

Relationships between lung function and physical characteristics in young adult black and white males and females

W.F. McDonnell, E. Seal Jr

Relationship between lung function and physical characteristics in young adult black and white males and females. W.F. McDonnell, E. Seal Jr.

ABSTRACT: The relationships of lung function to physical characteristics in young adults have not been adequately described for different gender-race groups in the United States. As part of a study of the effects of ozone exposure upon Black and White men and women, we measured lung volumes, expiratory flow rates, and airways resistance on a sample of 314 healthy 18-35 yr old nonsmokers. Regression analysis indicated that lung function was adequately described as a linear function of either height or sitting height in each of the four groups, and that while not always significant, gender and race differences in the height and sitting height coefficients were consistently present with those of males and Whites larger than those of females and Blacks, respectively. Lung volumes were frequently observed to be associated with body mass index as measured by Quetelet Index (weight-height²). The best fitting gender-race specific multiple regression models including these terms and occasional age terms are presented. Two additional models are presented, one of which simultaneously adjusts for both gender and race, and the other of which adjusts for gender for a given race. Comparison of predicted values from our study to those of other studies suggests that the population samples from this study may be similar to those of other American populations reported upon by others.

Eur Respir J, 1991, 4, 279-289.

Clinical Research Branch, Human Studies Division, Health Effects Research Laboratory, US Environmental Protection Agency, Research Triangle Park, N.C., USA.

Correspondence: W.F. McDonnell, US Environmental Protection Agency, Campus Box 7315, University of North Carolina, Chapel Hill, N.C. 27599-7315, USA.

Keywords: Lung function; prediction equations; spirometry.

Received: November 1989; accepted after revision October 31, 1990.

Although the research described in this article has been supported by the US Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

It has long been recognized that gender-race differences in lung function exist, and equations predicting normal values of lung function for North Americans have been generated for gender-race specific groups or which include appropriate adjustments [1-10]. Only in a few recent studies have community based samples of nonsmokers been utilized to generate these prediction equations [11-14]. In general, the variables measured have been limited to those obtained from the forced expiratory spirogram. Other measures of lung volumes or airway resistance have less frequently been reported.

Often, the major focus of interest in this area has been to describe the relationship of lung function to age, especially with regard to normal growth and decline of lung function. Because of the discontinuity in the age-lung function relationship which occurs at the time when lung growth ceases and the ageing process becomes evident, these two age ranges are usually studied separately. With few exceptions, the period of maximal function has not been examined in its own right; rather it is described as the tail of an age distribution, is usually represented by a small number of subjects, and is often not described accurately because all but the most

complex models for children or adults cannot account for the plateau in lung function which occurs at this time. In these investigations, height, which is strongly associated with lung function, has usually been regarded as a nuisance variable which was controlled for in order to better understand the pure relationship of lung function with age. The models which best describe lung function over a large age range will not necessarily be the best models for describing the height-lung function relationship at one extreme of the age distribution, particularly since nonlinear effects of age and interactions of age with height and other variables which may exist over a large age range are difficult to adjust for. Measures of other physical characteristics are rarely included in such equations. Of the few studies that have restricted their observations to the period of maximal function, the numbers of lifetime nonsmoking Blacks and/or women participants have been small.

The purpose of this report is to describe the relationships of various lung function measures to physical characteristics of lifetime nonsmoking, North American, Black and White men and women who are nearing or have reached physical maturity, but who have

not yet begun to demonstrate appreciable loss of lung function due to the ageing process. We have fitted our data using both gender-race specific regression equations and unified equations which allow adjustments for gender and/or race in a single equation. Complete tables of all regressions are not included in this manuscript; they may, however, be obtained from the author upon request.

Materials and methods

Subjects

Subjects for this study were men and women 18–35 yrs of age who had never smoked cigarettes, had no history of allergic rhinitis, asthma, or any other chronic or recent acute respiratory illness, and who were in good general health. They were self-selected volunteers recruited from among local university students and townspeople in the area including Chapel Hill, Durham, and Raleigh, N.C. to participate in a study of the effects of ozone upon the respiratory function of Blacks and Whites, men and women. As such, they needed to be fit enough to complete a modest two-hour exercise protocol. Each potential subject completed a medical questionnaire and underwent a physical examination and routine haematological and serum chemistry screening. Only subjects judged to be completely healthy were allowed to participate in the study.

Data collection

All subjects completed training in the performance of spirometry and body plethysmography on a day prior to data collection. On the day of the study, subjects completed measures of functional residual capacity (FRC), airways resistance (Raw), slow vital capacity (VC), and forced expiratory spirometry in triplicate in that order. Functional residual capacity and Raw were measured at end-exhalation in a constant volume body plethysmograph (CPI model 2000TB) by the methods of DuBois and co-workers [15, 16]. Specific airways resistance was calculated as the product of Raw and the thoracic gas volume (Vtg) at which Raw was measured. Vital capacity was measured by having the volunteer establish an end-expiratory baseline (FRC) while breathing on a dry seal spirometer (CPI model 220) followed by a maximal inspiration and a slow full exhalation. Inspiratory capacity (IC) and expiratory reserve volume (ERV) were calculated. Forced expiratory spirometry was performed on the same instrument. Time of onset for forced expiratory volume in one second (FEV_1) was calculated using the back extrapolation method, and end of test for forced vital capacity (FVC) was defined as the point at which no volume change greater than 3 ml occurred for 0.1 s. Other variables calculated from the forced expiratory spirogram included peak expiratory flow rate (PEF), mean forced expiratory flow rate between 25 and 75% of FVC (FEF_{25-75}), maximal instantaneous flow rates at 50%

of exhaled volume (\dot{V}_{50}) and at 75% of exhaled volume (\dot{V}_{75}).

Testing was completed between 8 a.m. and 1 p.m. at 22°C and 40% relative humidity, and noseclips were worn during all manoeuvres. Values were corrected to body temperature and pressure, saturated. Spirometry and plethysmography were performed in the standing and sitting positions, respectively. Electronic testing of spirometric and plethysmographic calibration was performed prior to each trial, and full calibration was performed every two weeks.

Data were reduced as follows. The means of all technically adequate measurements were used for FRC and sRaw. The IC and ERV were calculated as the means from the manoeuvres with the two largest vital capacities. The FEF_{25-75} , \dot{V}_{50} , and \dot{V}_{75} were selected from the manoeuvre with the largest sum of FVC and FEV_1 . The largest single values of FVC, FEV_1 , PEF, and VC were used. The ratio of FEV_1 to FVC was calculated from these largest values. Total lung capacity (TLC) was calculated as the sum of FRC and IC, and residual volume (RV) was calculated as the difference between FRC and ERV.

Statistical analysis

Determination of the most appropriate forms of the equations for height, for sitting height, and for Quetelet Index was accomplished for each of the four groups by examination of plots of moving averages of the dependent variable versus the independent variable and by polynomial regression including the linear and the quadratic terms. Tests of significance of the linear and quadratic coefficients were performed utilizing a partial F test [17]. When necessary to avoid problems of collinearity, the independent variables were centred prior to regression analysis by subtracting the sample mean of that variable from each person's value [17]. This technique, which increases the precision of the estimates, does not alter the value of the coefficient of the highest order term for the centred variable but does transform the intercept and lower order terms.

The differences in height or sitting height coefficients between the races were assessed statistically for each gender by evaluating the race-height or race-sitting height terms, respectively, in models containing subjects from both races. Differences between the genders were similarly assessed for each race. Simultaneous assessment of gender and race differences was not performed to avoid the necessity of including higher order interaction terms which introduced problems of collinearity. Selection of the best overall model for each gender-race group was accomplished utilizing multiple regression techniques. For each variable, the terms height, Quetelet Index, Quetelet Index², and age terms were included in the maximal model. For males, age and log age (with age transformed by subtracting 17) were included. For females, only age (similarly transformed) was added. These expressions were chosen because of previous observations suggesting that females have generally

completed lung growth by age 18 yrs while males may continue to have a small amount of growth until their early twenties followed by a plateau and eventual loss of lung function [13, 14, 18, 19]. A backwards elimination strategy was utilized that first assessed the statistical significance of the Quetelet² term. If significant, both the Quetelet and Quetelet² terms remained in the model without further testing. If not, Quetelet² was eliminated, and the model was refitted. The term (height, Quetelet) with the highest nonsignificant p value ($p > 0.05$) was then excluded. This process continued until only significant terms remained. The log age and age terms were assessed last. Any age term that was significant or the removal of which resulted in a substantial change in any remaining non-age coefficients of the model was retained in the model. Otherwise, it was excluded.

Unified models of the forms proposed by SCHWARTZ *et al.* [14] which included both gender and race terms, and by DOCKERY *et al.* [11] which included only a gender term were fitted to this data set. All data analysis was performed using Statistical Analysis System (SAS) programs, and all regression equations were generated using the REG procedure [20].

Results

Of the 347 subjects who performed lung function testing, 30 were eliminated on the basis of re-examination of questionnaires and pulmonary function. The

reasons and number initially excluded from this study included allergic rhinitis (3), childhood asthma (1), current smoking (1), any with a smoking history within 5 yrs or a duration of greater than 1 yr or an amount greater than 1 pack per week (18), history of cough and sputum (2), and FEV₁/FVC <70% (5). Three subjects were later excluded for disproportionate height, sitting height, weight, and FEV₁, suggesting measurement error or nonrepresentative subjects. Subjects who had technically inadequate measurement of forced expiratory spirometry (3), functional residual capacity (2), and vital capacity (1) were excluded from analysis of the affected variables, but were included for others. Measurement of sitting height was not recorded for 23 subjects.

The numbers, anthropometric characteristics, and lung function values for each gender-race group are presented in table 1. The majority of volunteers were in the age range of 18–25 yrs with a slightly larger proportion of White males over the age of 30 yrs. Whites were slightly taller than Blacks for both genders. Blacks had proportionally smaller sitting heights than did Whites. Blacks were somewhat heavier and had larger values for Quetelet Index. Lung volumes were uniformly larger in males and Whites than in females and Blacks, respectively. Little or no race difference in forced expiratory flow rates was observed, although gender differences were present. Blacks and females had larger values of FEV₁/FVC than did Whites and males.

Table 1. – Anthropometric and lung function values by gender and race

	Female		Male	
	Black	White	Black	White
n	67	89	75	83
Age yrs	23.2 (4.2)	23.3 (4.0)	22.9 (3.7)	25.0 (4.4)
Ht cm	165.2 (5.9)	167.1 (5.8)	179.0 (6.5)	180.3 (7.1)
Sit ht cm	71.3 (3.2)	73.9 (3.3)	76.3 (2.5)	78.6 (3.4)
Wt kg	63.4 (11.8)	58.7 (7.0)	76.4 (10.9)	74.7 (10.2)
Quetelet kg·m ⁻²	23.2 (3.8)	21.0 (2.2)	23.8 (3.0)	23.0 (2.8)
FVC l	3.36 (0.46)	3.86 (0.48)	4.67 (0.66)	5.39 (0.79)
FEV ₁ l	2.95 (0.37)	3.30 (0.38)	3.91 (0.55)	4.46 (0.65)
VC l	3.47 (0.49)	3.95 (0.49)	4.84 (0.69)	5.53 (0.84)
FRC l	2.17 (0.34)	2.64 (0.44)	2.86 (0.60)	3.34 (0.73)
TLC l	4.46 (0.55)	5.21 (0.62)	6.02 (0.85)	7.03 (1.01)
RV l	1.03 (0.31)	1.27 (0.34)	1.23 (0.41)	1.55 (0.44)
IC l	2.30 (0.43)	2.56 (0.43)	3.16 (0.53)	3.70 (0.75)
ERV l	1.14 (0.30)	1.38 (0.28)	1.64 (0.48)	1.80 (0.53)
PEF l·s ⁻¹	7.47 (1.31)	7.46 (1.10)	10.29 (1.61)	10.83 (1.65)
FEF ₂₅₋₇₅ l·s ⁻¹	3.80 (0.75)	3.72 (0.70)	4.35 (1.16)	4.69 (1.11)
\dot{V}_{75} l·s ⁻¹	1.85 (0.48)	2.01 (0.56)	2.10 (0.82)	2.35 (0.72)
\dot{V}_{50} l·s ⁻¹	4.39 (0.93)	4.25 (0.82)	4.93 (1.22)	5.27 (1.32)
FEV ₁ /FVC %	88.1 (4.3)	85.9 (5.0)	84.0 (5.5)	82.9 (5.2)
sRaw cmH ₂ O·s ⁻¹	3.19 (1.21)	4.09 (1.18)	3.50 (1.16)	3.73 (1.17)

Values are means±SD. Ht: standing height; Sit ht: sitting height; Wt: weight; Quetelet: weight·ht⁻²; FVC: forced vital capacity; FEV₁: forced expiratory volume in one second; VC: vital capacity; FRC: functional residual capacity; TLC: total lung capacity; RV: residual volume; IC: inspiratory capacity; ERV: expiratory reserve volume; PEF: peak expiratory flow; FEF₂₅₋₇₅: forced expiratory flow rate between 25 and 75% of FVC; \dot{V}_{75} and \dot{V}_{50} : maximal instantaneous flow at 75% and 50% exhaled volume; sRaw: specific airways resistance.

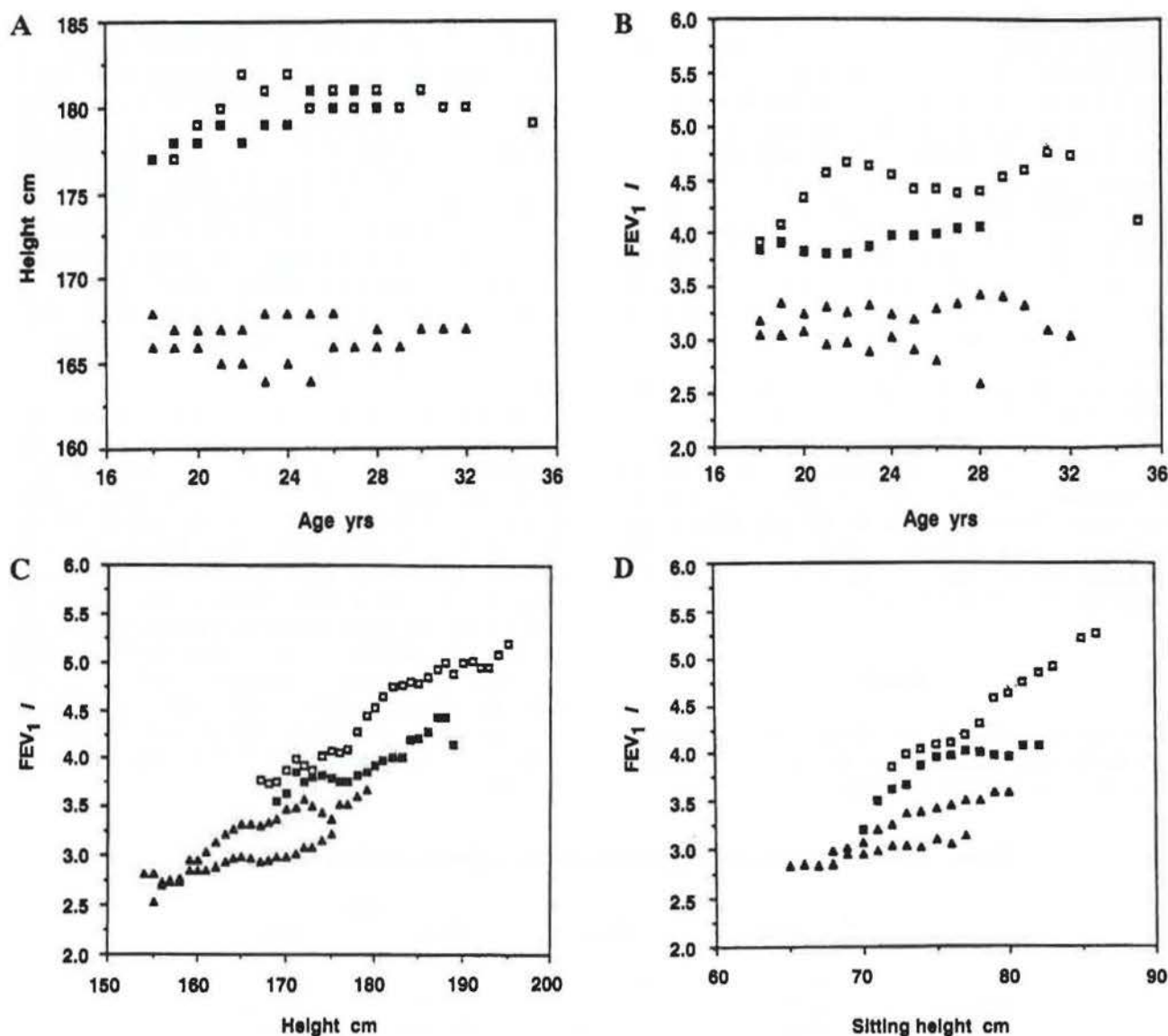


Fig. 1. — Moving averages of height and FEV₁ versus age, height, and sitting height by race and gender. Intervals of three yrs and five cm were averaged, respectively, for age, and for height and sitting height. FEV₁: forced expiratory volume in one second; □: White males; ■: Black males; △: White females; ▲: Black females.

Relationships with age

There was no relationship observed between height or sitting height and age for Black or White women. For White men, and to a lesser extent for Black men there appeared to be slight increases in height from age 18 yrs to the early twenties (figure 1A). There was no meaningful relationship between Quetelet Index and age for any of the groups. In general, measures of lung volume had small and usually nonsignificant relationships with age. One exception was for White men who had small significant initial increases followed by a plateau (fig. 1B). When height was controlled for, these increases with age became marginally significant or nonsignificant. Another exception was a small significant increase in RV with age in most gender-race groups. For the forced expiratory flow rates, the White males had a similar though diminished relationship with age as that for

volume while the other groups had no relationships or small declines with age. For FEV₁/FVC, the White men showed the same initial increase followed by a significant decline while the other groups experienced modest significant declines. There was little apparent relationship with specific airways resistance (sRaw) in any group.

Relationship to height

There were in general statistically significant linear relationships between the volume measurements and height for all four gender-race groups (table 2 and fig. 1C). In no case did the addition of a higher order height term significantly improve the fit of the model. The White males and the White females had larger height coefficients than the Black males and females,

Table 2. — Regression equations of lung function against height by gender and race

		Intercept (se)	Height (se)	r ²	Predicted
FVC [†] l	BF	-2.95 (1.37)	3.82 (0.83)	0.25*	3.74
	WF	-3.29 (1.25)	4.28 (0.75)	0.28*	4.20
	BM	-6.35 (1.69)	6.15 (0.94)	0.37*	4.41
	WM	-8.08 (1.64)	7.47 (0.91)	0.46*	4.99
FEV ₁ [†] l	BF	-1.74 (1.14)	2.84 (0.69)	0.21*	3.23
	WF	-2.39 (1.01)	3.41 (0.60)	0.27*	3.58
	BM	-3.98 (1.52)	4.41 (0.85)	0.27*	3.74
	WM	-6.37 (1.36)	6.00 (0.76)	0.44*	4.13
VC [‡] l	BF	-2.77 (1.52)	3.77 (0.92)	0.21*	3.83
	WF	-2.87 (1.31)	4.08 (0.79)	0.24*	4.27
	BM	-6.82 (1.75)	6.51 (0.98)	0.38*	4.57
	WM	-8.99 (1.72)	8.06 (0.95)	0.47*	5.12
TLC [‡] l	BF	-1.75 (1.74)	3.76 (1.05)	0.16*	4.83
	WF	-2.87 (1.72)	4.83 (1.03)	0.21*	5.58
	BM	-7.84 (2.22)	7.74 (1.24)	0.35*	5.71
	WM	-10.29 (2.15)	9.61 (1.20)	0.45*	6.53
FRC [‡] l	BF	-0.05 (1.15)	1.35 (0.70)	0.05	2.31
	WF	-0.51 (1.31)	1.89 (0.79)	0.06*	2.80
	BM	-6.02 (1.63)	4.96 (0.91)	0.29*	2.66
	WM	-6.75 (1.77)	5.60 (0.98)	0.29*	3.05

Regression equations of the form $FVC = A + B \cdot \text{height}$ were fitted with height in m. The values in the table are the intercepts and the height coefficients with their standard errors. Predicted values were calculated at a height of 1.75 m. r: correlation coefficient; BF: Black female; WF: White female; BM: Black male; WM: White male. *: p value <0.05 for testing the null hypothesis of $r = 0$; †: p value <0.05 for testing the null hypothesis $B(BF) = B(WF)$; ‡: p value <0.05 for testing the null hypothesis $B(BM) = B(WM)$; §: p value <0.05 for testing the null hypothesis $B(BF) = B(BM)$; †: p value <0.05 for testing the null hypothesis $B(WF) = B(WM)$. For other definitions see legend to table 1.

respectively. While the differences in the height coefficients between the races were only rarely statistically significant, some of them differed by a considerable amount, and in all cases except ERV those for Whites were larger than those for Blacks. The men of both races had larger height coefficients than did the women of the same race. In a number of cases, these differences were statistically significant. Predicted values for Whites and males at a height of 175 cm were larger than for Blacks and females.

Very little of the variance in flow measurements among individuals was explained by height, though many of the height coefficients were significantly different from zero (table available from authors). With the exception of PEF for which height coefficients were similar among the races or slightly larger in the Blacks, the coefficients for Whites were generally larger than for Blacks of the same gender. For Whites, the men usually had larger coefficients than the women. For Blacks, the results were variable. For sRaw and FEV₁/FVC there was little relationship with height.

Relationship to sitting height

As with height, most lung volumes had significant linear relationships with sitting height without statistically significant quadratic relationships (fig. 1D, table available from authors). In general the males and the Whites had larger sitting height coefficients than did the females and the Blacks. The degree of difference among the coefficients was similar to that for height when comparing races, but was larger than that for height when comparing genders. The differences in predicted values for lung function at a sitting height of 75 cm were smaller between the races than those calculated at a fixed standing height, but were still considerably different. The proportion of variance explained by linear regression with sitting height was similar, but somewhat smaller than that explained by height with a few exceptions. The relationships between forced expiratory flow rates and sitting height were consistently weak and usually not statistically significant.

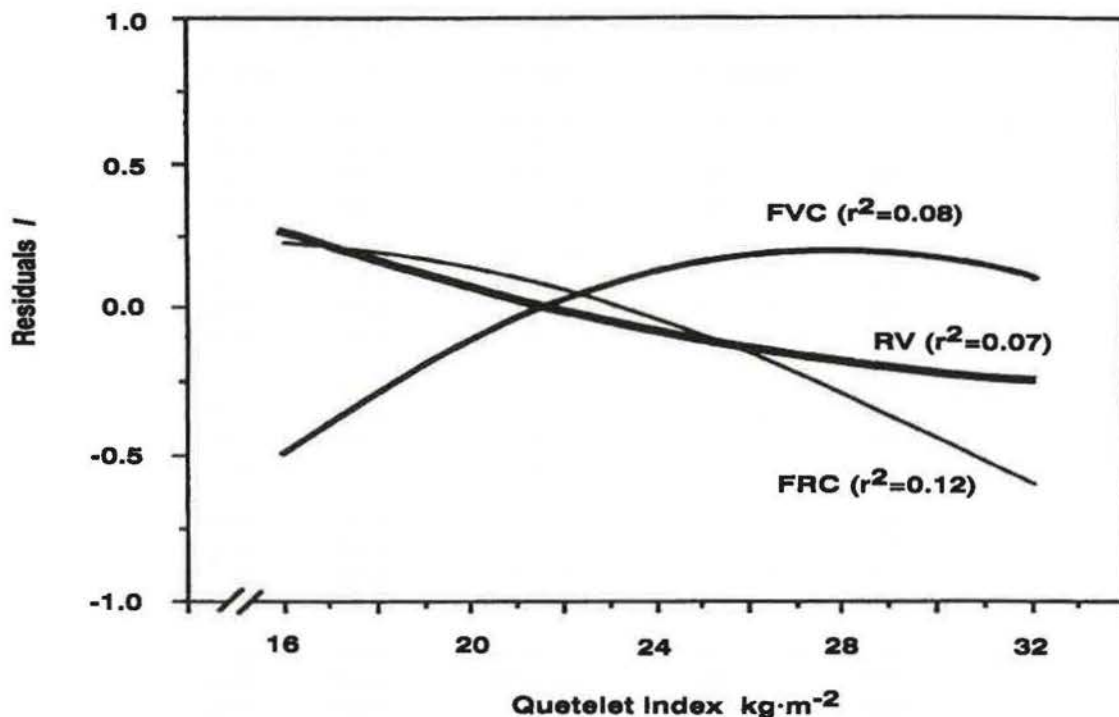


Fig. 2. — Relationships of residuals of lung volumes adjusted for height, gender, and race with Quetelet Index ($\text{wt} \cdot \text{ht}^{-2}$). FVC: forced vital capacity; RV: residual volume; FRC: functional residual capacity.

Relationship to Quetelet Index

Examination of moving averages of most dependent variables plotted against Quetelet Index suggested a variety of curvilinear functions, most of which were concave downward. The best fitting quadratic functions are available from the author. There were no significant relationships between Quetelet Index and height or sitting height for any of the gender-race groups. Relationships between lung volumes and Quetelet Index are significant in many cases with the proportion of variance explained ranging up to 20%. While the squared term for Quetelet Index is statistically significant in only a few cases, the signs of these terms are almost uniformly negative suggesting an inverted "U" shaped relationship.

Examination of graphs (not presented) of these data reveal slight increases in VC, FVC, FEV_1 , and PEF with increasing Quetelet Index, reaching a plateau at higher values of Quetelet. FRC, the variable with the strongest relationship, and RV decrease over the observed range of Quetelet Index. This is illustrated in figure 2 which is a quadratic fit of the residual variance after adjusting for height, race, and gender against Quetelet. The r^2 for each variable is the proportion of the residual variance explained by Quetelet Index. Other flow rates, TLC, FEV_1/FVC , and sRaw are poorly correlated with Quetelet.

Multivariable models

The best fitting equations for each gender-race group are contained in table 3. Height is usually a significant predictor, and Quetelet Index, with or without the quadratic term, contributes significantly for many of the lung volumes. Age sporadically accounts for some small proportion of the variance or influences the other coefficients. While the r^2 for each multivariable model is greater than that for the corresponding model which is univariate in height, the predicted values are similar.

Unified equations of the forms proposed by DOCKERY *et al.* [11] and SCHWARTZ *et al.* [21] are listed in table 4 for FVC and FEV_1 . Both predict significantly larger lung volumes for males compared to females and that of Schwartz also predicts a significant race effect. In neither of these models was age significant.

Discussion

The best fitting models for these samples indicate that lung volumes are associated consistently with a linear measure of height, frequently with Quetelet Index, and infrequently with age for young adults. The generally negligible relationships with age are in agreement with other reports describing a plateau in lung function from

Table 3. – Best fitting multiple regression equations by gender and race

		Age	LnAge	Height	Quetelet	Quetelet ²	Intercept	r ²	Pre- dicted
FVC l	BF	-	-	3.82 (0.83)	-	-	-2.95 (1.37)	0.25	3.74
	WF	-	-	4.44 (0.71)	0.06 (0.02)	-	-3.44 (1.19)	0.35	4.33
	BM	-	-	5.98 (0.90)	0.07 (0.03)	-0.01 (0.01)	-5.97 (1.62)	0.44	4.50
	WM	-	-	7.74 (0.87)	0.07 (0.02)	-	-8.55 (1.57)	0.51	4.98
FEV ₁ l	BF	-0.02 (0.01)	-	2.84 (0.67)	-	-	-1.61 (1.12)	0.26	3.28
	WF	-	-	3.64 (0.58)	0.01 (0.02)	-0.01 (0.00)	-2.68 (0.96)	0.36	3.69
	BM	-	-	4.27 (0.83)	0.05 (0.02)	-0.01 (0.01)	-3.67 (1.49)	0.33	3.80
	WM	-	-	6.18 (0.74)	0.05 (0.02)	-	-6.69 (1.33)	0.48	4.13
VC l	BF	-	-	3.59 (0.90)	0.03 (0.01)	-	-2.47 (1.49)	0.26	3.81
	WF	0.03 (0.01)	-	4.28 (0.72)	0.07 (0.02)	-	-3.24 (1.20)	0.38	4.37
	BM	-	-	6.31 (0.91)	0.09 (0.03)	-0.02 (0.01)	-6.37 (1.64)	0.48	4.67
	WM	-	-	8.31 (0.92)	0.06 (0.02)	-	-9.44 (1.67)	0.51	5.10
FRC l	BF	-	-	1.55 (0.66)	-0.03 (0.01)	-	-0.39 (1.08)	0.18	2.32
	WF	0.04 (0.01)	-	1.74 (0.69)	-0.07 (0.02)	-	-0.64 (1.15)	0.31	2.57
	BM	-	-	4.82 (0.84)	-0.02 (0.02)	-0.01 (0.01)	-5.64 (1.52)	0.41	2.80
	WM	0.03 (0.01)	-	5.18 (0.87)	-0.11 (0.02)	-	-6.24 (1.57)	0.46	2.95
TLC l	BF	-	-	3.76 (1.05)	-	-	-1.75 (1.74)	0.16	4.83
	WF	0.04 (0.01)	-	4.82 (0.98)	-	-	-3.13 (1.64)	0.29	5.47
	BM	-	-	7.53 (1.21)	0.06 (0.03)	-0.02 (0.01)	-7.32 (2.17)	0.41	5.86
	WM	0.04 (0.02)	-	9.60 (1.17)	-	-	-10.56 (2.12)	0.47	6.40
RV l	BF	-	-	-	-0.02 (0.01)	-	1.03 (0.04)	0.07	1.03
	WF	0.02 (0.01)	-	-	-0.06 (0.02)	-	1.05 (0.07)	0.19	1.13
	BM	-0.11 (0.03)	0.66 (0.16)	-	-0.05 (0.01)	-	0.86 (0.11)	0.27	1.33
	WM	0.03 (0.01)	-	1.99 (0.61)	-0.04 (0.02)	-	-2.26 (1.10)	0.25	1.34
IC l	BF	-	-	2.17 (0.79)	0.04 (0.01)	-	-1.29 (1.31)	0.24	2.51
	WF	-	-	3.12 (0.65)	0.08 (0.02)	-	-2.48 (1.08)	0.34	2.98
	BM	-	-	2.80 (0.86)	0.06 (0.02)	-	-1.89 (1.54)	0.22	3.01
	WM	-	-	4.79 (0.92)	0.13 (0.02)	-	-4.93 (1.66)	0.39	3.45
ERV l	BF	-	-	1.36 (0.60)	-	-	-1.11 (0.99)	0.07	1.27
	WF	0.02 (0.01)	-	1.25 (0.49)	-	-	-0.84 (0.82)	0.15	1.43
	BM	-	-	3.57 (0.73)	0.02 (0.02)	-0.01 (0.00)	-4.67 (1.31)	0.31	1.58
	WM	-	-	3.13 (0.65)	-0.04 (0.02)	-0.01 (0.00)	-3.76 (1.18)	0.41	1.72
PEF l·s ⁻¹	BF	-	-	-	0.12 (0.05)	-0.02 (0.01)	7.73 (0.18)	0.14	7.73
	WF	-	-	5.40 (1.81)	-0.01 (0.07)	-0.05 (0.01)	-1.19 (3.02)	0.22	8.26
	BM	-	-	7.60 (2.66)	0.14 (0.06)	-	-3.44 (4.77)	0.16	9.86
	WM	-0.29 (0.11)	2.52 (0.76)	5.49 (2.33)	-	-	-1.54 (4.15)	0.22	10.42
FEF ₂₅₋₇₅ l·s ⁻¹	BF	-0.06 (0.02)	-	-	-	-	4.19 (0.16)	0.13	3.95
	WF	-	-	3.52 (1.23)	-0.02 (0.05)	-0.02 (0.01)	-1.99 (2.05)	0.15	4.17
	BM	-	-	-	-	-	-	-	4.35

Table 3. - continued

\dot{V}_{75} $l \cdot s^{-1}$	WM	-	-	5.61 (1.60)	-	-	-	-	-5.44 (2.89)	0.13	4.38
	BF	-0.06 (0.01)	-	-	-	-	-	-	2.20 (0.09)	0.25	1.96
	WF	-	-	2.00 (1.01)	-	-	-	-	-1.33 (1.69)	0.04	2.17
	BM	-	-	-	-	-	-	-	-	-	2.10
\dot{V}_{50} $l \cdot s^{-1}$	WM	-	-	3.70 (1.05)	-	-	-	-	-4.31 (1.89)	0.13	2.17
	BF	-0.06 (0.03)	-	-	-	-	-	-	4.78 (0.20)	0.08	4.54
	WF	-	-	3.25 (1.43)	-	-	-	-0.03 (0.01)	-0.97 (2.39)	0.14	4.72
	BM	-	-	-	-	-	-	-	-	-	4.93
FEV ₁ /FVC %	WM	-	-	5.82 (1.95)	-	-	-	-	-5.23 (3.52)	0.13	4.96
	BF	-0.39 (0.12)	-	-16.94 (8.09)	-	-	-	-	118.55 (13.40)	0.20	87.3
	WF	-0.33 (0.13)	-	-	-	-	-	-0.16 (0.07)	87.83 (1.07)	0.13	86.5
	BM	-	-	-	-	-	-	-	-	-	84.0
sRaw $cmH_2O \cdot s^{-1}$	WM	-0.83 (0.36)	5.65 (2.56)	-	-	-	-	-	78.83 (2.44)	0.06	83.3
	BF	-	-	-	-	-	-	-	-	-	3.19
	WF	-	-	-	-	-	-	-	-	-	4.09
	BM	-	-	-	-	-	-	-	-	-	3.50
	WM	-	-	4.32 (1.76)	-	-	-	-	-4.05 (3.18)	0.07	3.51

Form of equation: $FVC = A + B \cdot (\text{age}-17) + C \cdot \ln(\text{age}-17) + D \cdot \text{height} + E \cdot (\text{Quetelet}-23) + F \cdot (\text{Quetelet}-23)^2$ with age in yrs, height in m, and Quetelet in $kg \cdot m^{-2}$. Values for the intercept and coefficients are in the columns with their standard errors in the table. Predicted values are calculated at age = 21 yrs, height = 1.75m, and Quetelet = 23 $kg \cdot m^{-2}$. Age: age-17; Lnage: $\ln(\text{age}-17)$; Quetelet=Quetelet-23. For other definitions see legends to tables 1 and 2.

Table 4. - Prediction equations for FVC and FEV₁ as functions of height, race, and gender

Model 1 (Black)

$$FVC = Ht^2 \cdot (1.455 - 0.227 \cdot \text{Gender})$$

$$FEV_1 = Ht^2 \cdot (1.218 - 0.139 \cdot \text{Gender})$$

Model 1 (White)

$$FVC = Ht^2 \cdot (1.658 - 0.279 \cdot \text{Gender})$$

$$FEV_1 = Ht^2 \cdot (1.371 - 0.190 \cdot \text{Gender})$$

Model 2

$$\ln FVC = 0.370 + 2.210 \cdot \ln Ht - 0.122 \cdot \text{Race} - 0.158 \cdot \text{Gender}$$

$$\ln FEV_1 = 0.289 + 2.021 \cdot \ln Ht - 0.104 \cdot \text{Race} - 0.130 \cdot \text{Gender}$$

Model 1 after DOCKERY *et al.* [11]. Model 2 after SCHWARTZ *et al.* [21]. Gender = 0 if male, 1 if female; race = 0 if White, 1 if Black; Ln: natural logarithm; all coefficients, $p < 0.01$. FVC: forced vital capacity; FEV₁: forced expiratory volume in one second.

the late teens to the early thirties [13, 14, 18, 19]. The few exceptions are consistent with the small age-related increase in height for White males and with normal ageing of the lung.

A model linear in height without interaction terms is consistent with a number of previously proposed prediction equations [8-10, 12]. Other investigators have proposed models including higher order height terms [11, 22], interaction terms of height with other variables [11, 13, 23], or transformed variables [14]. We have explored these possibilities in each of our four data sets. In no case did the addition of a height squared term to a model containing height explain a significantly greater proportion of the variance in FVC or FEV₁ for our samples nor did addition of the interaction, quadratic, and logarithmic terms proposed by SCHOENBERG *et al.* [13]. These additional terms seem most useful when creating unified equations [11, 14], predicting over large age ranges [13], or for simplifying graphical presentation of data [11]. They do not appear to improve prediction of lung function for a given gender-race group in this age range.

Associations of FVC and FEV₁ with weight (or deviations from ideal weight) have previously been described with lung function increasing with weight at low weights and decreasing at much higher values of weight [11, 13]. In our samples, FRC clearly decreased with increasing Quetelet Index, which is consistent with increased chest wall weight resulting in a lower end-expiratory volume. We observed significant reductions in RV, slight increases in FVC, FEV₁, VC, and PEF, and very little relationship of TLC with increasing Quetelet Index. In older adults, airway closure is the major determinant of RV. In young, healthy individuals, however, chest wall mechanics also play a role [24] with more muscular individuals being able to generate higher end-expiratory pressures resulting in lower RV and larger VC and FVC. The increases in FEV₁ and PEF are

consistent with increased muscular effort during the initial, effort-dependent stage of forced exhalation.

The data from this study indicate that in this population of young adults, men generally have larger volumes and flow rates than women, and Whites generally have larger volumes than and flow rates similar to Blacks even following adjustment for height or sitting height. This is in agreement with previous reports for adults [1, 11–14] and in contrast with what has been observed for children in whom Blacks and females often have larger expiratory flow rates [13, 14, 25].

Using regression equations linear in height, males consistently had larger height coefficients than females with these differences more likely to be statistically significant in Whites than Blacks. These findings are similar to those of numerous other studies [8–12, 14]. Whites uniformly had larger height coefficients than Blacks for both genders, although these differences were rarely statistically significant. The values of the height coefficients for the Black and White males, however, are very similar to those observed by ROSSITER and WEILL [1] who also observed consistent but not statistically significant race differences. While this lack of statistical significance prevents the formation of definitive conclusions, the agreement of our findings with those of others [1, 3, 14] strongly suggests that these differences in height coefficients are real, and that the lack of statistical significance is the result of a small sample size and inadequate power. The race differences observed in the coefficients of sitting height and in the predicted values at a given sitting height are consistent with previous observations that differences in upper body to lower body proportion do not fully account for the observed race differences in lung function [4, 21].

While many of the published prediction equations for lung function have been gender and race specific, as are the current ones, there have been several attempts to generate unified models which provide predictions for Blacks and Whites, males and females. ROSSITER and WEILL [1] suggested that a proportional scaling factor could be applied to predict the lung function of Blacks from prediction equations for Whites. Although this was approximately true in their data, the considerable race differences in intercepts for their regression equations are mathematically inconsistent with this notion. In our data, the predicted value at 1.75 m height of Whites was greater than that of Blacks by 12%, 11%, 15%, and 18% for FVC, FEV₁, TLC, and FRC, respectively. With the exception of FRC, this is consistent with the data of ROSSITER and WEILL [1]. In our data set, however, the percentage differences appeared to increase somewhat with increasing height, suggesting that the race differences may not be exactly proportional.

COLE [22] proposed a general model of the form $FVC = X + \text{Height}^k(A + B \cdot \text{Age})$ for adult males, and he presents statistical arguments that for $K=2$, the use of the intercept term X is unnecessary. DOCKERY *et al.* [11] have modified this model to $FVC = \text{Height}^2(A + B \cdot \text{Sex} + C \cdot \text{Age} + D \cdot \text{Age}^2)$ for describing the lung function of White adult males and females which reduces to the form $FVC = \text{Ht}^2(A + B \cdot \text{Sex})$ over the age range included in the

current paper. SCHWARTZ *et al.* [14] in a recent report uses a model of the form $\ln(FVC) = A + B \cdot \ln(\text{Ht}) + C \cdot \text{Race} + D \cdot \text{Sex}$ which is equivalent to $FVC = \text{Ht}^{B \cdot e(A+C \cdot \text{Race} + D \cdot \text{Sex})}$ with B approximately equal to 2 for young adults. Both of these equations allow for gender-race differences in the coefficient of the Ht^2 term, and have the property of producing gender-race predictions which differ only by a constant proportion. Equations of this form, however, assume zero intercepts and equal exponents for the height term for all gender-race groups.

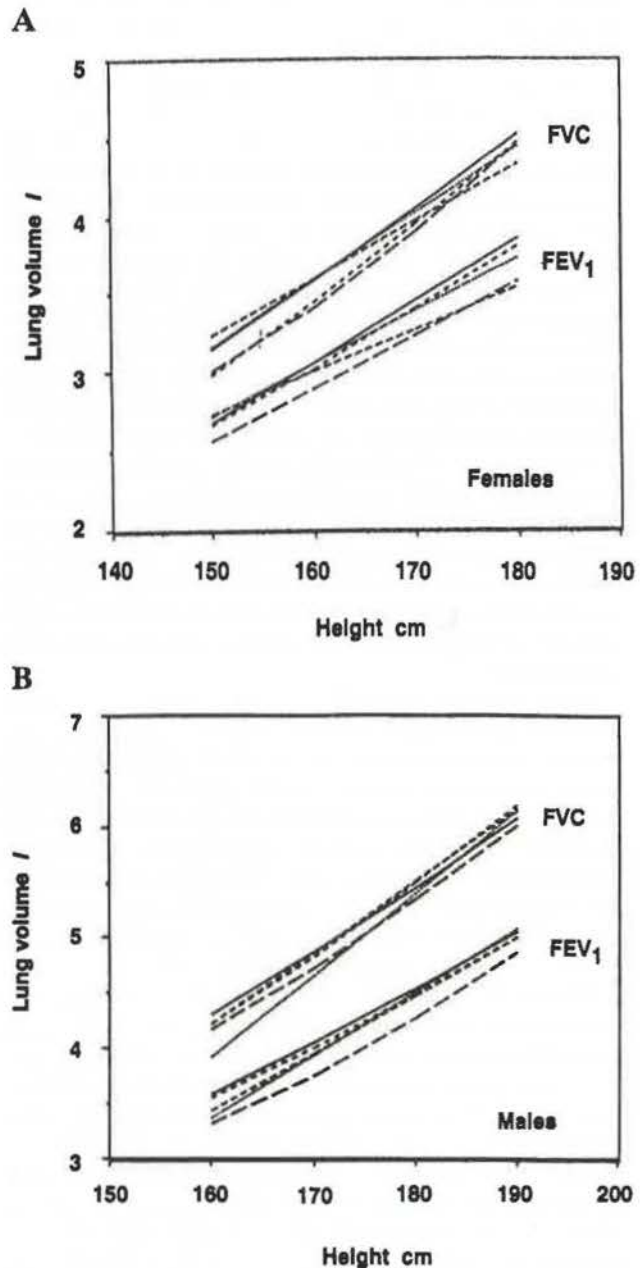


Fig. 3. — Comparison of predicted lung volume-height relationships for 25 yr old White males and females. — : DOCKERY *et al.* [11]; - - : SCHOENBERG *et al.* [13]; . . . : KNUDSON *et al.* [12]; - · - : SCHWARTZ *et al.* [14]; ····· : McDONNELL and SEAL. FVC: forced vital capacity; FEV₁: forced expiratory volume in one second.

We have examined the ability of these unified models and the current gender-race specific models to describe our data set, utilizing analysis of residuals, and have tested the assumptions of zero intercepts and equal height coefficients for the variables FVC, FEV₁, and TLC. Visual examination of plots of residuals *versus* height and *versus* predicted values by race and gender revealed no gross errors in prediction over the range of observed data. There were indications in this data set, however, that such unified models may provide somewhat biased estimates at some heights for given gender-race groups. This is suggested by the slight gender differences in associations between residuals from these models and height and by some violations of the assumptions of zero intercepts and equal height exponents.

The appeal of the gender-race specific models is their simplicity of form, ease of use, and freedom from gender-race bias in predicting lung function. On the other hand, they require stratification of the data set with resultant loss of precision for each gender-race group. The unified models overcome this problem of small numbers within a particular group by allowing all data to be used in estimating parameters for the entire study population. The utility of such models for either predictive purposes or for the study of the physiological bases of the gender-race differences, however, depends upon selection of an appropriate model, and the degree of accuracy demanded by the question to be answered.

Our data set, which is of marginal size for evaluation of complex models, suggests that in general, the unified models provide reasonably accurate predictions over the ranges of ages and heights studied here. The suggestion of bias in some estimates, however, demands rigorous examination in other large data sets to determine under which circumstances such models can be used with confidence.

Because the volunteers for this study were self-selected, and because individuals were excluded for any history of chronic disease, any current illness, any recent acute respiratory illness, or the inability to perform moderate exercise, our samples are not necessarily representative of the general population of lifetime nonsmoking North Americans. The extent to which they are representative can be estimated by comparing the predicted values of lung function from this data set with those from other, population-based studies.

Plots of FVC and FEV₁ *versus* height are presented in figure 3 for the current study and for four previously published studies of nonsmokers [11–14]. Because only one study included adequate numbers of Black females and none had adequate numbers of nonsmoking Black males, only data for White males and females are plotted. Age-adjusted models linear in height were used to provide predictions for the current study. It can be seen that the predictions of FVC and FEV₁ for the females are remarkably similar to those of the previous studies although they are consistently higher than those of SCHOENBERG *et al.* [13]. For males the FEV₁ values are similar over the entire height range while the FVC values are somewhat lower than those observed in the other populations at low values of height. Again, the

Schoenberg predictions are generally smaller than those of the other four studies. The FVC and FEV₁ predictions for Black women in the current study were higher than those predicted from the studies of SCHOENBERG *et al.* [13] and SCHWARTZ *et al.* [14] by approximately 200 ml. The Black males in the current study were quite similar to those of the Schwartz study with differences ranging from -70 to +160 ml. The differences for the Black men in this study and in the Schoenberg study, which included smoking men, were similar or larger than for the women. DOCKERY *et al.* [11] observed that lung function values for Blacks under age 55 yrs were 13.5% less than for Whites of the same gender. Others have reported differences ranging from 10–15% [1–4]. The predicted values of Blacks over a variety of heights in the current study ranged from 5–15% lower than for Whites of equal height with a representative difference of 10–12%. This puts the relationships of lung function between our samples of Blacks and Whites within the range of those previous reports, but precludes making definitive statements about how representative our samples are of the general population.

In summary, little change in lung function was observed over the age range of 18–35 yrs. We found lung volumes to be adequately described as linear functions of height, and for some variables, notably FRC, found significant relationships with Quetelet Index while controlling for differences in height. Forced expiratory flow rates were only modestly associated with height. Whites and males had larger predicted values for most lung function variables than did Blacks and females, respectively. In general, the height coefficients were significantly larger for males than females, and though the race differences in height coefficients were not significant for lung volumes, Whites consistently had larger coefficients than Blacks in both genders. Gender-race differences in lung function were only partially accounted for by differences in sitting height. Two models which included gender and/or race terms described the data with reasonable accuracy, but evidence of bias of some estimates in this data set indicates the need for further study of such models.

Acknowledgements: The authors thank P. Ives, S.A. Salaam, L. Raggio, and J. Green for assistance in collecting lung function data; M. Eads for assistance with data management; G. Heiss and E. Davis for conceptual and statistical guidance; and R. Chapman and C. Hayes for thoughtful reviews.

References

1. Rossiter CE, Weill H. — Ethnic differences in lung function: evidence for proportional differences. *Int J Epidemiol*, 1974, 3, 55–61.
2. Lapp NL, Amandus HE, Hall R, Morgan WKC. — Lung volumes and flow rates in black and white subjects. *Thorax*, 1974, 29, 185–188.
3. Oscherwitz M, Edlavitch SA, Baker TR, Jarboe T. — Differences in pulmonary functions in various racial groups. *Am J Epidemiol*, 1972, 96, 319–327.

4. Damon A. - Negro-White differences in pulmonary function. *Human Biology*, 1966, 38, 380-393.
5. Densen PM, Jones EW, Bass HE, Breuer J, Reed E. - A survey of respiratory disease among New York City postal and transit workers. *Environmental Research*, 1969, 2, 277-296.
6. Seltzer CC, Siegelau AB, Friedman GC, Collen MF. - Differences in pulmonary function related to smoking habits and race. *Am Rev Respir Dis*, 1974, 110, 598-608.
7. Cherniack RM, Raber MB. - Normal standards for ventilatory function using an automated wedge spirometer. *Am Rev Respir Dis*, 1972, 106, 38-46.
8. Higgins MW, Keller JB. - Seven measures of ventilatory lung function. *Am Rev Respir Dis*, 1973, 108, 258-272.
9. Morris JF, Koski A, Johnson LC. - Spirometric standards for healthy nonsmoking adults. *Am Rev Respir Dis*, 1971, 103, 57-67.
10. Crapo RO, Morris AH, Gardner RM. - Reference spirometric values using techniques and equipment that meet ATS recommendations. *Am Rev Respir Dis*, 1981, 123, 659-664.
11. Dockery DW, Ware JH, Ferris BG, Glicksberg DS, Fay ME, Avron S, Speizer FE. - Distribution of forced expiratory volume in one second and forced vital capacity in healthy, white, adult never-smokers in six U.S. cities. *Am Rev Respir Dis*, 1985, 131, 511-520.
12. Knudson RJ, Slatin RC, Lebowitz MD, Burrows B. - The maximal expiratory flow-volume curve. *Am Rev Respir Dis*, 1976, 113, 587-600.
13. Schoenberg JB, Beck GJ, Bouhuys A. - Growth and decay of pulmonary function in healthy blacks and whites. *Respir Physiol*, 1978, 33, 367-393.
14. Schwartz JD, Katz SA, Fegley RW, Tochman MS. - Analysis of spirometric data from a national sample of healthy 6 to 24 year olds (NHANES II). *Am Rev Respir Dis*, 1988, 138, 1405-1414.
15. DuBois AB, Botelho SY, Bedell GN, Marshall R, Comroe JH. - A rapid plethysmographic method for measuring thoracic gas volume: a comparison with a nitrogen washout method for measuring functional residual capacity in normal subjects. *J Clin Invest*, 1956, 35, 322-326.
16. Dubois AB, Botelho SY, Comroe JH. - A new method for measuring airway resistance in man using a body plethysmograph: values in normal subjects and in patients with respiratory disease. *J Clin Invest*, 1956, 35, 327-335.
17. Kleinbaum DG, Kupper LL, Muller KE. - *In: Applied regression analysis and other multivariable methods*. 2nd edn, PSW-Kent, Boston, 1988.
18. Burrows B, Cline MG, Knudson RJ, Taussig LM, Lebowitz MD. - A descriptive analysis of the growth and decline of the FVC and FEV₁. *Chest*, 1983, 83, 717-724.
19. Detels R, Sayre JW, Tashkin DP, Massey FJ, Coulson AH, Rokaw SN. - The UCLA population studies of chronic obstructive respiratory disease: VI. Relationship of physiologic factors to rate of change in forced expiratory volume in one second and forced vital capacity. *Am Rev Respir Dis*, 1984, 129, 533-537.
20. SAS Institute Inc. - SAS user's guide: statistics, version 5 edition. Cary N.C., SAS Institute Inc, 1985.
21. Schwartz J, Katz SA, Fegley RW, Tochman MS. - Sex and race differences in the development of lung function. *Am Rev Respir Dis*, 1988, 138, 1415-1421.
22. Cole TJ. - Linear and proportional regression models in the prediction of ventilatory function. *J R Statist Soc A*, 1975, 138, 297-337.
23. Cole TJ. - The influence of height on the decline in ventilatory function. *Int J Epidemiol*, 1974, 3, 145-152.
24. Leith DE, Mead J. - Mechanisms determining residual volume of the lungs in normal subjects. *J Appl Physiol*, 1967, 23, 221-227.
25. Strobe GL, Helms RW. - A longitudinal study of spirometry in young black and young white children. *Am Rev Respir Dis*, 1984, 130, 1100-1107.

Relations entre la fonction pulmonaire et les caractéristiques physiques chez de jeunes adultes noirs et blancs de sexe masculin et féminin. W.F. McDonnell, E. Seal Jr.

RÉSUMÉ: Les relations entre la fonction pulmonaire et les caractéristiques physiques de jeunes adultes n'ont pas été décrites adéquatement pour différents groupes de sexe et de race aux Etats-Unis. Dans le cadre d'une étude sur les effets de l'exposition à l'ozone sur des hommes et des femmes blancs et noirs, nous avons mesuré les volumes pulmonaires, les débits expiratoires et la résistance des voies aériennes dans un échantillon de 314 sujets bien portants, non fumeurs, âgés de 18 à 35 ans. L'analyse de régression indiquait que la fonction pulmonaire était décrite adéquatement comme fonction linéaire, soit de la taille, soit de la taille assise, dans chacun des quatre groupes, et que, quoique pas toujours significatives, les différences de sexe et de race dans les coefficients de taille et de taille assise, étaient habituellement présentes, celles des hommes et des blancs étant plus importantes que celles des femmes et des noirs. Des volumes pulmonaires apparaissent fréquemment associés, à l'index de masse corporelle mesuré par l'index de Quetelet (taille multipliée par hauteur²). Nous présentons les modèles de régression multiple spécifique au sexe et à la race qui conviennent le mieux, en incluant ces termes, et occasionnellement le terme de l'âge. Deux modèles supplémentaires sont présentés, dont l'un tient compte simultanément à la fois du sexe et de la race, et l'autre tient compte du sexe dans une race déterminée. La comparaison des valeurs prédites dans notre étude avec celles d'autres travaux, suggère que les échantillons de population de cette étude peuvent être similaires à ceux d'autres populations américaines rapportées précédemment.

Eur Respir J, 1991, 4, 279-289.