some patients in our sample had chest wall disorders, other than obesity, or that some had pleural or lung parenchymal disease that was undiagnosed and which resulted in a normal DLCO. However, each patient selected for the study had seen their primary care physician prior to being tested, and there were no indications that these kinds of disorders existed. Although all of the patients included in our sample had normal forced expired flow rates when they were tested, it is possible that some of them had real asthma and that airway function happened to be normal at the time of testing. However, none of the patients selected had increased RV, which is another indicator of peripheral airway disease.[35] Another limitation is that our entire patient population was white, and the findings may not translate to other ethnic groups.

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