Reference Spirometric Values Using Techniques and Equipment that Meet ATS Recommendations[1-3]

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SUMMARY Forced expiratory volumes and flows were measured in 251 healthy nonsmoking men and women using techniques and equipment that meet American Thoracic Society (ATS) recommendations. Linear regression equations using height and age alone predict spirometric parameters as well as more complex equations using additional variables. Single values for 95 % confidence intervals are acceptable and should replace the commonly used method of subtracting 20 % to determine the lower limit of normal for a predicted value.

Our study produced predicted values for forced vital capacity and forced expiratory volume in one second that were almost identical to those predicted by Morris and associates (1) when the data from their study were modified to be compatible with the back extrapolation technique recommended by the ATS. The study of Morris and colleagues was performed at sea level in rural subjects, whereas ours was performed at an altitude of 1,400 m in urban subjects. Either the present study or the study of Morris and co-workers, modified to back extrapolation, could be recommended for predicting normal values. AM REV RESPIR DIS 1981; 123:659-664

Introduction

The American Thoracic Society (ATS) and The American College of Chest Physicians have both recommended that spirometry be part of the routine evaluation of patients with respiratory diseases and those at risk of developing respiratory diseases (2). Attempts have been made and are being made to standardize the methods of performing, measuring, and interpreting spirograms (2-4). A statement on standardization has been issued by the ATS (5). Numerous reports of reference values with prediction equations have been published, but few studies have used the equipment and techniques suggested by the ATS (5, 6) (table 1).

Most prediction equations are linear regressions, using height and age as independent variables, although nonlinear equations have been proposed (7). It is a common practice, for several of the spirometric parameters, to calculate a predicted value from a regression equation using ± 20 % as the range of normal, despite evidence which suggests that this is not a valid way to define normal limits for predicted values (14). There is also disagreement on whether or not smokers should be included in reference studies. We believe that studies using lifetime nonsmoking populations provide the best predictors for reference values because of the high association of smoking with pulmonary disease. Four studies that reported normal values for lifetime nonsmokers (1, 7-9), which we believe to be the most appropriate reference population, did not consistently use either equipment or techniques that meet ATS standards.

The present study was performed to provide prediction equations and more precise lower limits of normal for spirometric parameters in healthy, well-screened normal subjects using ATS recommended techniques and equipment demonstrated to satisfy ATS criteria (5).

Methods

More than 90 % of the subjects were volunteers from the Church of Jesus Christ of Latter-day Saints (Mormon). Each volunteer filled out a modified British Research Council questionnaire (15), was examined by a pulmonary physician, and received a chest radiograph. "Normal" subjects were those who met all of the following criteria: (1) a lifetime nonsmoker (total smoking of less than 0.5 pack-yr and no smoking within 6 months of the study); (2) no symptoms of lung, heart, or chest wall disease; (3) a normal chest radiograph; (4) a normal physical examination of the heart, lungs, and chest wall.

All tests were performed between 4 and 9 P.M. in the LDS Hospital Pulmonary Function Laboratory at Salt Lake City, Utah (altitude, 1,400 m). Subjects were weighed and measured in indoor clothing without shoes. Age was recorded to the nearest birthday. Spirometry was performed with a water-seal metal bell spirometer (P1300, Warren E. Collins, Braintree, Mass.) connected to a potentiometer (10, 16). This spirometer meets ATS requirements (6) (courtesy of Dr. John L. Hankinson, National Institute of Occupational Safety and Health Appalachian Laboratory, Morgantown, W.Va., who tested the same model 13.5-L Collins, metal bell spirometer). The spirometer was calibrated daily (16). Spirometric analysis was performed with a previously described computerized system (10, 16) modified to provide timed forced expiratory volumes and flows using the back extrapolation technique recommended by the ATS (5). Analog data from the potentiometer were sampled 100 times/s with a 10-bit analog-to-digital signal converter (resolution, ± 15 ml). Sampling was initiated during the inspiration that preceded the forced expiratory maneuver. A three-point running average of the volume differences was continuously computed until the maximal volume difference occurred (peak flow). The waveform was then back extrapolated from the point of peak flow to determine time zero (3, 5). The extrapolated volume was always less than 10 % of the forced vital capacity (FVC). The waveforms with zero time, 1-s and 3-s time marks were displayed to the technician, who verified them. The data were stored on magnetic disks and were processed by a data analysis program called STRATO (17). All displaceable volumes were reported in liters BTPS, and the forced expiratory flow during the middle half of the forced vital capacity

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TABLE 1

COMPARISON OF TECHNIQUES AND INSTRUMENTS IN SPIROMETRY REFERENCE STUDIES

Study	Time Zero Technique	Instrument Type	Instrument Meets ATS Specifications	Altitude (M)	Locale	Smokers
Present study	BE	Collins 13.5-L metal bell	Yes	1,400	Urban	No
Morris, *et al.* (1)	K	Stead-Wells	Yes	< 150	Rural	No
Schoenberg, *et al.* (7)	?	Pneumotachygraph	?	SL	Mixed	No
Knudson, *et al.* (8)	BE	Pneumotachygraph	?	730	Urban	No
Cherniack and Raber (9)	F	Wedge®	Yes	230	Mixed	No
Schmidt, *et al.* (10)	K	Collins 13.5-L metal bell	Yes	1,400	Urban	Yes
Kory, *et al.* (11)	K	Collins 13.5-L metal bell	Yes	Mixed	Urban	Yes
Cotes, *et al.* (12)	K*	McKerrow water-seal	No	SL	?	Yes
Ferris, *et al.* (13)	BE	Collins 6-L	No	310	Rural	Yes†

Definitions of abbreviations: ATS, American Thoracic Society, BE = back extrapolation technique (5); K = Kory technique (11); F = minimal flow threshold; SL = at or near sea level.

* Modified to Kory technique (100 ml rather than 200 ml used).

† Separate smokers and nonsmokers.

(FEF$_{25-75}$) was reported in liters BTPS/s. Spirograms were performed on subjects in a sitting position until three acceptable tracings were obtained *(5)*. The best test was defined by the Intermountain Thoracic Society (ITS) as the test with the highest sum of FVC and the forced expiratory volume in one second (FEV$_1$) (3). Although the ATS recommends computing the FEF$_{25-75}$ from the best test, it suggests reporting the largest FVC and FEV$_1$ regardless of the tracing from which they were obtained *(5)*. The best test values for FVC and FEV$_1$ were therefore compared with the largest values of FVC and FEV$_1$ recorded by each subject.

Multiple linear regressions were performed with standard statistical programs using STRATO (17–19). The spirometric values were regressed against the independent variables of height, age, weight, and body surface area. Transformations (X^2, ln X, $\sqrt{X}$, $X_1 \cdot X_2$, X^3) of FVC and FEV$_1$ and all independent variables were tested in an attempt to improve the predictability of the equations. The standard error of the estimate (SEE) and the coefficient of determination (R^2) were calculated for each equation. Residuals (measured value − predicted value) were graphically examined by comparing them with each independent variable and with the predicted dependent variable.

The standard errors ($S_{\hat{Y}}$) for predicted single new dependent values ($\hat{Y}$) were calculated from equations presented by Zar (18) (see Appendix). For all spirometric values and ratios, 95 % confidence limits were calculated by one-tailed *t* tests, because clinical interest is usually focused on whether or not the patient's measured value is less than the lower limit of normal. Separate 95 % confidence limits for each dependent variable were calculated as a function of height and age, at 10-cm and 10-yr increments, respectively, over the entire range of height and age of the sample population.

Results

Three hundred and eleven subjects were screened; 251 (126 women and 125 men) were designated "normal" and were included in the study (table 2). Each age decade, from 15 through 84 yr, contained an equal number of subjects (table 3).

The mean differences between the largest and the best test values were 8.0 ± 24.6 ml for FVC and 7.1 ± 28.6 ml for FEV$_1$. The minimal spirometer accuracy recommended by the ATS is ± *50* ml, or ± 3 % of the reading *(5,* 6). Only two of the 251 subjects had a difference (maximum—best test) that exceeded these recommendations. For the regressions of FVC and FEV$_1$ against height and age, there was no significant difference between equations using maximal or best test values. Within-subject coefficients of variation were measured for the three repeated tests of FVC and FEV$_1$ in *50* subjects. The coefficient of variation ± SD for FVC was 2.01 ± 1.21 %; for FEV$_1$, 1.96 ± 1.41 %.

The regression equations for men and women are shown, respectively, in tables 4 and 5. Tables of normal value by height and age are contained in tables B and C in the Appendix. We did not find that the addition of weight, body surface area, or transformations significantly improved the predictability of the regression equations using height and age alone. Analysis of residuals showed that homoscedasticity was present for all equations. For those who wish to calculate precise confidence limits for each patient, the formulas and methods for measuring the 95 % confidence interval for a single new predicted value are shown in the Appendix. For any new predicted value, the confidence interval and, therefore, the lower limit of normal increases as height and age vary from *the* mean height and age of the sample population. We found, however, that the range of confidence interval sizes was small and that, for clinical purposes, one could substitute a single mid-range value for all equations (tables 4 and 5). Such a substitution made a maximal error in the 95 % confidence interval of less than 1 % for FVC, FEV$_1$, and FEV$_3$, and of only 1.6 % for FEF$_{25-75}$. A comparison of several simple regression equations with the complex nonlinear equations recommended by Schoenberg and colleagues (7) is summarized in table 6. Morris and associates (1) calculated their forced expiratory volumes and flows using the Kory technique rather than the back extrapolation technique now recommended by the ATS (1, 5, 11). The average FEV$_1$ calculated with the back extrapolation technique exceeds that calculated with the Kory technique by 179 ml (20). (In 20 of our normal subjects, this mean difference was 1% ml). By adding 179 ml to FEV$_1$, we adjusted the predicted

TABLE 2

PHYSICAL CHARACTERISTICS OF SUBJECTS

	Men Range	Men Mean ± SD	Women Range	Women Mean ± SD
Age, yr	15–91	49 ± 20	17–84	49 ± 20
Height, cm	157–194	175 ± 7	146–178	161 ± 7
Weight, kg	60–111	78 ± 13	44–105	68 ± 13

TABLE 3

AGE DISTRIBUTION OF SUBJECTS

Age (yr)	Men	Women
15–24	17	18
25–34	18	18
35–44	19	19
45–54	19	18
55–64	18	19
65–74	17	17
75–84	15	17
85–91	2	
Total	125	126

TABLE 4

PREDICTION EQUATIONS FOR SPIROMETRIC PARAMETERS IN MEN

Test, Units	Equations			R^2	SEE	95 % Confidence Interval*
FVC, L BTPS	0.0600H	−0.0214A	−4.650	0.54	0.644	1.115
$FEV_{0.5}$, L BTPS	0.0327H	−0.0152A	−1.914	0.53	0.414	0.708
FEV_1, L BTPS	0.0414H	−0.0244A	−2.190	0.64	0.486	0.842
FEV_3, L BTPS	0.0535H	−0.0271A	−3.512	0.62	0.587	1.017
FEF_{25-75}, L BTPS/s	0.0204H	−0.0380A	+ 2.133	0.42	0.962	1.666
FEV_1/FVC, %	−0.1300H	−0.152 A	+ 110.49	0.26	4.78	8.28
FEV_3/FVC, %	−0.0627H	−0.145 A	+ 112.09	0.52	2.68	4.64

Definitions *of abbreviations:* FVC = forced vital capacity; H = height in cm; A = age in yr; R^2 = coefficient of determination; SEE = standard error of the estimate; FEV = forced expiratory volume in the number of seconds indicated by subscript; FEF_{25-75} = forced expiratory flow during the middle half of the forced vital capacity.

* The 95 % confidence interval is calculated from a one-tailed *t* test. It is the single value recommended for all heights and ages in this study. When subtracted from the predicted value, it yields the lower limit of normal. Tables of normal values for men and women are available from the authors on request.

TABLE 5

PREDICTION EQUATIONS FOR SPIROMETRIC PARAMETERS IN WOMEN

Test, Units	Equations			R^2	SEE	95 % Confidence Interval.
FVC, L BTPS	0.0491H	−0.0216A	− 3.590	0.74	0.393	0.676
$FEV_{0.5}$, L BTPS	0.0238H	−0.0185A	−0.809	0.72	0.294	0.506
FEV_1, L BTPS	0.0342H	−0.0255A	− 1.578	0.80	0.326	0.561
FEV_3, L BTPS	0.0442H	−0.0257A	−2.745	0.80	0.360	0.620
FEF_{25-75}, L BTPS/s	0.0154H	−0.0460A	+ 2.683	0.60	0.792	1.363
FEV_1/FVC, %	−0.2020H	−0.252 A	+ 126.58	0.43	5.26	9.06
FEV_3/FVC, %	−0.0937H	−0.163 A	+ 118.16	0.48	3.11	5.36

For definitions of abbreviations, see Table 4.

TABLE 6

COMPARISON OF LINEAR AND NONLINEAR EQUATIONS FOR PREDICTING FVC AND FEV_1

Reference	Variable	Formula Format	SEE	R^2
Schoenberg, et *al.* (7)	FVC F	aHW + blnA + cAH + dW + eW² + fAW + k	0.433	0.56
Morris, et *al.* (1)	FVC F	aH + bA + k	0.520	0.50
Schmidt, et el. (10)	FVC F	aH + bA + k	0.360	0.58
Present study	FVC F	aHW + blnA + cAH + dW + eW² + fAW + k	0.398	0.74
Resent study	FVC F	aH + bA + k	0.391	0.74
Schoenberg, et el. (7)	FVC M	aHW + blnA + cAW + dW² + k	0.597	0.56
Morris, et el. (1)	FVC M	aH + bA + k	0.740	0.42
Schmidt, et el. (10)	FVC M	aH + bA + k	0.460	0.53
Present study	FVC M	aHW + blnA + cAW + dW² + k	0.624	0.57
Present study	FVC M	aH + bA + k	0.645	0.53
Schoenberg, et al. (7)	FEV_1 F	aH + bHW + clnA + dAH + eW² + k	0.323	0.68
Morris, et el. (1)	FEV_1 F	aH + bA + k	0.470	0.53
Schmidt, *et al.* (10)	FEV_1 F	aH + bA + k	0.290	0.71
Present study	FEV_1 F	aH + bHW + clnA + dAH + eW² + k	0.324	0.81
Present study	FEV_1 F	aH + bA + k	0.328	0.80
Schoenberg, et *al.* (7)	FEV_1 M	aHW + blnA + cW + dW² + eAHW + k	0.440	0.64
Morris, et el. (1)	FEV_1 M	aH + bA + k	0.550	0.53
Schmidt, et *al.* (10)	FEV_1 M	aH + bA + k	0.390	0.64
Present study	FEV_1 M	aHW + blnA + cW + dW² + eAHW + k	0.483	0.66
Present study	FEV_1 M	aH + bA + k	0.482	0.65

Definitions *of* abbreviations: SEE = standard error of the estimate, in liters BTPS; R^2 = coefficient of determination; FVC = forced vital capacity; F = female; H = height; in = natural logarithm; A = age; W = weight; k = constant; M = male; FEV_1 = forced expiratory volume in one second.

values reported by Morris and co-workers to approximate those that would have been obtained by the back extrapolation method. These values were used in a graphic comparison of the five studies of lifetime nonsmokers (figure 1).

Discussion

The equations in this study were generated using the best test from three acceptable tracings. Nathan and colleagues (22) have shown that little is gained by doing more than three tests. In our normal subjects there was no significant difference between selecting the largest FVC or FEV_1 result or using the best test result. We therefore recommend using the best test method of selection because of its simplicity. The equations in tables 4 and 5 would, however, apply to either method of test selection. Comparison of equations using height and age with the nonlinear equations proposed by Schoenberg and co-workers (7) (table 6) shows that the coefficient of determination and the SEE of the simpler, linear equations are comparable to, if not better than, those of the more complicated, nonlinear equations. When we added multiple transformations of the independent variable in both linear and nonlinear regressions (including the regressions proposed by Schoenberg and associates), we could not demonstrate significant improvement over the linear regressions that used only height and age. We therefore recommend that the simpler linear regressions using height and age be used.

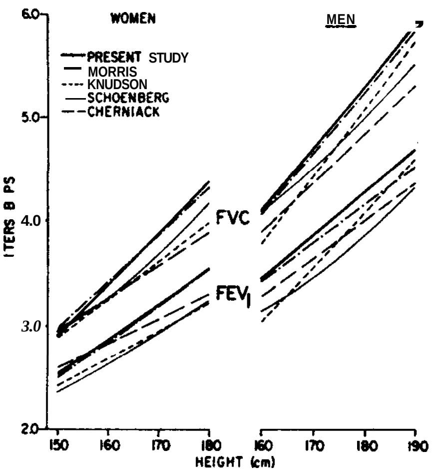

Fig. 1. Comparisons of forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) in five reference studies of lifetime nonsmokers: Morris and associates (1), Knudson and colleagues (8), Schoenberg and coworkers (7), Cherniack and Raber (9), and the present study. Calculations were made for a person 40 yr of age. Weights for the data of Schoenberg and associates are average weights from actuarial tables for each height (21). The data of Morris and co-workers were adjusted to a back extrapolation technique (20).

The 95 % confidence intervals for all predicted spirometric values are relatively constant as height and age vary from the mean height and age of the sample population. With almost constant confidence intervals over a wide range of predicted values, it is not reasonable to consider the predicted value ± 20 % as normal. **For** example, the predicted FEV_1 for men varies from **5.48** to 2.11 L BTPS. The recommended confidence interval of **0.84** L (table **4)** would, therefore, constitute from **15** to 40 % of the predicted value, making it untenable to use ± **20 %** to define the limits of normal. We therefore recommend that ***95*** % confidence intervals (single value as in tables **4** and ***5***, or calculated as in the Appendix) be used to define the lower limit of normal and that the practice of subtracting ***20*** % be abandoned.

Our study population was quite similar to that reported on by Morris and associates (1), because both studies contained lifetime nonsmokers and large numbers of Mormons. The differences between our population and theirs were that our population was urban and lived at 1,400-m altitude, whereas their population was rural and lived near sea level. The study of Morns and colleagues has been criticized for using an unusual population (7). We believe that it was unusual only in that it consisted of healthy, lifetime nonsmokers. Mormons generally come from a diverse northern and middle European background. In comparison with other studies, our population was more highly screened, which might explain the higher spirometric values of the present study when compared to 3 of the **4** studies using nonsmokers (figure **1).** The results reported by **Morris** and **as**sociates, when adjusted to approximate the back extrapolation technique, were quite similar to ours. For female **FVC** and FEV_1 and male **FVC,** our study results were almost identical to the adjusted values of Morris and colleagues (1). The correlation between the two studies was not as good for **male** FEV_1 but was still excellent until the **extremes** of age and height were reached. The main difference betweeen the male FEV_1 equations was the age coefficient, a difference that might be explained by the more even age distribution in our study.

Both the present study and Morris and co-workers' study (adjusted for back extrapolation) conform to ATS technique and equipment recommendations. The high correlation between these two studies of subjects with similar ethnic backgrounds is important because they are separated by the passage of 10 years and by 1,400-m altitude, and because one concerns rural and the other, urban subjects. Either the present study or Morris and colleagues' study (6) (adjusted to approximate the back extrapolation technique) ***can*** be recommended for the prediction of reference values for rural or urban whites of northern and middle European extraction from sea level to 1,400-m altitude.

TABLE A

INVERTED VARIANCE-COVARIANCE MATRIX VALUES FOR THE CALCULATION OF $S_{\hat{Y}}$

	C_{11}	C_{12} or C_{21}	C_{22}
Female spirometry	$2.2456 \; 10^{-4}$	$3.6042 \; 10^{-5}$	$2.5956 \; 10^{-6}$
Male spirometry	$2.1460 \; 10^{-4}$	$2.8452 \; 10^{-5}$	$2.4318 \; 10^{-6}$

Definitions of abbrwiatlons: See text of the Appendix. These values are the same for forced vital capacity (FVC), timed forced expiratory volumes ($FEV_{0.5}$, *FEV,*. FEV_3), forced expiratory flow during *the* middle half of the *FVC* (FEF_{25-75}), FEV_1/FVC, and *FEVJFVC.*

TABLE B

PREDICTED SPIROMETRIC VALUES FOR ADULT WOMEN

Height (cm)	Age (yr)	FVC (L)	FEV, (L)	FEV,/FVC (%)	FEF_{25-75} (L/s)
150	20	3.34	3.04	91.3	4.07
	30	3.13	2.79	88.8	3.81
	40	2.91	2.53	86.2	3.15
	50	2.69	2.28	83.7	2.89
	60	2.48	2.02	81.2	2.23
	70	2.26	1.77	78.7	1.77
155	20	3.59	3.21	90.3	4.15
	30	3.37	2.88	87.0	3.89
	40	3.18	2.70	85.2	3.23
	50	2.94	2.45	82.7	2.77
	60	2.72	2.19	80.2	2.31
	70	2.51	1.94	77.7	1.86
160	20	3.83	3.38	89.3	4.23
	30	3.62	3.13	88.7	3.77
	40	3.40	2.87	84.2	3.31
	50	3.19	2.62	81.7	2.86
	60	2.97	2.36	79.2	2.39
	70	2.75	2.11	78.7	1.93
165	20	4.08	3.55	88.3	4.30
	30	3.86	3.30	85.7	3.84
	40	3.85	3.05	83.2	3.38
	50	3.43	2.79	80.7	2.92
	60	3.22	2.53	78.2	2.46
	70	3.00	2.28	75.7	2.00
170	20	4.32	3.73	87.2	4.38
	30	4.11	3.47	84.7	3.92
	40	3.89	3.22	82.2	3.46
	50	3.68	2.88	79.7	3.00
	60	3.46	2.71	77.2	2.54
	70	3.24	2.45	74.7	2.08
175	20	4.57	3.90	86.2	4.46
	30	4.35	3.64	83.7	4.00
	40	4.14	3.39	81.2	3.54
	50	3.92	3.13	78.7	3.08
	60	3.71	2.88	78.2	2.62
	70	3.49	2.82	73.6	2.16
180	20	4.82	4.07	85.2	4.53
	30	4.60	3.81	82.7	4.07
	40	4.38	3.56	80.2	3.61
	50	4.17	3.30	77.7	3.15
	60	3.95	3.05	75.1	2.69
	70	3.74	2.79	72.6	2.23

Definitions of abbreviations: L = liters BTPS; *US* = liters BTPS/s.

Appendix

For these multiple linear regression equations, the standard error ($S_{\hat{Y}}$) of **a** single new predicted value ($\hat{Y}$) for **a given** height and age is calculated from the fol-

TABLE C

PREDICTED SPIROMETRIC VALUES FOR ADULT MEN

Height (cm)	Age (yr)	FVC (L)	FEV_1 (L)	FEV_1/FVC (%)	FEF_{25-75} (L/s)
155	20	4.22	3.74	87.4	4.53
	30	4.01	3.49	85.8	4.16
	40	3.79	3.25	84.3	3.78
	50	3.58	3.01	82.8	3.40
	60	3.37	2.76	81.3	3.02
	70	3.15	2.52	79.7	2.64
160	20	4.52	3.95	86.7	4.64
	30	4.31	3.70	85.2	4.26
	40	4.09	3.46	83.7	3.88
	50	3.88	3.21	82.1	3.50
	60	3.61	2.97	80.6	3.12
	70	3.45	2.73	79.1	2.74
165	20	4.82	4.15	86.1	4.74
	30	4.61	3.91	84.5	4.36
	40	4.39	3.66	83.0	3.98
	50	4.18	3.42	81.5	3.60
	60	3.97	3.18	80.0	3.22
	70	3.75	2.93	78.4	2.84
170	20	5.12	4.36	85.4	4.84
	30	4.91	4.12	83.9	4.46
	40	4.69	3.87	82.4	4.08
	50	4.48	3.63	80.8	3.70
	60	4.27	3.36	79.3	3.32
	70	4.05	3.14	77.8	2.94
175	20	5.42	4.57	84.8	4.94
	30	5.21	4.32	83.2	4.56
	40	4.99	4.08	81.7	4.18
	50	4.78	3.84	80.2	3.80
	60	4.57	3.59	78.7	3.42
	70	4.35	3.35	77.2	3.04
180	20	5.72	4.77	84.1	5.04
	30	5.51	4.53	82.8	4.66
	40	5.29	4.29	81.1	4.28
	50	5.08	4.04	79.5	3.90
	60	4.87	3.80	78.0	3.52
	70	4.65	3.55	76.5	3.14
185	20	6.02	4.98	83.5	5.15
	30	5.81	4.74	81.9	4.77
	40	5.59	4.49	80.4	4.39
	50	5.38	4.25	78.9	4.01
	Bo	5.17	4.01	77.4	3.63
	70	4.95	3.76	75.9	3.25
190	20	6.32	5.19	82.8	5.25
	30	6.11	4.94	81.3	4.07
	40	5.89	4.70	79.8	4.49
	50	5.88	4.46	78.2	A.11
	Bo	5.47	4.21	76.7	3.73
	70	5.25	3.97	75.2	3.35

For definitions of abbreviations, see Table B.

lowing equation (18): $S_{\hat{Y}} = [(SEE)^2 (1 + 1/n + C_{11}(H - \bar{H})^2 + C_{12}(H - \bar{H})(A - \bar{A}) + C_{21}(A - \bar{A})(H - \bar{H}) + C_{22}(A - \bar{A})^2)]^{1/2}$. Because $C_{12} = C_{21}$ the equation can be simplified to: $S_{\hat{Y}} = [(SEE)^2 (1 + 1/n + C_{11}(H - \bar{H})^2 + 2C_{12}(H - \bar{H})(A - \bar{A}) + C_{22}(A - \bar{A})^2)]^{1/2}$. For both equations, SEE is the standard error of the estimate; n, the population size; H, the height, in cm; A, age, in yr, at which the new prediction is to be made; $\bar{H}$ and $\bar{A}$, mean height and age, respectively, in the sample used to generate the regression equation; C_{11}, C_{12}, C_{21}, and C_{22} are the values from the inverted variance-covariance matrix corresponding to the appropriate combinations of height and age. The subscript 1 corresponds to height; 2, to age.

Tables 2 and 3 contain the appropriate values of n and the mean heights and ages. Table A contains the appropriate C_{11}, C_{12}, C_{21}, and C_{22} values for the prediction equations in this study. The 95 % confidence intervals using a one-tailed t test in samples of 125 or 126 subjects (present study) can be calculated using the formula: $\hat{Y}$ = predicted $\hat{Y} \pm 1.66\ S_{\hat{Y}}$.

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References

1. Morris JF, Koski A, Johnson LC. Spirometric standards for healthy nonsmoking adults. Am Rev Respir Dis 1971; 103:57-67.

2. Permutt S, Chester E, Anderson W, Cugell D, Petty TL, Sharp JT. Office spirometry in clinical practice. Statement of the American College of Chest Physicians' Committee on clinic and office pulmonary function testing. Chest 1978; 74: 298.

3. Kanner RE, Morris AH, eds. Clinical pulmonary function testing: a manual of uniform laboratory procedures for the intermountain area. Salt Lake City: Intermountain Thoracic Society, 1975.

4. Ferris BG (Principal Investigator). Epidemiology standardization project. Am Rev Respir Dis 1978; 118(Part 2):55-88.

5. Gardner RM, et al. Snowbird workshop on standardization of spirometry: a statement by the American Thoracic Society. Am Rev Respir Dis 1979; 119:831-8.

6. Gardner RM. Hankinson JL, West BJ. Evaluating commercially available spirometers. Am Rev Respir Dis 1980; 121:73-82.

7. Schoenberg JB. Beck GJ, Bouhuys A. Growth and decay of pulmonary function in healthy blacks and whites. Respir Physiol 1978; 33: 367-93.

8. Knudson RJ. Slatin RC, Lebowitz MD, Burrows B. The maximal expiratory flow-volume curve. Am Rev Respir Dis 1976; 113:587-600.

9. Cherniack RM, Raber MB. Normal standards for ventilatory function using an automated wedge spirometer. Am Rev Respir Dis 1972; 106: 38-44.

10. Schmidt CD, Dickman ML, Gardner RM, Brough FK. Spirometric standards for healthy elderly men and women. Am Rev Respir Dis 1973; 108:933-9.

11. Kory RC, Callahan R, Boren HG, Syner JC. The Veterans Administration—Army cooperative study of pulmonary function. Clinical spirometry in normal men. Am J Med 1961; 30: 243-58.

12. Cotes JE, Rossiter CE, Higgins ITT, Gilson JC. Average normal values for the forced expiratory volume in white Caucasian males. Br Med J 1966; 1:1016-19.

13. Fems BG, Anderson DO, Zickmantel R. Prediction values for screening tests of pulmonary function. Am Rev Respir Dis 1965; 91:252-61.

14. Sobol BJ, Sobol PG. Per cent of predicted as the limit of normal in pulmonary function testing: a statistically valid approach. Thorax 1979; 34:1-3.

15. Medical Research Council's Committee on the aetiology of clinic bronchitis: Standardized questionnaires on respiratory symptoms. Br Med J 1960; 2:1665.

16. Dickman ML, Schmidt CD, Gardner RM. Marshall HW, Day WC, Warner HR. On-line computerized spirometry in 738 normal adults. Am Rev Respir Dis 1969; 100:780-90.

17. Warner HR. Computer-assisted medical decision-making. New York: Academic Press. 1979.

18. Zar JH. Biostatistical analysis. Englewood Cliffs, NJ: Prentice-Hall, 1974.

19. Afifi AA, Azen SP. Statistical analysis: a computer oriented approach. New York: Academic Press, 1973.

20. Smith AA, Gaensler EA. Timing of forced expiratory volume in one second. Am Rev Respir Dis 1975; 112:882-5.

21. Association of Life Insurance Medical Directors and the Society of Actuaries. 1979 Build and Blood Pressure Study.

22. Nathan SP, Lebowitz MD. Knudson RJ. Spirometric testing: number of tests required and selection of data. Chest 1979; 76:384-8.