Spirometry Reference Values for Nonexposed Blue-Collar Workers

Martin Petersen, M.S., and John Hankinson, Ph.D.

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Epidemiologic research into occupationally related lung disease often requires the comparison of a study population with an external reference group. To establish such a reference group, carefully selected blue-collar workers who had no obvious adverse occupational pulmonary exposure performed simple spirometry, were administered a standard questionnaire, and had standard chest roentgenograms taken. Prediction equations were established for six pulmonary function indices, and a method is given for using these equations to compare a study group with this external nonexposed group. Asymptomatic nonsmokers with negative roentgenograms were extracted from the overall group, and comparison with published data for other such normal groups indicated that the present group is similar to most of them, indicating that there are no serious biases in the present group.

Lung volumes and flow rates obtained from spirometry are often used as indices for investigating health hazards in the workplace. These indices are often used for comparison of subjects exposed to some substance and nonexposed subjects. The determination of which subjects to include in each group depends on the hypothesis to be tested. Often, under strict interpretation of an hypothesis, one cannot obtain enough nonexposed subjects to make it reasonably likely that a true hazard (if it existed) would be detected. A slight modification of the hypothesis can often be made so that more subjects can be included in the nonexposed group, and the new hypothesis is still of substantial interest. One such modification is the comparison of an exposed group with nonexposed subjects from a different study. In this case, the data for the nonexposed subjects are generally in the form of prediction equations.

In addition to being based on subjects examined at another time (and often in another place and by another investigator), these equations often suffer from other limitations: they may not distinguish between smoking groups, sexes, or races; they may be based on a general population, rather than a working population; they may be based on asymptomatic nonsmokers with negative roentgenograms; or they may be based on data obtained with a different type of spirometer or with different spirometry techniques. The present study was designed to eliminate all of these additional limitations except possibly the last.

Prediction equations for normal subjects are also useful for clinical purposes, and the present study allowed such prediction equations to be developed. These are compared with commonly used equations from the literature to determine if the present normal subgroup was unusually healthy or unhealthy.

Methods

Three major industry groups were chosen for study. These were food and kindred products, synthetic textile mills, and electrical equipment and supplies. Details of the sample selection are given elsewhere.[1]

Fourteen plants were studied, all of which are located in North Carolina. Each plant was inspected by an industrial hygienist, after which persons working in dusty areas or with known lung irritants, regardless of the amount, were excluded from the study. Nearly all exclusions were based on visual inspection, material safety data sheets, and conversations with the plant manager about the plant process.

As an extra precaution, respirable dust measurements were taken with a TSI gravimetric dust sampler and MSA Model G pumps with 10-mm cyclone, and subjects were eliminated if the measurement in their job or area exceeded an arbitrary limit of one fourth of the threshold limit value of 5 mg/m^3 for respirable nuisance dust (i.e., 1.25 mg/m^3). It is expected that many subjects were eliminated needlessly to be certain that the nonexposed group was experiencing no significant exposures. The maximum exposure to such respirable dust in those areas included was 0.75 mg/m^3.

An occupational history questionnaire was administered to each subject, and participants were eliminated if they

From the National Institute for Occupational Safety and Health, Division of Respiratory Disease Studies, 944 Chestnut Ridge Rd., Morgantown, WV 26505 (Mr. Petersen for further correspondence).

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had been substantially exposed to respiratory hazards in the past. As a compromise between purity and necessary sample size, subjects who had worked at previous jobs with suspected exposure for a total of five or more years were eliminated from the study. Such exposures included cotton, flax, hemp, jute, or paper and pulp or employment in sawmills, mines, farms, and grain elevators, as well as in areas that were eliminated in the industries studied, such as mixing areas in bakeries and receiving areas in poultry plants.

Each participant was administered a questionnaire on respiratory symptoms of the Medical Research Council of Great Britain.[1,2] In addition, smoking and the previously mentioned occupational histories were obtained. Chest roentgenograms were also taken, and each film was interpreted independently by three "B" readers according to the ILO U/C 1971 Classification.[3] For each subject, at least five maximal forced expiratory maneuvers on a high-fidelity waterless rolling-sealed spirometer (Ohio model 840) were recorded, and all values were corrected to body temperature, pressure, and saturation. The largest forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), and peak flow (PF) were taken regardless of the curves on which they occurred. Maximal expiratory flows at 50% and 75% of FVC (FEF50% and FEF75%) were calculated by the method of maximum envelope.[4] The spirometer and methods met the minimum spirometry standards recommended by the American Thoracic Society.[5]

Only white and black subjects were included in the analysis. Analysis of the data was accomplished with the use of the general linear models procedure of the Statistical Analysis System.[6] The dependent variables used were FVC, FEV_1, the ratio of FEV_1 and FVC (FEV_1/FVC%), PF, FEF50%, and FEF75%. The independent variables were race, sex, smoking status (smokers, ex-smokers, never smokers, pipe or cigars only smokers), age, height, weight, highest grade of school completed, all two-way interactions involving at least one of the first three independent variables, and the three-way interaction involving only the first three independent variables. (Two- and three-way products of continuous variables were excluded for simplicity and because they were not expected to improve the fit of the model substantially.) Analyzing the data for the group as a whole instead of by race, sex, and smoking status has two advantages. First, the residual error can be pooled, yielding more degrees of freedom for the F tests. Second, the two-way interaction terms involving one of the last four main effects represent differences in slopes between categories. Thus, if the two-way interaction is not significant, the slopes can reasonably be averaged to obtain one slope applicable to all categories.

Except for FEV_1/FVC%, Knudson et al[4] suggested developing separate equations for males under 25 years of age and females under 20 years of age. This was tested as a last step in the present model-fitting procedure, and the models were altered when necessary. The details of the model-fitting procedure are given in the Appendix.

The model-fitting technique was repeated for data on normal subjects, using only race, sex, age, height, weight, highest grade of school completed, and all two-way interactions involving either race or sex. Normal subjects were defined as nonsmokers with negative chest roentgenograms (as determined by at least two of the three readers), with no persistent cough, persistent phlegm, moderate breathlessness (when walking with other people of the same age on level ground), persistent wheezing, or asthma (C3, C6, C12, C15, and C17 on questionnaire; see Appendix 1 in reference 1).

Results

Basic demographic data are shown in Tables 1 through 3. There was a good distribution by race and sex (Table 1). There were few pipe or cigar smokers, but they were grouped separately to distinguish them from the nonsmoking group. The only distinguishing aspect of the sample as a whole is that the subjects were fairly young (Tables 2 and 3).

The final equations for nonexposed subjects are given in Table 4 for males and Table 5 for females. These equations were formed by evaluating the overall model for particular values of race, sex, smoking status, and age group. When the coefficients of a continuous variable or the constants were not statistically different between two groups, a single estimate was made that was applicable to both groups. The equations for FEF50% and FEF75% for pipe or cigar smokers were obtainable because certain interactions were assumed to be zero. These equations are not very reliable because of small sample size, but they are included because they were different from those for any other smoking group.

Because the subjects included in this study were considered nonexposed, it was expected that industry would not be related to any pulmonary function index after adjustment for the other terms in the model. When industry (milk processing, meat processing, poultry processing, bakery, synthetic textiles, and electrical equipment) and its two-way interactions with the main effects in each above model were added, the simultaneous test of these industry-related terms was not significant for any pulmonary function index.

The demographic data for the normal subjects are shown in Tables 6 and 7. This subset was also a young group. To use a predicted value minus a multiple of the standard error of the estimate to classify individuals as "normal" or "abnormal," the prediction equation used should be based on at least 100 observations. For each race by sex group, the sample size was less than 100. However, by analyzing all the data together and assuming that high-order interactions were zero, the coefficients were effectively estimated by combining two or more groups, and since the race by sex interaction was never significant, the constant was also effectively estimated by combining two or more groups.

The final equations for normal subjects are shown in Tables 8 and 9. They were formed in the same manner as those for nonexposed subjects.

Discussion

The participation rate for the blue-collar workers was 55%. This low rate was probably due to the fact that no suspected occupational health problem existed at these plants. It is possible that subjects with health problems would be more likely to participate than those without health problems. On the other hand, some subjects with

Table 1 — Sample Sizes by Race, Sex and Smoking Status for Nonexposed Blue-Collar Workers

	White Males	Black Males	White Females	Black Females	Total
Current smokers	199	160	138	111	**608**
Ex-smokers	82	35	35	37	**189**
Nonsmokers	89	76	154	137	**456**
Pipe/cigar smokers	20	5	1	0	**26**
Total	**390**	**276**	**328**	**285**	**1,279**

Table 2 — Means and Standard Deviations by Race and Sex for Nonexposed Blue-Collar Workers

	White Males (n=390)		Black Males (n=276)		White Females (n=328)		Black Females (n=285)	
	Mean	SD*	Mean	SD	Mean	SD	Mean	SD
Age, yr	33	13.5	29	9.9	39	13.4	33	10.9
Height, cm	174	6.8	174	6.9	161	6.3	161	6.0
Weight, kg	78	16.6	78	14.3	65	14.8	72	16.9
Grade	11	2.5	11	2.1	11	2.0	11	2.0
FVC	4.88	0.838	4.39	0.773	3.31	0.614	2.97	0.522
FEV_1	3 93	0.812	3.61	0.711	2.70	0.576	2.50	0.475
FEV_1/FVC%	80	8.8	82	8.4	81	7.6	84	7.3
PF	9.45	1.956	9.18	2.075	6.25	1.350	6.35	1.483
FEF50%	4.93	1.598	4.88	1.597	3.71	1.156	3.76	1.125
FEF75%	1.94	0.959	1.92	0.838	1.38	0.724	1.48	0.671

* SD indicates standard deviation

Table 3 — Distribution of Age, Height, Weight, and Grade (Years of Education) for Nonexposed Blue-Collar Workers

Age, yr	Frequency	Height, cm	Frequency	Weight, kg	Frequency	Grade	Frequency
<20	84	<150	23	<50	64	<7	50
20-29	533	150-159	216	50 – 59.75	194	7-8	123
30-39	278	160-169	494	60 – 69.75	342	9-10	260
40-49	185	170-179	402	70 – 79.75	303	11-12	725
50-59	151	180-189	136	80 – 89.75	187	13-15	90
60-69	48	≥190	8	≥90	189	≥16	31

health problems who were under a doctor's care may not have felt the need to be examined in the study. A further discussion of this has been published previously.[1]

Because the entire data set cannot be presented, comparisons of a study group with this external control group must be made using the equations in Tables 4 and 5. A reasonable procedure is to calculate a predicted value (from Tables 4 and 5) for each subject in the study group and subtract it from the subject's observed value. A *t* test is then performed to determine whether the mean of the differences is zero. This procedure tests the hypothesis that the mean of a pulmonary function index is the same for both the study and the external comparison groups, adjusted for differences in the independent variables in the equation.

Studies showing pulmonary function models for "nonexposed subjects," other than strictly asymptomatic subjects, are rare. Miller[7] gives results for FEV_1/FVC% for two general population groups in the West Indies. The equation for male smokers and nonsmokers was 87 – 0.12Age, while that for female smokers and nonsmokers was 87 – 0.016Age. The predicted values from these equations are larger than the ones derived from Tables 4 and 5 for subjects with the following minimum ages: 21 years for male smokers, 30 years for male nonsmokers, 35 years for female smokers, and 60 years for female nonsmokers; a height of 174 cm for males and 161 cm for females is assumed. The larger predicted values for Miller's subjects are in contrast to the idea that general populations are less healthy than working populations. Differences between the two studies that might explain Miller's larger values are geographic area (West Indies vs North Carolina), race (ancestors from India and Africa vs American-born white and black parents, although race was not found to be related to FEV_1/FVC% in the current study), spirometers (Collins vs Ohio), and different investigating teams.

Equations for normal subjects are quite common in the literature. The models in Tables 8 and 9 can be used as

Table 4 — Parameters of Prediction Equations for Pulmonary Function Indices for Nonexposed Male Blue-Collar Workers

Index (SEE, R)*	Smoking Status	Age Group†	White Males					Black Males				
			Constant	Age	Height	Weight	Grade	Constant	Age	Height	Weight	Grade
FVC (0.5467, 0.8576)	All	Both	−5.379	−0.0211	0.06139	0.00387	...	−4.538	.0211	0.05298	0.00387	...
FEV$_1$ (0.4678, 0.8558)	Current	Young	−4.277	−0.0025	0.04942	...	...	−3.336	−0.0025	0.04110	...	...
	Current	Old	−3.366	−0.0389	0.04942	...	...	−2.425	−0.0389	0.04110	...	...
	Ex, Non, PC‡	Young	−4.147	−0.0025	0.04942	...	...	−3.206	−0.0025	0.04110	...	...
	Ex, Non, PC	Old	−3.236	−0.0389	0.04942	...	...	−2.295	−0.0389	0.04110	...	...
FEV$_1$/FVC% (6.89, 0.5487)	Current	Both	102.8	−0.40	−0.058	...	...	102.8	−0.40	−0.058	...	...
	Ex	Both	103.9	−0.39	−0.058	...	...	103.9	−0.39	−0.058	...	...
	Non, PC	Both	101.8	−0.28	−0.058	...	...	101.8	−0.28	−0.058	...	...
PF (1.5419, 0.7477)	Current	Young	−4.508	0.0512	0.06675	0.01075	0.0567	−4.969	0.0512	0.06675	0.01075	0.0567
	Current	Old	−1.944	−0.0514	0.06675	0.01075	0.0567	−2.405	−0.0514	0.06675	0.01075	0.0567
	Ex, Non, PC	Young	−4.149	0.0512	0.06675	0.01075	0.0567	−4.610	0.0512	0.06675	0.01075	0.0567
	Ex, Non, PC	Old	−1.585	−0.0514	0.06675	0.01075	0.0567	−2.405	−0.0514	0.06675	0.01075	0.0567
FEF50% (1.1912, 0.6249)	Current	Both	0.460	−0.0626	0.03314	0.00667	...	0.311	−0.0626	0.03314	0.00667	...
	Ex	Both	0.839	−0.0610	0.03314	0.00667	...	0.093	−0.0610	0.03314	0.00667	...
	Non	Both	0.499	−0.0410	0.03314	0.00667	...	0.093	−0.0410	0.03314	0.00667	...
	PC	Both	0.205	−0.0371	0.03314	0.00667	...	−0.509	−0.0371	0.03314	0.00667	...
FEF75% (0.6256, 0.6867)	Current	Both	0.866	−0.0513	0.01637	−0.00298	...	0.598	−0.0447	0.01637	−0.00298	...
	Ex	Both	1.007	−0.0473	0.01637	−0.00298	...	0.475	−0.0407	0.01637	−0.00298	...
	Non	Both	0.983	−0.0447	0.01637	−0.00298	...	0.496	−0.0382	0.01637	−0.00298	...
	PC	Both	0.476	−0.0285	0.01637	−0.00298	...	−0.320	−0.0219	0.01637	−0.00298	...

* SEE indicates standard error of estimate; R, multiple correlation coefficient
† Young, <25 years; Old, ≥25 years
‡ PC indicates subjects who had smoked pipes or cigars, but had never smoked cigarettes

Table 5 — Parameters of Prediction Equations for Pulmonary Function Indices for Nonexposed Female Blue-Collar Workers

Index (SEE, R)*	Smoking Status	Age Group†	White Females					Black Females				
			Constant	Age	Height	Weight	Grade	Constant	Age	Height	Weight	Grade
FVC (0.5467, 0.8576)	All	Both	−2.982	−0.0211	0.04437	0.00013	...	−2.141	−0.0211	0.03596	0.00013	...
FEV$_1$ (0.4678, 0.8558)	Current	Young	−2.743	−0.0109	0.03510	...	...	−1.802	−0.0109	0.02677	...	...
	Current	Old	−2.014	−0.0255	0.03510	...	...	−1.073	−0.0255	0.02677	...	...
	Ex, Non, PC‡	Young	−2.613	−0.0109	0.03510	...	...	−1.672	−0.0109	0.02677	...	...
	Ex, Non, PC	Old	−1.879	−0.0255	0.03510	...	...	−0.933	−0.0255	0.02677	...	...
FEV$_1$/FCV% (6.89, 0.5487)	Current	Both	104.5	−0.40	−0.058	...	...	104.5	−0.40	−0.058	...	...
	Ex	Both	105.7	−0.39	−0.058	...	...	105.7	−0.39	−0.058	...	...
	Non, PC	Both	103.5	−0.28	−0.058	...	...	103.5	−0.28	−0.058	...	...
PF (1.5419, 0.7477)	Current	Young	−5.980	0.0512	0.06675	0.01075	0.0567	−6.441	0.0512	0.06675	0.01075	0.0567
	Current	Old	−3.929	−0.0514	0.06675	0.01075	0.0567	−4.390	−0.0514	0.06675	0.01075	0.0567
	Ex, Non, PC	Young	−5.621	0.0512	0.06675	0.01075	0.0567	−6.082	0.0512	0.06675	0.01075	0.0567
	Ex, Non, PC	Old	−3.570	−0.0514	0.06675	0.01075	0.0567	−4.031	−0.0514	0.06675	0.01075	0.0567
FEF50% (1.1912, 0.6249)	Current	Both	0.057	−0.0626	0.03314	0.00667	...	−0.092	−0.0626	0.03314	0.00667	...
	Ex	Both	0.599	−0.0610	0.03314	0.00667	...	−0.147	−0.0610	0.03314	0.00667	...
	Non	Both	−0.289	−0.0410	0.03314	0.00667	...	−0.695	−0.0410	0.03314	0.00667	...
	PC	Both	−0.566	−0.0371	0.03314	0.00667	...	−1.281	−0.0371	0.03314	0.00667	...
FEF75% (0.6256, 0.6867)	Current	Both	0.389	−0.0412	0.01637	−0.00298	...	0.120	−0.0355	0.01637	−0.00298	...
	Ex	Both	0.530	−0.0380	0.01637	−0.00298	...	−0.003	−0.0315	0.01637	−0.00298	...
	Non	Both	0.506	−0.0355	0.01637	−0.00298	...	0.018	−0.0289	0.01637	−0.00298	...
	PC	Both	−0.002	−0.0193	0.01637	−0.00298	...	−0.798	−0.0127	0.01637	−0.00298	...

* SEE indicates standard error of estimate; R, multiple correlation coefficient
† Young, <20 years; old, ≥20 years
‡ PC indicates subjects who had smoked pipes or cigars, but had never smoked cigarettes

normal equations, but, except for blacks, they are not necessarily superior to those already in the literature. The primary purpose of extracting equations for normal subjects is to compare them with other equations in the literature to determine if the normal group being studied has unusually high or low spirometric values. The same conclusion could then be extended to the entire group of nonexposed subjects.

The method described for using the equations in Tables 4 and 5 can also be used to compare the present normal group with those already described in the literature. Predicted values based on equations from the literature were subtracted from the observed values for the present normal group. Table 10 contains the mean of these differences for four of these published studies. Comparisons were made for all subjects combined and for white sub-

Table 6 — Sample Sizes, Means, and Standard deviations (SD) by Race and Sex for Normal (Asymptomatic, Nonsmoking, Nonexposed) Blue-Collar Workers

Variable	White Males (n = 62)		Black Males (n = 63)		White Females (n = 96)		Black Females (n = 94)	
	Mean	SD*	Mean	SD	Mean	SD	Mean	SD
Age, yr	29	11.3	27	8.5	40	14.1	34	12.3
Height, cm	174	6.9	174	7.3	162	5.3	161	5.9
Weight, kg	76	13.6	77	13.7	65	13.6	73	16.5
Grade	11	2.7	12	1.6	11	2.2	11	1.9
FVC	5.03	0.845	4.43	0.814	3.40	0.602	3.00	0.551
FEV_1	4.25	0.715	3.77	0.699	2.78	0.523	2.54	0.483
FEV_1/FVC%	84	5.3	85	7.0	82	7.3	85	7.3
PF	9.88	1.880	9.83	1.822	6.43	1.185	6.54	1.641
FEF50%	5.72	1.297	5.37	1.437	3.82	1.045	3.88	1.181
FEF75%	2.46	0.889	2.15	0.821	1.43	0.725	1.54	0.653

* SD indicates standard deviation

Table 7 — Distributions for Age, Height, and Weight for Normal Blue-Collar Workers

Age, yr	Frequency	Height, cm	Frequency	Weight, kg	Frequency	Grade	Frequency
<19	23	<150	4	<50	14	<7	12
20-29	143	150-159	61	50-59.75	56	7-8	26
30-39	55	160-169	140	60-69.75	86	9-10	56
40-49	40	170-179	79	70-79.75	83	11-12	183
50-59	38	≥180	31	80-89.75	39	13-15	24
≥60	16	. . .	. . .	≥90	37	≥16	14

Table 8 — Parameters of Prediction Equations for Pulmonary Function Indices for Normal Male Blue-Collar Workers

Index (SEE, R)*	Age Group†	White Males				Black Males			
		Constant	Age	Height	Weight	Constant	Age	Height	Weight
FVC (0.5631, 0.8451)	Both	−3.157	−0.0175	0.04717	0.00612	−3.763	−0.0175	0.04717	0.00612
FEV_1 (0.4422, 0.8738)	Both	−1.984	−0.0239	0.03759	0.00457	−2.466	−0.0239	0.03759	0.00457
FEV_1/FVC% (7.08, 0.4526)	Both	93.0	−0.27	. . .	. . .	93.0	−0.27	. . .	. . .
PF (1.3987, 0.7993)	Young	−5.093	0.1260	0.06550	0.02206	−5.338	0.0991	0.06550	0.02206
	Old	−1.824	−0.0372	0.06550	0.02206	−1.259	−0.0641	0.06550	0.02206
FEF50% (1.0812, 0.6889)	Both	−3.558	−0.0255	0.05211	0.01274	3.632	−0.0581	0.01315	0.01274
FEF75% (0.6090, 0.7149)	Both	−1.685	−0.0354	0.02975	. . .	1.835	−0.0354	0.00721	. . .

* SEE indicates standard error of estimate; R, multiple correlation coefficient
† Young, <25 years; old ≥25 years

jects only when it was not clear which racial groups were included in the published report. The comparison with Kory and co-workers'[8] equations was restricted to males, as were the data of Kory et al. Similarily, the comparison with Knudson and co-workers'[9] equations was restricted to white subjects, as were the data of Knudson et al. The comparisons with Kory et al, Morris et al,[10] and Crapo et al[11] were made both for white subjects and for all subjects, ignoring race. The present normal group has FEV_1 and FVC values that are similar to those of the group studied by Kory et al when race is ignored, but only the white subjects are similar to the groups studied by Morris et al and Crapo et al, which probably reflects the expectation that these latter two studies included few, if any black subjects. The FEV_1 values for the present group of white males were still a little larger on average than those for males studied by Morris et al, and the FEV_1 and FEV_1/FEC% for white females were on average a little smaller than those

Table 9 — Parameters of Prediction Equations for Pulmonary Function Indices for Normal Female Blue-Collar Workers

Index (SEE, R)*	Age Group†	White Females				Black Females			
		Constant	Age	Height	Weight	Constant	Age	Height	Weight
FVC (0.5631, 0.8451)	Both	−3.895	−0.0175	0.04717	0.00612	−4.501	−0.0175	0.04717	0.00612
FEV_1 (0.4422, 0.8738)	Both	−2.607	−0.0239	0.03759	0.00457	−3.089	−0.0239	0.03759	0.00457
FEV_1/FVC% (7.08, 0.4526)	Both	93.0	−0.27	...	...	93.0	−0.27	...	...
PF (1.3987, 0.7993)	Young	−7.333	0.1260	0.06550	0.02206	−6.769	0.0991	0.06550	0.02206
	Old	−4.070	−0.0372	0.06550	0.02206	−3.505	−0.0641	0.06550	0.02206
FEF50% (1.0812, 0.6889)	Both	−4.404	−0.0255	0.05211	0.01274	2.785	−0.0581	0.01315	0.01274
FEF75% (0.6090, 0.7149)	Both	−1.953	−0.0354	0.02975	...	1.567	−0.0354	0.00721	...

* SEE indicates standard error of estimate; R, multiple correlation coefficient
† Young, <20 years; old, ≥20 years

Table 10 — Comparison of Normals With Published Equations

Study	Variable	Males: Overall (n=125) Mean*	Significance	Males: Whites Only (n=62) Mean	Significance	Females: Overall (n=190) Mean	Significance	Females: Whites Only (n=96) Mean	Significance
Kory et al	FVC	−0.11	NS†	0.23	$p < .01$	...	...	...	...
	FEV_1	−0.07	NS	0.21	$p < .01$	...	...	...	...
Morris et al	FVC	−0.43	$p < .01$	−0.08	NS	−0.33	$p < .01$	−0.06	NS
	FEV_1	−0.12	$p < .05$	0.17	$p < .05$	−0.14	$p < .01$	0.06	NS
Crapo et al	FVC	−0.47	$p < .01$	−0.12	NS	−0.34	$p < .01$	−0.08	NS
	FEV_1	−0.34	$p < .01$	−0.06	NS	−0.34	$p < .01$	−0.14	$p < .01$
	FEV_1/FVC%	1.18	$p < .05$	0.91	NS	−1.22	$p < .01$	−1.75	$p < .01$
Knudson et al	FVC	...	...	0.16	NS	...	...	0.09	NS
	FEV_1	...	...	0.13	$p < .05$	...	...	0.00	NS
	FEV_1/FVC%	...	...	−0.16	NS	...	...	−2.20	$p < .01$
	FEF50%	...	...	0.47	$p < .01$	...	...	0.05	NS
	FEF75%	...	...	0.11	NS	...	...	−0.20	$p < .01$

* The authors' observed minus published predicted
† NS indicates not significant

for females studied by Crapo et al. White males in the current study were found to have larger mean FEV_1 and FEF50% values than males studied by Knudson et al. White females in the current study were found to have smaller mean FEV_1/FVC% and FEF75% values than females studied by Knudson et al. It should be mentioned that Knudson et al obtained flows from the "best curve," while in the current study, values were obtained from the maximum envelope. The maximum envelope method appears to yield values for FEF50% and FEF75% that are 0.14 and 0.04 l/s higher than the best curve methods (based on in-house results). This does not appear to explain completely the flow rate differences observed between the current study and Knudson and co-workers' study. It is clear that the current group (together with the authors' methods, equipment, and staff) does not yield ventilatory function indices that are consistently higher or lower than those reported in the literature, even though the populations lived in different regions of the country, five spirograms (even if the first three were acceptable) were used, and the spirometers were not exactly the same. In addition, Crapo et al estimated that the backward extrapolation method for calculating FEV_1, which was used in the Crapo et al, Knudson et al, and present studies, yielded values that averaged 0.18 l higher than those obtained by the method used by Kory et al, as in the studies by Kory et al and Morris et al. Adjusting for this requires the subtraction of 0.18 from the Table 10 values for FEV_1 for Kory et al and Morris et al. Assuming Kory et al had both blacks and white subjects in their study, as it appears from the FVC results, this adjustment makes their results more different from those of the present study. On the other hand, assuming the Morris et al study involved mostly white subjects, the adjustment makes their results almost identical to those of the present study for males, and only slightly more different for females. The general conclusion is that the equations in Tables 4 and 5 should not yield unusually high or low values compared with those of other studies.

The above comparisons have been made either for white subjects only or ignoring race because the other studies were either restricted to whites or ignored race. One method of obtaining equations for FEV_1 and FVC for black subjects is to multiply the prediction equation for white subjects by a constant. Based on several studies,[12-16] the constant is often chosen to be 0.85 or 0.90. For the present equations, 0.85 would be too large an adjustment for males unless they were fairly old. For FVC the difference between the authors' equations for black subjects (Tables 8 and 9) and the 85% rule could be as much as 0.27 l, depending on age, height, and weight (the largest differences occurring in young and large subjects), while for FEV_1 the largest difference could be about 0.26 liters. For females, the 85% adjustment was almost never enough for FVC, with values as much as 0.28 l higher than those obtained by the authors' equations for black subjects (the largest differences occurring for old and small subjects). The 85% rule for FEV_1 was also generally not enough for females with a maximum underadjustment of 0.23 l (for old and small subjects). Multiplying by 0.9 was almost never a large enough adjustment for males or females.

APPENDIX

Model-Fitting Procedure

For the nonexposed group, the first step was to test the three-way interaction and to eliminate it if the *p* value was greater than .05. If it was deleted, the next step was to eliminate the two-way interaction with the largest *p* value, if that *p* value was greater than .05. This was continued until all remaining two-way interactions had $p \leq .05$. The process was repeated for all main effects that did not form part of any two- or three-way interactions that remained in the model. These restrictions result in the models being hierarchical. The entire process was repeated until all remaining effects had $p \leq .05$ or were required to make the model hierarchical.

Next, smoking groups were combined when possible by comparing slopes or adjusted means, as appropriate. Groups were not combined if $p \leq .05$. If a group could be combined with either of two noncombinable groups, then it was combined with the one with the closest point estimate. Two groups were combined only if all comparisons resulted in this decision to combine (e.g., two groups were not combined if the slopes on age could be grouped together, but the intercepts could not).

To see if the slope for age changed at Knudson and coworkers' suggested ages, the term [(age − 25)agegpm + (age − 20)*agegpf] was added to each model, including that for FEV/FVC%, where agegpm = 1 for males at least 25 years old, but was 0 otherwise, and agegpf = 1 for females at least 20 years old, but was 0 otherwise. A two-way interaction between this term and any other term whose interaction with age was also in the model was added. These new terms were all tested simultaneously and, if they were significantly related to a pulmonary function index, the previously mentioned model-fitting method was employed on these new variables. These new variables force the (projection) lines for males to intersect at age 25 and force the (projection) lines for females to intersect at age 20.

The same procedure was used for the subset of normal subjects, except that there was no three-way interaction to test.

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