Reference Values for Pulmonary Function in Asian Indians Living in the United States*

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Objective: To establish reference values for pulmonary function in the Asian-Indian population living in the United States.

Design: Five-year cross-sectional study of pulmonary function in healthy adult Asian Indians living in the United States, using American Thoracic Society guidelines for measuring pulmonary function.

Setting: Measurement of pulmonary function in healthy nonsmoking Asian Indians in a pulmonary function laboratory or at festivals, picnics, and ceremonies where subjects could be conveniently recruited.

Participants: Four hundred sixty subjects from a population of Asian Indians residing in the Chicago metropolitan area.

Measurements: Spirometry was performed in all subjects with measurements of FEV_1, FVC, and forced expiratory flow between 25% and 75% of vital capacity (FEF_{25-75}). Lung volumes were measured in eighty subjects. Prediction equations for FEV_1, FVC, and FEF_{25-75} were derived using multiple regression analysis.

Results: Three hundred sixty-three subjects (226 men and 137 women) met the inclusion criteria. Spirometric values derived from our prediction equations, when compared to the values for whites from the selected studies in the literature, showed FVC to be 20 to 24% lower in men and 25 to 28% lower in women. FEV_1 was 16 to 23% lower in men and 20 to 26% lower in women. Differences were not quite as large when compared to values from African Americans and other studies on Asians.

Conclusions: We provide reference values for pulmonary function in nonsmoking Asian Indians living in the United States. These reference values should be used for evaluation of pulmonary function in this population. *(CHEST 2004; 126:1225–1233)*

Key words: Asian Indians; predicted equations; pulmonary function; racial differences; reference values; spirometry

Abbreviations: ATS = American Thoracic Society; FEF_{25-75} = forced expiratory flow between 25% and 75% of vital capacity; FRC = functional residual capacity; TLC = total lung capacity; VC = vital capacity

Race has been consistently shown to be a determinant of pulmonary function. White subjects of European descent usually have larger static and dynamic lung volumes and forced expiratory flow rates than most other races.[1–5] These differences persist after adjustments are made for age, stature, smoking, air pollution, habitual activity, and altitude. Possible explanations for these racial differences remain purely speculative at this time. Differences may be partially due to differences in body build, nutrition, physical activity, air pollution, and socioeconomic factors.

Representing one sixth of the total world population, the Asian-Indian population is the second largest after the Chinese.[6] Results of the 2000 US Census revealed that 1,678,765 Asian Indians live in the United States. The population of Asian Indians in Canada and Europe is also rising.

Despite the sizeable number of Asian-Indian population in the United States, reliable reference values

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for pulmonary function for this group based on studies in the United States are unavailable. Asian Indians living in the United States may perhaps differ from Asian Indians living in India, concerning nutrition, physical activity, community air pollution, and socioeconomic factors. Previous studies[7–14] for reference values on the Indian subcontinent have included smokers and addressed subjects within narrow age ranges. They also lacked the vigorous quality assurance program of American Thoracic Society (ATS) guidelines.[7–14]

To establish proper regression models that account for the decline in pulmonary function with age, we studied pulmonary function in a cross-section of healthy nonsmoking Asian-Indian population living in the United States. Our study was aimed at eliminating deficiencies of existing studies by rigidly following ATS guidelines and using subjects across wide age ranges in a nonsmoking cross-section of the Asian-Indian population.

Materials and Methods

Recruitment

The study included 460 subjects recruited from 1993 to 1997. Healthy adult subjects of both sexes were chosen from a population of nonsmoking Asian Indians residing in the Chicago metropolitan area. All subjects were Indian-born immigrants to the United States. The pulmonary function tests were performed in the pulmonary function laboratory at North Chicago VA Medical Center or at festivals, picnics, and ceremonies where subjects could be conveniently recruited. Some subjects were medical residents, and nursing staff of Asian-Indian origin. The research protocol was reviewed and approved by the institutional review board, which consists of the Research and Development Committee and The Human Studies Subcommittee.

Interview and Clinical Examination

Positive smoking status was defined by any answer indicating prior or current history of smoking cigarettes, pipe, cigars, or marijuana use. Smokers were excluded for various reasons, but most importantly because of the lack of a standard decrement in lung function at a given exposure level.[15] All subjects were screened by means of a self-administered health questionnaire[16] to exclude cardiopulmonary or other diseases that might affect pulmonary function. Specifically, subjects with a history of asthma, chronic bronchitis, chronic cough, exposure to any toxic chemicals, or surgery involving the chest wall were not eligible. A brief physical examination was performed by one of the authors to rule out any acute or chronic respiratory illness. Subjects with abnormal physical examination findings were excluded. The chest was examined for evidence of surgery and auscultated for wheezes and crackles. Subjects who were unable to perform spirometry according to ATS guidelines[15,17,18] were excluded. Spirometry was postponed if the subjects had any flu-like illness or cold. Age was recorded to the nearest year, height was measured to the nearest inch with the subject standing barefoot, and weight in light street clothes was recorded to the nearest pound. Subjects were weighed on a balanced scale, and height was measured on a stadiometer by one observer.

Table 2—*Factors Used to Exclude Participants From Healthy Subgroups*

Factors	Female	Male
Poor spirometry quality	16	21
Smoker		18
History of asthma/allergy	5	7
Upper respiratory infection	2	4
Chronic cough	4	8
Chest surgery		4
Abnormal chest radiograph finding	1	4
Others	1	2
Total	29	68

Participant Preparation and Equipment and Quality Assurance

All subjects signed an informed consent document. After the purpose of the tests and the methods to be used were explained to the subjects, spirometric testing was performed by trained personnel using a Collins Eagle I (Collins; Braintree, MA) water-sealed spirometer with microprocessor support that met ATS accuracy requirements. The same type of spirometer was used both in the laboratory and out of the laboratory. The ATS

Table 1—*Subject Characteristics**

Characteristics	Included Subjects: Men (n = 226)	Included Subjects: Women (n = 137)	Excluded Subjects: Men (n = 68)	Excluded Subjects: Women (n = 29)
Age, yr	39.97 ± 14.13	39.80 ± 14.85	34.95 ± 16.0	49.83 ± 14.8
Height, cm	171.12 ± 7.36	158.22 ± 6.95	169.9 ± 7.36	155.50 ± 8.17
Weight, kg	70.80 ± 9.2 (n = 193)	58.65 ± 8.98 (n = 122)	70.15 ± 9.96 (n = 58)	57.83 ± 12.60 (n = 28)
Actual FEV_1, L	3.07 ± 0.67	2.18 ± 0.47	2.72 ± 0.78	1.60 ± 0.62
Predicted FEV_1, L	3.65 ± 0.63	2.62 ± 0.48	3.45 ± 0.65	2.36 ± 0.59
Actual FVC, L	3.70 ± 0.74	2.57 ± 0.52	3.34 ± 0.85	1.93 ± 0.69
Predicted FVC, L	4.68 ± 0.66	3.32 ± 0.51	4.51 ± 0.65	3.02 ± 0.55
Actual $FEF_{25–75}$, L	3.30 ± 1.20	2.42 ± 0.84	2.83 ± 1.36	1.67 ± 0.85
Predicted $FEF_{25–75}$, L	4.04 ± 0.84	3.13 ± 0.61	3.75 ± 0.89	2.71 ± 0.59
Actual TLC, L	5.49 ± 0.92 (n = 51)	4.06 ± 0.52 (n = 29)	NA	NA
Predicted TLC, L	6.76 ± 0.54 (n = 51)	5.04 ± 0.49 (n = 29)	NA	NA
Actual FRC, L	2.52 ± 0.70 (n = 51)	1.98 ± 0.39 (n = 29)	NA	NA

*Data are presented as mean ± SD. NA = not applicable.

Table 3—*Prediction Equations for Asian Indians Living in the United States for Both Sexes*

Variables	Regression Equations	Lower Limit of Normal	R^2	SEE
Men (n = 226)				
FVC	$-2.754 + [0.043 \times \text{height}] + (-0.024) \times \text{age}$	− 0.78	0.584	0.478
FEV_1	$-1.936 + [0.035 \times \text{height}] + (-0.026) \times \text{age}$	− 0.64	0.662	0.388
FEF_{25-75}	$0.736 + [0.025 \times \text{height}] + (-0.044) \times \text{age}$		0.361	0.962
TLC (n = 29)	$-5.152 + [\text{height} \times 0.064] + (-0.017) \times \text{age}$		0.221	0.828
Women (n = 137)				
FVC	$-0.842 + [0.027 \times \text{height}] + (-0.020) \times \text{age}$	− 0.57	0.564	0.346
FEV	$-0.401 + [0.021 \times \text{height}] + (-0.021) \times \text{age}$	− 0.46	0.646	0.281
FEF_{25-75}	$0.720 + [0.019 \times \text{height}] + (-0.032) \times \text{age}$		0.405	0.653
TLC (n = 51)	$3.536 + [\text{height} \times 0.003] + (-0.01) \times \text{age}$		0.001	0.543

guidelines for spirometry were rigidly followed.[15,17–20] Spirometry was performed in a sitting position. The subject was asked to assume a correct posture with head elevated. Excessive flexion or extension of the neck was avoided. The subject was then asked to inhale completely. After placing a nose clip and the mouthpiece, the subject was asked to exhale with maximal force. The instructions were repeated as necessary with subjects coached vigorously. The whole procedure was repeated for a minimum of three maneuvers, but not more than eight times. Individual spirograms were acceptable if they were free from artifacts such as cough or closed glottis during the first second of exhalation, early termination or cut off, variable effort, leak, or obstructed mouthpiece. Acceptability criteria also included spirograms having good starts with extrapolated volume $< 5\%$ of FVC or 0.15 L, whichever was greater, and satisfactory exhalation of 6 s or a plateau in the volume-time curve. After three acceptable spirograms were obtained, reproducibility criteria were applied. The two largest FVC values had to be within 0.2 L of each other, and the two largest FEV_1 values had to be within 0.2 L of each other. If both these criteria were met, then the session was concluded. If both these criteria were not met, the testing was continued until both these criteria were met with analysis of additional acceptable spirograms, or a total of eight tests were performed, or if the subject could not continue the test. The three best results were saved.

Additionally, functional residual capacity (FRC) was measured using Collins Apex DS 620 (Collins) lung volume module with closed-circuit helium dilution method in eighty subjects (51 men

Table 4—*Comparison of Current Study With Pulmonary Function Values From Other Ethnic Groups**

Variables	Year	Subjects, No.	Age Range, yr	FEV_1, L	FVC, L	TLC, L
Men						
Current study	1997	226	20–80	3.02	3.69	5.28
Crapo et al[21]†	1981	125	15–91	3.96	4.89	6.95
Knudson et al[22]†	1983	86	20–84	3.81	4.64	NA
Morris et al[23]†	1974	517	20–84	3.63	4.84	NA
Johannsen and Erasmus[24]‡	1968	120	20–50	2.96	4.07	NA
Miller et al[25]‡	1970	96	35–54	3.05	3.79	NA
Sharp et al[26]§	1996	528	70–90+	3.45	4.47	NA
Enright et al[20]‡	1986	64	65–85+	3.41	3.86	NA
Chatterjee and Saha[14]‖	1988	334	20–60	3.23	3.97	NA
Vijayan et al[34]‖	1990	130	15–40	3.31	3.99	NA
Women						
Current study	1997	137	16–80	2.12	2.55	3.56
Crapo et al[21]†	1981	126	15–84	2.92	3.54	4.62
Knudson et al[22]†	1983	204	20–87	2.79	3.36	NA
Morris et al[23]†	1971	517	20–84	2.72	3.54	NA
Johannsen and Erasmus[24]‡	1968	100	20–50	2.25	2.74	NA
Miller et al[25]‡	1970	109	35–54	2.19	2.74	NA
Enright et al[20]‡	1986	171	65–85+	2.03	2.87	NA
Udwadia et al[12]‖	1986	288	15–65	2.16	2.89	NA
Chatterjee and Saha[13]‖	1993	230	20–59	1.99	2.42	NA
Vijayan et al[34]‖	1990	117	15–40	2.39	2.89	NA

*FEV_1, FVC, and TLC values were calculated for a 45-year-old man with a height of 1.75 m, and a 45-year-old woman with height of 1.65 m. See Table 1 for expansion of abbreviation.

†White studies.

‡African-American studies.

§Japanese-American study.

‖Asian-Indian studies from India.

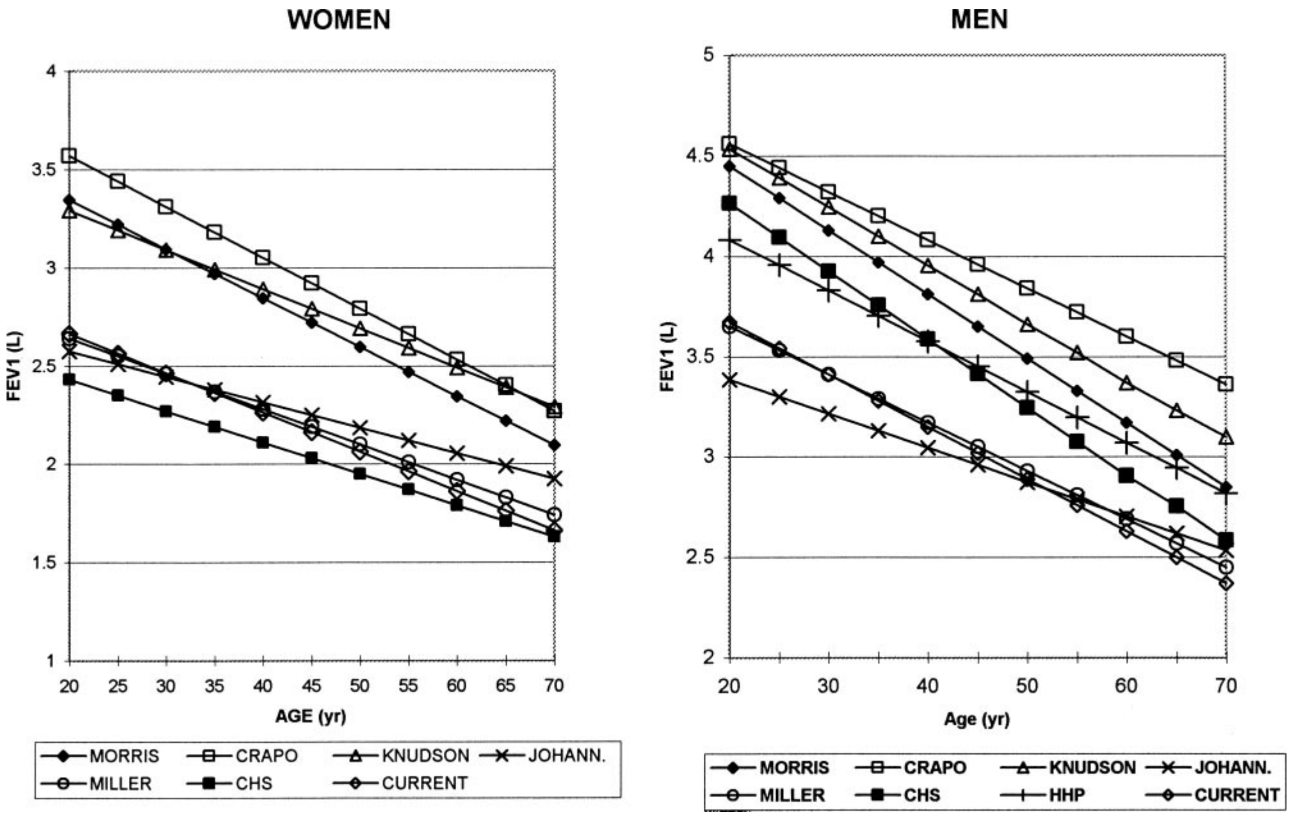

FIGURE 1. Predicted FEV_1 values over the observed range of age for healthy Asian-Indian subjects at a height of 1.75 m for men and 1.65 m for women, compared to other ethnic studies. Data from Crapo et al,[21] Knudson et al,[22] Enright et al,[20] Johannsen and Erasmus,[24] and Sharp et al[26] are shown (please note that the current study and the data from Miller et al[25] are overlapping). CHS = Cardiovascular Health Study[20]; HHP = Honolulu Heart Program.[26]

and 29 women) who were able to come to the pulmonary function laboratory for testing. Residual volume was obtained by subtracting expiratory reserve volume from FRC. Total lung capacity (TLC) was obtained by adding residual volume and vital capacity (VC).

Processing of Results

Time zero of each maneuver was determined using the back-extrapolation technique. The FEV_1, FVC, forced expiratory flow between 25% and 75% of VC (FEF_{25-75}), and peak expiratory flow were all computed by standardized techniques, with resolutions of 10-mL volume, 10 mL/s flow, and 2-ms forced expiratory time. The peak expiratory flow time was defined as the time in milliseconds from the back-extrapolated time zero until the time of peak flow. The results were corrected to body temperature (body temperature and pressure, saturated conditions) using the spirometer temperature sampled at the beginning of each test session. The largest values of FVC and FEV_1 from the three stored acceptable maneuvers were reported. The mean values for FEV_1, FVC, and FEF_{25-75} for all subjects, and mean values for TLC in 80 subjects were calculated. Pounds and inches were converted to kilograms and centimeters prior to statistical analysis.

Statistical Analysis

Results from participants whose spirometry test sessions did not meet the ATS[15] standards for acceptability and reproducibility were excluded from all analysis. Multiple linear regression analysis was applied to observed lung function values as a function of standing height and age. The FEV_1, FVC, FEF_{25-75}, and TLC were dependent variables, while height and age were independent variables. Predicted values were determined for each dependent variable for a subject 45 years of age with a height of 175 cm for men, and 165 cm for women. Correlation coefficients (r), r^2, and SEE are also reported; $p \leq 0.05$ were considered to be significant. Lower limits of normal were calculated for FEV_1 and FVC in both sexes. Statistical analysis was done using SPSS 11.5 statistical software (SPSS; Chicago, IL).

RESULTS

Of the 460 subjects screened, 363 subjects (226 men and 137 women) met the inclusion criteria. Subject characteristics are displayed in Table 1. Ninety-seven subjects were not eligible. The age range for men was 20 to 86 years (mean, 39.9 years), and for women was 16 to79 years (mean, 39.6 years). Heights ranged 155 to 184 cm for men (mean, 171.1 cm), and 150 to 174 cm for women (mean, 158.2 cm). Excluded subjects had comparable mean age and height to study subjects but lower mean FVC and FEV_1 values (Table 1). The reasons for exclusions of subjects are shown in Table 2.

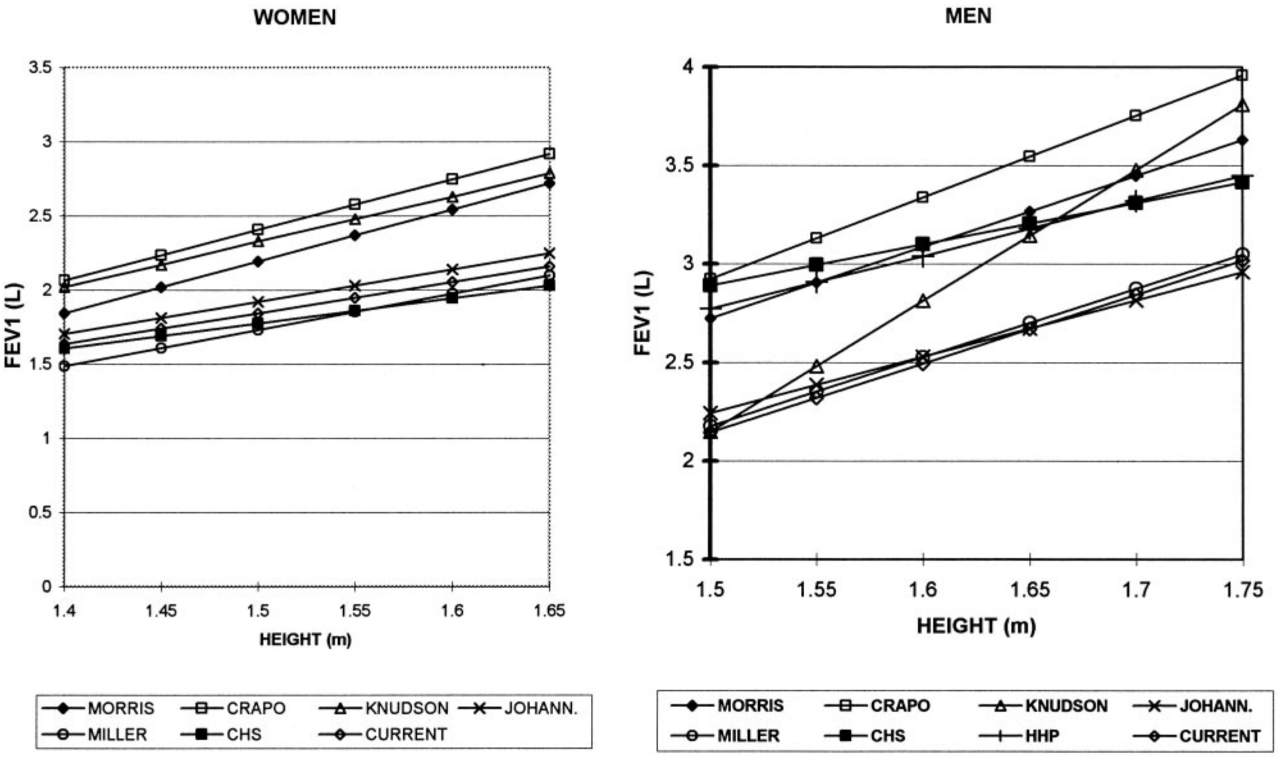

FIGURE 2. Predicted FEV_1 values over the observed range of height for healthy Asian-Indian subjects at age 45 years, compared to other ethnic studies. Data from Enright et al,[20] Crapo et al,[21] Miller et al,[25] Sharp et al,[26] Knudson et al,[22] Johannsen and Erasmus,[24] and Morris et al[23] are shown (please note that the current study and the data from Miller et al[25] are overlapping). See Figure 1 legend for expansion of abbreviations.

FEV_1, FVC, and $FEF_{25–75}$ values were obtained in all 363 subjects. TLC was obtained in 80 subjects. Multiple linear regression yielded prediction equations for each parameter based on age and height. Prediction equations using multiple regression analysis formula derived for men and women subjects, incorporating age and height as independent variables, are shown in Table 3. These equations were used to generate predicted values for each parameter (FEV_1, FVC, $FEF_{25–75}$, and TLC) for age of 45 years and height of 175 cm (165 cm for women). These values were compared with selected white, African-American, Japanese, and Asian-Indian reference values (Table 4).

When compared to the selected studies in white subjects, our results for men were 16 to 23% lower for FEV_1, and 20 to 24% lower for FVC. In women, FEV_1 ranged from 20.5 to 26% lower and FVC from 25 to 28% lower. When we compared our results with those found in Japanese and African-American studies,[24–26] the interracial differences in pulmonary function testing values were not as large. In men, FVC ranged from 2 to 9% lower, and FEV_1 from 2% greater to 11% lower. In women, FVC ranged from 7 to 11% lower, and FEV_1 from 4% greater to 6% lower. The differences were also small when compared with Asian-Indian studies.[7–14] FVC was 7% lower, and FEV_1 ranged from 6 to 8% lower in men. In women, FVC ranged from 5% greater to 12% lower, and FEV_1 ranged from 6% greater to 11% lower. A comparison of FEV_1 and FVC for men and women between our results and the selected studies are illustrated in Figures 1–4. A comparison of calculated values for a 45-year old man and woman with heights of 1.75 m and 1.65 m, respectively, are shown in Table 4. Lower limits of normal for FEV_1 and FVC in both sexes are shown in Table 3. Age distribution is shown in Table 5.

Discussion

Race has been consistently shown to be an important determinant of pulmonary function. There are known differences in normal lung volumes among various ethnic or racial groups. FVC and FEV_1 values of African Americans are approximately 12% lower than those of whites.[20,21,24–26] Similarly, normal values for several Asian populations have been shown to be lower than those for whites.[7–14,33–35] In

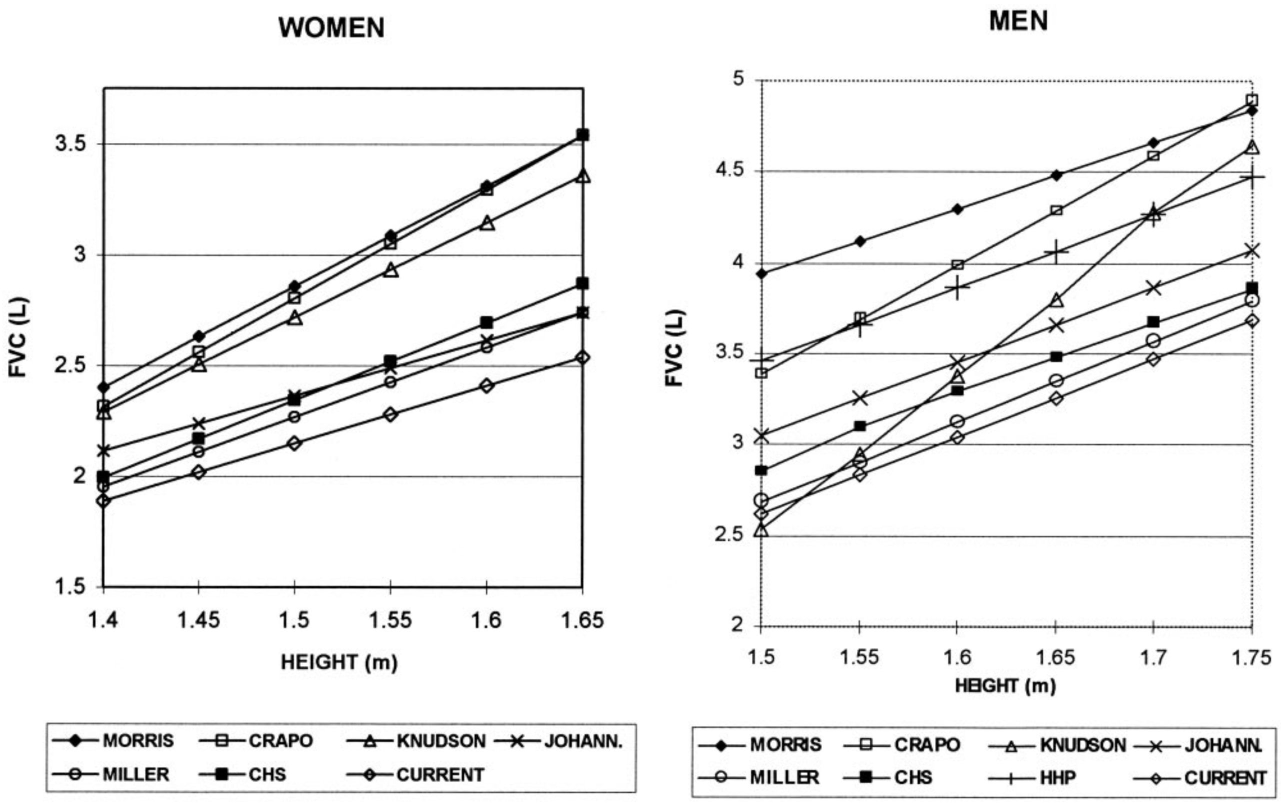

FIGURE 3. Predicted FVC values over the observed range of height for healthy Asian-Indian subjects at age 45 years, compared to other ethnic studies. Data from Enright et al,[20] Crapo et al,[21] Miller et al,[25] Sharp et al,[26] Knudson et al,[22] Johannsen and Erasmus,[24] and Morris et al[23] are shown. See Figure 1 legend for expansion of abbreviations.

contrast, studies of American Indians[29] and Hispanic Americans[30] have shown pulmonary function test values similar to those of whites. The reasons for these racial differences are not well defined. Differences in thoracic height and body stature[31] have been shown to affect spirometric volumes. Orientals have been shown to have smaller lung volumes and larger sitting-to-total-height ratios than whites of the same age and height.[32,33]

Currently there are no reliable prediction equations for pulmonary function applicable to the Asian-Indian population based on survey of Asians Indians living in the United States. As lung function is race dependent, it is essential to use appropriate reference spirometric values and prediction equations for each individual race. Our study addresses this issue for Asian Indians living in the United States, and provides specific spirometric reference values and prediction equations for this population utilizing ATS criteria for accuracy and reproducibility.[7–14]

Data for reference equations in the literature have been obtained from population-based studies designed either for other epidemiologic purposes or specifically for creation of prediction equation.[15] To avoid any bias, we specifically designed this study to create reference values for Asian Indians living in the United States. We recruited a sizeable number of healthy Asian Indians from both sexes with a wide age range living in the Chicago area, and we believe they represent adult Asian-Indian population living in the United States reasonably well. We developed prediction equations for FEV_1, FVC, and $FEF_{25–75}$ in all subjects.

We found a significantly higher correlation coefficient for FEV_1 and FVC and a significantly lower SEE. $FEF_{25–75}$ and TLC, however, did not show a significant relationship. One possible explanation for this finding is the fact that $FEF_{25–75}$ is a variable measure and TLC was measured only in 80 subjects, which is a relatively smaller sample.

Several studies reporting reference values of pulmonary function from India have included smokers and had a rather narrow age range. In addition, they have lacked standardized equipment and adherence to ATS guidelines.[15] Kamat et al[7] reported a 20 to 24% decrease in pulmonary function test results of Asian Indians when compared to age- and height-adjusted values of the white population; in this study,

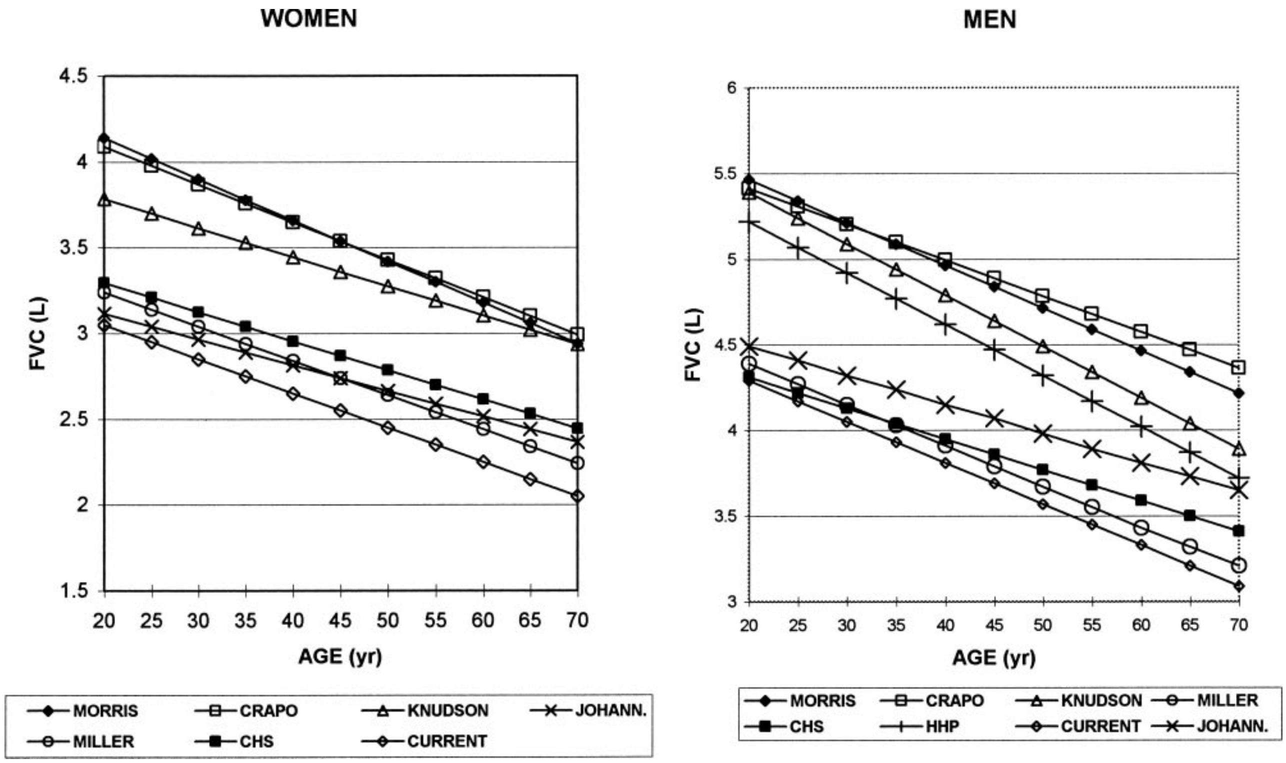

FIGURE 4. Predicted FVC values over the observed range of age for healthy Asian-Indian subjects at a height of 1.75 m for men and 1.65 m for women, compared to other ethnic studies. Data from Enright et al,[20] Crapo et al,[21] Miller et al,[25] Sharp et al,[26] Knudson et al,[22] Johannsen and Erasmus,[24] and Morris et al[23] are shown (please note that the current study and the data from Miller et al[25] are overlapping). See Figure 1 legend for expansion of abbreviations.

smokers were not excluded. Although the size of subject population was large, the inclusion of smokers clouds the issue for acceptance as norms for healthy Indian population. The study of Miller et al[25] had a sufficient number of Asian Indians, but a narrow age range (35 to 54 years); similarly, this study also included smokers. Vijayan et al[34] studied 247 Asian-Indian subjects with an age range of 15 to 40 years. Asymptomatic nonsmokers and the relatives of patients attending the tuberculosis research center were allowed to take part in this study. Other studies[13,14] from Calcutta may not reflect the normal values for healthy nonsmokers, as Calcutta is known to have high level of air pollution.[35]

We found slightly different values for mean FEV_1 and FVC from those reported in studies performed in India, but we adhered to the ATS guidelines for performance of pulmonary function. The differences in study population and inclusion/exclusion criteria may contribute to these variations.

The interracial differences are quite large when prediction equations for the white-American population from the selected studies are applied to the Asian-Indian population. Based on our study, FVC was overpredicted 20 to 24% in men and 25 to 28% in women, and FEV_1 was overpredicted 16 to 23% in men and 20.5 to 26% in women. One common practice has been to utilize prediction equations for African Americans to predict pulmonary functions in Asian Indians, as they are considered to be close. These two populations, however, are not identical. In our study, we demonstrated that FVC is overpredicted 2 to 9% in men and 7 to 11% in women when African-American–predicted values are used. Simi-

Table 5—*Age Distribution for Both Sexes*

Age Groups, yr	Men	Women
16–20	4	8
21–25	13	20
26–30	56	22
31–35	46	14
36–40	21	8
41–45	15	18
46–50	19	13
51–55	14	10
56–60	13	8
61–65	10	11
66–70	9	1
71–86	6	4

larly, FEV_1 is over/underpredicted between − 2 to 11% in men and − 4 to 6% in women when African-American equations are used.

As in most prior studies, our study sample represented a cross-section of the population, which makes it vulnerable to a cohort effect. A longitudinal study would have been ideal but is difficult to accomplish. In longitudinal predictions, reference equations based on cross-sectional surveys may overestimate a longitudinal change.[15] Similarly, in clinical predictions, an accelerated decline in ventilatory function may be underrated if it is compared with cross-sectional standards.[36] Therefore, comparisons between cross-sectional and longitudinal investigations must be made cautiously. Because of the difficulty of performing longitudinal studies, most of the reference value studies are cross-sectional.

Age range, another important determinant of lung function, was wide in our study (20 to 86 years for men and 16 to 79 years for women). Accurate prediction of normal reference values for subjects between ages of 15 years and 20 years may be difficult because of the continued development of lungs in this age group.[22] While women seem to attain their maximal values for VC by the age of 16 years,[15] VC for men continues to increase until growth in height ceases, and may not reach maximum until age 25 years. Our study included four men and three women within the age range of 19 to 20 years, and one man and three women within the age range of 16 to 18 years.

Smoking is a well-established adverse factor affecting lung function, and has quite a variable effect. Ex-smokers may have reversible or irreversible ventilatory decrements. While the spirometric values of young ex-smokers may be higher than nonsmokers, the spirometric values of older ex-smokers may be intermediate compared to current smokers or nonsmokers.[15] To eliminate any confounding effects related to current or prior smoking, we excluded all current or ex-smokers from our study.

In conclusion, this study represents a cross-section of the Asian-Indian population who are immigrant and naturalized US citizens. They may perhaps differ from Asian Indians living in India, concerning nutrition, physical activity, community air pollution, and socioeconomic factors. Therefore, the reference values presented here are specific to Asian Indians living in the United States. Reference values from Indian studies may not therefore be appropriate for application to Asian Indians living in the United States. Our study provides accurate spirometric reference values and prediction equations for the Asian Indians, an ever-growing population in the United States. These reference values should be used for evaluation of pulmonary function in this population.

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