Performance of American Thoracic Society-Recommended Spirometry Reference Values in a Multiethnic Sample of Adults

The Multi-Ethnic Study of Atherosclerosis (MESA) Lung Study

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Background: The American Thoracic Society recommends race-specific spirometric reference values from the National Health and Nutrition Survey (NHANES) III for clinical evaluation of pulmonary function in whites, African-Americans, and Mexican-Americans in the United States and a correction factor of 0.94 for Asian-Americans. We aimed to validate the NHANES III reference equations and the correction factor for Asian-Americans in an independent, multiethnic sample of US adults.

Methods: The Multi-Ethnic Study of Atherosclerosis (MESA) recruited self-identified non-Hispanic white, African-American, Hispanic, and Asian-American participants aged 45 to 84 years at six US sites. The MESA-Lung Study assessed prebronchodilator spirometry among 3,893 MESA participants who performed acceptable tests, of whom 1,068 were asymptomatic healthy non-smokers who performed acceptable spirometry.

Results: The 1,068 participants were mean age 65 ± 10 years, 60% female, 25% white, 20% African-American, 23% Hispanic, and 32% Asian-American. Observed values of FEV₁, FEV₆, and FVC among whites, African-Americans, and Hispanics of Mexican origin in MESA-Lung were slightly lower than predicted values based on NHANES III. Observed values among Hispanics of non-Mexican origin were consistently lower. Agreement in classification of participants with air-flow obstruction based on lower limit of normal criteria was good (overall $\kappa = 0.88$). For Asian-Americans, a correction factor of 0.88 was more accurate than 0.94.

Conclusions: The NHANES III reference equations are valid for use among older adults who are white, African-American, or Hispanic of Mexican origin. Comparison of white and Asian-American participants suggests that a correction factor of 0.88, applied to the predicted and lower limits of normal values, is more appropriate than the currently recommended value of 0.94.

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Abbreviations: ATS = American Thoracic Society; ERS = European Respiratory Society; LLN = lower limits of normal; MESA = Multi-Ethnic Study of Atherosclerosis; NHANES = National Health and Nutrition Survey

The most recent spirometry guidelines of the American Thoracic Society and European Respiratory Society (ATS/ERS) recommend reference values derived from the National Health and Nutrition Survey (NHANES) III for general use in the United States.^{1,2} NHANES III was a population-based, representative sample of the US population composed predominantly of whites, African-Americans, and Mexican-Americans.³ The NHANES III reference equations have never been validated in a large study of adults, and they may not

apply to other sizable proportions of the US population, including Asian-Americans and Hispanics of non-Mexican origin. Given the absence of Asian-Americans in NHANES III, a correction factor for Asian-Americans of 0.94 times reference equations for whites for FEV₁ and FVC has been suggested.¹ This recommendation was based on two studies, one including 40 Asian-Americans between the ages of 22 and 33 years⁴ and the other including 3,076 elderly Japanese-Americans between the ages of 71 and 90 years.⁵

We therefore attempted to validate the NHANES III reference values for whites, African-Americans, and Hispanics in an independent, multiethnic cohort study of adults and to evaluate the accuracy of correction factors for Asian-Americans in the same cohort. Because the cohort included Hispanics of non-Mexican origin and participants up to age 89 years, we also evaluated the accuracy of NHANES III reference equations among Hispanic subgroups and among participants 80 to 89 years old.

METHODS

Multi-Ethnic Study of Atherosclerosis

The Multi-Ethnic Study of Atherosclerosis (MESA) is a multicenter prospective cohort study designed to investigate the prevalence, correlates, and progression of subclinical cardiovascular disease.⁶ In 2000 to 2002, MESA recruited 6,814 men and women aged 45- to 84-years old from six US communities. MESA participants are non-Hispanic white, African-American, Hispanic, or Asian. About 70% of the Asian subjects were of Chinese origin. Exclusion criteria included clinical cardiovascular disease, pregnancy, weight >300 lb, or a serious medical condition that precluded long-term participation. The protocols of MESA and all studies described herein were approved by the Institutional Review Boards of all collaborating institutions and the National Heart, Lung and Blood Institute.

MESA-Lung Study

The MESA-Lung Study enrolled 3,965 participants who were sampled randomly from MESA participants who consented to genetic analyses, underwent baseline measures of endothelial function, and attended MESA Exam 3 or 4 during the MESA-Lung recruitment period in 2004 to 2006 (99%, 89%, and 88% of the MESA cohort, respectively). Asian-Americans were oversampled, such that the final cohort was 35% white, 26% African-American, 23% Hispanic, and 16% Asian-American.

The healthy nonsmoking sample for the validation of spirometry measures comprised all MESA-Lung participants who completed

adequate-quality spirometry, had never smoked, had no respiratory symptoms or diagnoses, and had BMI <35 kg/m². These exclusions mirrored those in NHANES III² except for the BMI threshold.

Spirometry

Spirometry was conducted in 2004 to 2006 in accordance with the ATS/ERS recommended guidelines⁷ with all participants performing at least three acceptable maneuvers. Tests were conducted using equipment similar to that used in NHANES III. All spirometry exams were reviewed at the Spirometry Reading Center by at least one author (J.L.H.), and each test was graded for quality on a five-point scale (A-D, F), a National Lung Health Education Program modified version using both FVC and FEV₁ quality factors.⁸ Low-quality spirometry was defined as a quality score <C (at least two-acceptable curves with both FVC and FEV₁ values repeatable within 250 mL).

Covariates

Race/ethnicity was defined by self-report according to 2000 US Census criteria as race (white, African-American, and so forth) and ethnicity (Hispanic or non-Hispanic).⁶ Participants self-identifying as Hispanic were categorized as Hispanic. Hispanic subgroups were ascertained according to self-response as Mexican, Dominican, Puerto Rican, Cuban, or Other Hispanic and were categorized as being of Mexican and non-Mexican origin. Any smoking history was defined by self-report as a lifetime history of >100 cigarettes, 20 cigars, or 20 pipefuls of tobacco. Current smoking status was confirmed with urinary cotinine measures; levels >500 µg/L were treated as consistent with current smoking. Respiratory diagnoses and symptoms were assessed with standard questionnaire items.⁹ Height and weight were measured at the time of the spirometry exam using calibrated scales and measures, and BMI was calculated as weight (kg)/height (m)².

Statistical Analysis

We compared mean differences in values observed in the MESA-Lung Study with those predicted based on NHANES III equations for whites, African-Americans, and Hispanics. Each participant's age, sex, height, race/ethnic-specific predicted values for FEV₁, FEV₆, FVC, FEV₁/FVC, and the corresponding lower limits of normal (LLN) were calculated using the NHANES III reference equations.² The difference between the values observed and the predicted values (value_{observed} - value_{pred}) were calculated with accompanying 95% CI. For Asian-Americans, we multiplied predicted and LLN values for whites by the recommended correction factor of 0.94, in addition to a correction factor of 0.88. A correction factor of 0.88 was chosen based on the current ATS/ERS 2005 recommendation for total lung capacity of 0.88 for Asians,¹ and the 0.88 correction factor recommendation in the American College of Occupational and Environmental Medicine position statement for spirometry in the occupational setting.¹⁰ Further, we described the percentage of this healthy cohort that was defined as abnormal based on LLN criteria, which is expected to be 5% of the cohort.

We also assessed the agreement of classification of the airflow obstruction based on LLN criteria using NHANES reference equations compared with internal reference equations derived for this purpose following the approach described for NHANES III.² Race/ethnic and gender-specific reference equations were estimated in our healthy, nonsmoking sample in the MESA-Lung Study using linear regression with backward elimination. The intercept for the LLN was calculated as intercept of the predicted

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equation – 1.645 times the standard error of the estimate of the prediction equation. Agreement of classification of airflow obstruction was tested with the κ test. Analyses were performed using SAS 9.1 (SAS Institute; Cary, NC) and R (R Foundation; Vienna, Austria).

RESULTS

MESA-Lung Sample

Of the 3,893 participants who performed spirometry in the MESA-Lung Study, we excluded 2,825 for the reasons listed in Table E1 in the online supplement, which left 1,068 in the healthy nonsmoking sample. The mean age for the healthy nonsmoking sample was 65 ± 10 years, 60% were women, and the race/ethnic distribution was 25% white, 20% African-American, 23% Hispanic, and 32% Asian-American. Hispanics were of 47% Mexican, 31% Caribbean, and 22% other origin. The characteristics, anthropomorphic measures, and lung function of the included participants are shown in Table 1. Although the mean age and height were similar for whites and African-Americans, mean spirometry values were lower for African-American than white subjects.

Differences in Observed Minus Predicted Volumes

Figure 1 shows the FEV_1 observed in the healthy nonsmoking sample minus the predicted FEV_1 based on the NHANES III equations for men (Fig 1A) and women (Fig 1B) vs age. The difference in observed minus uncorrected predicted volumes for Asian-American participants (dashed line) was greater than for other race/ethnic groups. Similar relationships were observed for FEV_6 and FVC.

Table 2 shows the observed minus predicted values in milliliters for FVC, FEV_6 , and FEV_1 with 95% CIs, stratified by race/ethnicity and gender. Observed values were lower than predicted values for whites and African-American, although the upper bounds of the 95% CIs were close to zero among whites.

Differences between observed compared with predicted values among Hispanics of Mexican origin were small with 95% CIs that included zero. However, observed values among Hispanics of non-Mexican origin were consistently and significantly lower than predicted values among both men and women.

Differences between observed and predicted values were large for Asian-American participants when no correction factor or a correction factor of 0.94 was

Table 1—Characteristics of Healthy, Never-Smoking Participants in the Multi-Ethnic Study of Atherosclerosis (MESA)-Lung Study Stratified by Race/Ethnicity (Healthy Nonsmoking Sample)

	White n = 270	African-American n = 210	Hispanic n = 245	Asian-American N = 343
Age, mean $\pm$ SD, y	66 $\pm$ 10.4	66 $\pm$ 9.8	64 $\pm$ 9.9	65 $\pm$ 9.6
Male gender, %	43.7	40.5	38.0	32.9
Height, mean $\pm$ SD, cm	168 $\pm$ 9.9	167 $\pm$ 9.1	161 $\pm$ 9.1	159 $\pm$ 8.1
BMI, mean $\pm$ SD, kg/m ²	26.2 $\pm$ 3.6	27.9 $\pm$ 3.7	27.7 $\pm$ 3.7	23.7 $\pm$ 3.2
Educational attainment, %				
< High school	2.2	6.7	40.8	22.7
High school graduate	17.8	20.5	24.9	15.7
Some college	21.1	31.4	25.3	22.4
College graduate	25.2	19.5	4.9	21.3
> Bachelor's degree	33.7	21.9	4.1	17.8
Income, %, \$				
< 12,000	2.2	4.29	16.3	20.4
12,000-25,000	9.3	15.7	26.5	25.1
25,000-35,000	10.0	11.9	22.4	12.5
35,000-50,000	14.8	22.4	17.1	12.8
50,000-100,000	32.6	30.0	13.1	15.2
> 100,000	31.1	15.7	4.49	14.0
Born outside of United States, %	7.41	14.8	64.5	98.0
Years in United States, ^a median, IQR	33 (20, 42)	29 (22, 34)	29 (19, 35)	19 (11, 28)
Hypertension ^b	37%	51%	36%	32%
Diabetes ^c	4.4%	13.3%	9.8%	10.5%
FVC, mean $\pm$ SD, L	3.53 $\pm$ 0.99	2.90 $\pm$ 0.77	3.13 $\pm$ 0.91	2.76 $\pm$ 0.75
FEV_1 , mean $\pm$ SD, L	2.67 $\pm$ 0.77	2.26 $\pm$ 0.58	2.45 $\pm$ 0.72	2.13 $\pm$ 0.60
FEV_6 , mean $\pm$ SD, L	3.36 $\pm$ 0.94	2.78 $\pm$ 0.71	3.00 $\pm$ 0.86	2.66 $\pm$ 0.72
FEV_1 /FVC, mean $\pm$ SD, %	76.12 $\pm$ 6.32	78.33 $\pm$ 6.89	78.23 $\pm$ 5.63	77.07 $\pm$ 5.89

MESA = Multi-Ethnic Study of Atherosclerosis; IQR = interquartile range.

^aAmong those born outside of United States.

^bSelf-report of hypertension, use of medication for hypertension, systolic blood pressure > 140 mm Hg, or diastolic blood pressure > 90 mm Hg.

^cSelf-report of diabetes, use of medication for diabetes, or fasting plasma glucose > 126 mg/dL.

FIGURE 1. Observed values of FEV_1 among healthy, never-smoking participants minus predicted FEV_1 from the NHANES III reference equations by age for men and women. Note: Predicted values for Asians were calculated using NHANES equations for whites without the use of a correction factor. Regression lines smoothed using LOESS. NHANES = National Health and Nutrition Survey.

used. Use of the 0.88 correction factor yielded small differences between observed and predicted values with 95% CIs that crossed zero.

Observed Minus Expected FEV_1/FVC Ratio

Figure 2 shows the measured FEV_1/FVC minus the predicted FEV_1/FVC vs age for men (Fig 2A) and women (Fig 2B). For all race/ethnic groups, includ-

ing Asian-Americans, the FEV_1/FVC was not significantly different from the predicted values.

Comparison With the Lower Limits of Normal

Table 3 shows the percentage of healthy nonsmoking participants below the NHANES III LLN for spirometry values. Approximately 5% of the whites, African-Americans, and Hispanics had volumes less

Table 2—Observed Minus Predicted (NHANES III) Spirometry Values Among Healthy, Never-Smoking Men and Women in the MESA-Lung Study, Stratified by Race/Ethnicity

	White	African-American	Mexican Hispanic	Non-Mexican Hispanic	Asian-American 1 × white	Asian-American 0.94 × white	Asian-American 0.88 × white
Males							
No.	118	85	42	51	113	113	113
Diff in FVC (95% CI), mL	-138 (-250, -27)	-224 (-350, -98)	74 (-100, 247)	-215 (-395, -36)	-432 (-523, -341)	-195 (-285, -106)	41 (-47, 129)
Diff in FEV ₆ (95% CI), mL	-138 (-237, -38)	-230 (-346, -114)	37 (-127, 201)	-238 (-397, -80)	-370 (-454, -285)	-146 (-229, -63)	78 (-4, 159)
Diff in FEV ₁ (95% CI), mL	-88 (-172, -3)	-177 (-273, -82)	101 (-28, 231)	-164 (-294, -34)	-260 (-335, -186)	-83 (-157, -10)	93 (21, 165)
Females							
No.	152	125	74	78	230	230	230
Diff in FVC (95% CI), mL	-112 (-175, -49)	56 (-23, 135)	15 (-81, 112)	-222 (-308, -136)	-408 (-459, -357)	-240 (-290, -190)	-72 (-120, -23)
Diff in FEV ₆ (95% CI), mL	-100 (-158, -43)	58 (-13, 130)	29 (-62, 121)	-202 (-284, -120)	-379 (-428, -330)	-218 (-266, -170)	-56 (-103, -10)
Diff in FEV ₁ (95% CI), mL	-83 (-128, -38)	68 (11, 124)	38 (-41, 118)	-154 (-226, -83)	-294 (-335, -252)	-165 (-205, -124)	-36 (-76, 4)

Diff = difference; NHANES = National Health and Nutrition Survey. See Table 1 for expansion of other abbreviations.

than the LLN, as would be expected in an asymptomatic nonsmoking sample. For Asian-Americans, a correction factor of 0.88 resulted in the expected proportion less than the LLN, whereas the 0.94 correction did not.

Since LLN criteria for the classification of airflow obstruction depend on reference equations, we compared the agreement among all subjects (n = 3,713) with classification of airflow obstruction by the LLN from NHANES III reference equations and the LLN from reference equations derived from our healthy nonsmoking sample. Table 4 shows the agreement for classification of airflow obstruction using NHANES III equations and equations derived from our healthy nonsmoking sample. Agreement was excellent ($\kappa = 0.88$), and was highest among white men and lowest, but acceptable, among Asian men.

Participants Older Than 80 Years

A relatively small number (n = 62) of our healthy nonsmoking sample were older than 80 years of age at the time of spirometry testing. Table 5 shows the observed minus predicted values (milliliters) among these participants. Although all of these values appear to be slightly higher than predicted, only the 95% CIs for the observed minus predicted FEV₁ for whites excluded zero.

DISCUSSION

We validated the reference equations derived from the NHANES III for whites, African-Americans, and Mexican-Americans in this independent sample. In general, NHANES III performed well, with small differences between observed and expected values for lung function that were generally less than the ATS/ERS repeatability criteria of 150 mL,⁷ on average, among whites, African-Americans, and Hispanics. There was also excellent agreement of classification of abnormal lung function by the LLN. Predicted values derived for Mexican-Americans, however, were less accurate when applied to Hispanics of non-Mexican origin. The currently recommended correction factor for Asians of 0.94 yielded appreciably biased estimates of predicted and LLN values for Asian-Americans.

The volumes observed in our healthy nonsmoking sample were slightly but consistently lower than those predicted by the NHANES equations. These lower values might be explained by methodological differences between the two studies. The equipment used in the MESA-Lung Study was similar to that used in NHANES III; however, NHANES III procedures required a minimum of five maneuvers and had no

FIGURE 2. Observed values of FEV_1/FVC ratio among healthy, never-smoking participants minus predicted FEV_1/FVC ratio from the NHANES III reference equations by age for men and women. Note: Predicted values for Asians were calculated using NHANES equations for whites. Regression lines smoothed using LOESS. See Figure 1 legend for expansion of abbreviation.

expiratory time limits. In contrast, the MESA-Lung Study followed the ATS/ERS guidelines and required three acceptable maneuvers. In addition, the maneuvers in the MESA-Lung Study were often terminated in those participants whose plateaus were not achieved within 15 s. These minor methodological differences would be expected to result in values approximately 50 to 100 mL lower in our healthy nonsmoking older

adults compared with NHANES III, similar to our results for whites, African-American women, and Hispanics of Mexican origin.

Differences in observed minus predicted FVC, FEV_1 , and FEV_6 were larger among African-American men and Hispanics of non-Mexican origin and may be of clinical significance. Explanations for the difference among African-American men but not African-American

Table 3—Healthy, Never-Smoking Participants in the MESA-Lung Study Below the Lower Limit of Normal From NHANES III Reference Equations

	White	African-American	Hispanic	Asian-American 1 × white	Asian-American 0.94 × white	Asian-American 0.88 × white
No.	270	210	245	343	343	343
FVC < LLN (95% CI), %	7.4 (4.3, 10.5)	7.6 (4.0, 11.2)	8.2 (4.7, 11.6)	24.5 (20.0, 29.1)	14.3 (10.6, 18.0)	8.2 (5.3, 11.1)
FEV ₆ < LLN (95% CI), %	6.3 (3.4, 9.2)	6.2 (2.9, 9.5)	6.9 (3.7, 10.1)	22.4 (18.0, 26.9)	12.2 (8.8, 15.7)	6.4 (3.8, 9.0)
FEV ₁ < LLN (95% CI), %	4.1 (1.7, 6.4)	5.2 (2.2, 8.3)	4.9 (2.2, 7.6)	19.5 (15.3, 23.8)	10.8 (7.5, 14.1)	6.4 (3.8, 9.0)
FEV ₁ /FVC% < LLN (95% CI), %	3.3 (1.2, 5.5)	5.2 (2.2, 8.3)	4.1 (1.6, 6.6)	4.4 (2.2, 6.5)		

LLN = lower limit of normal. See Tables 1 and 2 for expansion of other abbreviations.

women are not readily available but may relate to the different sampling approaches of MESA and NHANES III or chance. NHANES III and other studies have reported a race correction factor for African-Americans of 0.85. In our healthy African-American men the corresponding race correction factor would be 0.81, a result that suggests that the different sampling approaches of MESA and NHANES III may have been particularly marked for African-American men. Nonetheless, the agreement in classification by LLN criteria was high among African-American men, which suggests that the clinical relevance of any difference is limited. Application of predicted values derived from Hispanics of Mexican origin to Hispanics of non-Mexican origin may be expected to cause some misclassification, possibly due to differences in smoking habits, culture, and ancestry, as was observed.

Observed values for Asian-American participants were significantly lower than predicted values for FVC, FEV₁, and FEV₆ but not for the FEV₁/FVC%. These findings are consistent with a large study from Hong Kong.¹¹ When the ATS/ERS recommended correction factor was applied, the differences between observed and predicted values were reduced, but a relatively large difference still existed. A correction factor of 0.88 appears to be best for the subjects in

the current study. Because our study was predominantly Chinese-American participants, we cannot eliminate the possibility that the differences may be due to differences between Americans of Japanese and Chinese descent. Also Figure 1 suggests a single correction factor may not be appropriate for all ages, a finding supported by Ip et al,¹¹ who concluded that “blanket application of correction factors for Asian populations may not be appropriate.”

NHANES III predicted values, derived from participants less than 80-years old, appear to be slightly lower than observed values among older participants—probably because of a survivor bias—but were still valid for participants in this study older than 80 years of age. In addition, no extreme deviations from observed minus predicted values appear in the figures for participants older than 80 years. Therefore, the use of NHANES III reference values beyond the age of 80 does not appear to result in significant misclassification. A proposed revision to the NHANES III reference equations was recently published,¹² and although not specifically tested, it is likely that similar results would have been obtained for whites over 45 years when using these new equations.¹²

The NHANES III reference equations for whites, African-Americans, and Mexican-Americans were validated in an independent sample, the MESA-Lung Study, and there was good to excellent agreement for

Table 4—Agreement (κ) of Classification of Airflow Obstruction Based on the FEV₁/FVC < LLN From NHANES III Reference Equations and the LLN from Healthy, Never-Smoking Participants in the MESA-Lung Study

Race	Gender	No.	κ	95% CI
White	M	683	0.94	(0.91-0.98)
	F	669	0.86	(0.80-0.92)
Asian	M	316	0.75	(0.64-0.86)
	F	308	0.89	(0.79-0.98)
Black	M	480	0.92	(0.87-0.96)
	F	508	0.86	(0.78-0.93)
Hispanic	M	417	0.86	(0.78-0.94)
	F	455	0.81	(0.71-0.91)
All		3,713	0.88	(0.85-0.90)

F = female; M = male. See Tables 1 to 3 for expansion of other abbreviations.

Table 5—Observed Minus Predicted (NHANES III) Values Among Healthy, Never-Smoking Participants >80 Years of Age in the MESA-Lung Study

	White	African-American	Hispanic
No.	30	14	18
Diff in FVC, (95% CI), mL	56 (−108, 219)	138 (−241, 517)	94 (−128, 316)
Diff in FEV ₆ , (95% CI), mL	92 (−45, 230)	117 (−194, 429)	58 (−169, 286)
Diff in FEV ₁ , (95% CI), mL	119 (1, 238)	103 (−118, 323)	34 (−137, 205)
Diff in FEV ₁ /FVC%, (95% CI), mL	4 (1, 7)	1 (−4, 6)	−1 (−4, 2)

See Tables 1 and 2 for expansion of other abbreviations.

classification by the FEV₁/FVC ratio. For Asian-Americans, a correction factor of 0.88 applied to the FVC and FEV₁ predicted and LLN values from the NHANES III reference equations for whites was more accurate than the currently recommended correction factor of 0.94. The NHANES reference values appear to be appropriate for whites, African-Americans, and Hispanics of Mexican origin in the United States and, with a correction factor, Asian-Americans.

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Dr Hankinson: contributed to data collection, conception and design of original idea, data analysis, and original draft and final revision of the manuscript.

Dr Kawut: contributed to conception and design of original idea, interpretation of data, and final revision of the manuscript.

Dr Shahar: contributed to conception and design of original idea, interpretation of data, and final revision of the manuscript.

Dr Smith: contributed to conception and design of original idea, interpretation of data, and final revision of the manuscript.

Ms Stukovsky: contributed to data collection, conception and design of original idea, and final revision of the manuscript.

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REFERENCES

1. Pellegrino R, Viegi G, Brusasco V, et al. Interpretative strategies for lung function tests. *Eur Respir J*. 2005;26(5):948-968.
2. Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general U.S. population. *Am J Respir Crit Care Med*. 1999;159(1):179-187.
3. Centers for Disease Control and Prevention. *Plan and Operation of the Third National Health and Nutrition Examination Survey, 1988-94*. Vital Health Stat Series No. 1. National Center for Health Statistics;(32); 1994.
4. Korotzer B, Ong S, Hansen JE. Ethnic differences in pulmonary function in healthy nonsmoking Asian-Americans and European-Americans. *Am J Respir Crit Care Med*. 2000;161(4 pt 1):1101-1108.
5. Sharp DS, Enright PL, Chiu D, Burchfiel CM, Rodriguez BL, Curb JD. Reference values for pulmonary function tests of Japanese-American men aged 71 to 90 years. *Am J Respir Crit Care Med*. 1996;153(2):805-811.
6. Bild DE, Bluemke DA, Burke GL, et al. Multi-ethnic study of atherosclerosis: objectives and design. *Am J Epidemiol*. 2002;156(9):871-881.
7. Miller MR, Hankinson J, Brusasco V, et al; ATS/ERS Task Force. Standardisation of spirometry. *Eur Respir J*. 2005; 26(2):319-338.
8. Ferguson GT, Enright PL, Buist AS, Higgins MW. Office spirometry for lung health assessment in adults: a consensus statement from the National Lung Health Education Program. *Chest*. 2000;117(4):1146-1161.
9. Ferris BG. Epidemiology standardization project. *Am Rev Respir Dis* 1978;118(6 Pt 2):1-120.
10. Townsend MC; American College of Occupational and Environmental Medicine. ACOEM position statement. Spirometry in the occupational setting. *J Occup Environ Med*. 2000; 42(3):228-245.
11. Ip MS, Ko FW, Lau AC, et al; Hong Kong Thoracic Society; American College of Chest Physicians (Hong Kong and Macau Chapter). Updated spirometric reference values for adult Chinese in Hong Kong and implications on clinical utilization. *Chest*. 2006;129(2):384-392.
12. Stanojevic S, Wade A, Stocks J, et al. Reference ranges for spirometry across all ages: a new approach. *Am J Respir Crit Care Med*. 2008;177(3):253-260.