Performance of Maximum Inspiratory Pressure Tests and Maximum Inspiratory Pressure Reference Equations for 4 Race/Ethnic Groups

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BACKGROUND: Maximum inspiratory pressure (MIP) is an important and noninvasive index of diaphragm strength and an independent predictor of all-cause mortality. The ability of adults over a wide age range and multiple race/ethnicities to perform MIP tests has previously not been evaluated. METHODS: The Multi-Ethnic Study of Atherosclerosis recruited white, African American, Hispanic, and Chinese American participants, ages 45–84 years, and free of clinical cardiovascular disease in 6 United States cities. MIP was measured using standard techniques among 3,849 Multi-Ethnic Study of Atherosclerosis participants. The MIP quality goal was 5 maneuvers, with the 2 largest values matching within 10 cm H_2O. Correlates of MIP quality and values were assessed in logistic and linear regression models. RESULTS: The 3,849 participants with MIP measures were 51% female, 35% white, 26% African American, 23% Hispanic, and 16% Chinese American. Mean ± SD MIP was 73 ± 26 cm H_2O for women and 97 ± 29 cm H_2O for men. The quality goal was achieved by 83% of the cohort and was associated with female sex, older age, race/ethnicity, study site, low ratio of forced expiratory volume in the first second to forced vital capacity (FEV_1/FVC), and wheeze with dyspnea. The multivariate correlates of MIP were male sex, younger age, higher body mass index, shorter height, higher FVC, higher systolic blood pressure (in women) and health status (in men). There were no clinically important race/ethnic differences in MIP values. CONCLUSIONS: Race-specific reference equations for MIP are unnecessary in the United States. More than 80% of adults can be successfully coached for 5 maneuvers, with repeatability within 10 cm H_2O. *Key words: diaphragm strength, respiratory muscle strength, maximum inspiratory pressure, quality control, pulmonary function testing.* [Respir Care 2009;54(10):1321–1328. © 2009 Daedalus Enterprises]

Introduction

Maximum inspiratory pressure (MIP) is a measure of the strength of inspiratory muscles, primarily the diaphragm, and allows for the assessment of ventilatory failure, restrictive lung disease, and respiratory muscle strength. The test is quick and noninvasive, but it is highly dependent on participant effort and coaching. The range of normal values is broad, and low values should be interpreted relative to the lower limit of normal values for age and sex.[1]

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Respiratory muscle weakness is an independent predictor of all-cause mortality, and MIP has previously been

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shown to be associated with incident cardiovascular events, including myocardial infarction, cardiovascular death, and possibly stroke.[2] These associations were independent, in large part, of other measures of pulmonary function, such as the forced vital capacity (FVC).

Previous studies have reported the correlates of MIP in older whites and African Americans.[3-6] However, these studies could not adequately evaluate potential race/ethnic differences in MIP due to limited minority recruitment[3-5] or recruitment of minorities at only one study site.[6] This type of confounding can be substantial, since MIP is highly dependent on coaching by individual technologists.

We evaluated correlates of MIP in a large multi-ethnic study that was specifically designed to avoid site-by-race confounding[7] and examined potential differences in MIP across these 4 race/ethnic groups in the whole cohort and in a subset of healthy participants. We also described correlates of achieving a MIP quality goal and provided reference equations from the healthy subset of the cohort.

Methods

Study Sample

The Multi-Ethnic Study of Atherosclerosis (MESA) is a multicenter prospective cohort study to investigate the prevalence, correlates, and progression of subclinical cardiovascular disease in individuals without clinical cardiovascular disease.[7] In 2000 through 2002 the study recruited 6,814 men and women, ages 45–84 years old, from 6 United States communities (see Table 1 for the list). The study participants are non-Hispanic white, African American, Hispanic, or Asian (of Chinese origin). Multiple race/ethnic groups were recruited at all 6 sites. Exclusion criteria included clinical cardiovascular disease (physician diagnosis of heart attack, stroke, transient ischemic attack, heart failure, or angina), current atrial fibrillation, any cardiovascular procedure, pregnancy, active cancer treatment, weight > 300 lbs, serious medical condition that precluded long-term participation, nursing-home residence, cognitive inability, inability to speak English, Spanish, Cantonese, or Mandarin, plan to leave the community within 5 years, and chest computed tomogram within the past year. The protocols were approved by the institutional review boards of all the collaborating institutions and the National Heart Lung Blood Institute.

Table 1. Characteristics of the 3,849 Participants Who Attempted Maximum Inspiratory Pressure Measurements in the Multi-Ethnic Study of Atherosclerosis Lung Study

Study Site (%*)	
Winston-Salem, North Carolina	14.5
New York, New York	18.6
Baltimore, Maryland	12.1
Minneapolis/St Paul, Minnesota	14.1
Chicago, Illinois	18.7
Los Angeles, California	21.9
Height (mean ± SD cm)	166 ± 10
BMI (% in given kg/m^2 range)	
<18.5	3.2
18.5–25	28.9
25–30	37.2
30–35	19.8
>35	10.8
Cigarette smoking status (%)	
Never	50.9
Past	39.4
Current	9.7
Physician-diagnosed asthma (%)	11.5
FVC (mean ± SD L)	3.19 ± 0.96
FEV$_1$ (mean ± SD L)	2.38 ± 0.73
FVC (mean ± SD % predicted)	95.3 ± 16.9
FEV$_1$ (mean ± SD % predicted)	93.7 ± 18.4
FEV$_1$/FVC (mean ± SD)	0.75 ± 0.09
Health status (%)	
Better than average	60.3
Average	35.1
Worse than average	4.6

* Percent values do not sum to 100 because of rounding.
BMI = body mass index
FVC = forced vital capacity
FEV$_1$ = forced expiratory volume in the first second

The MESA Lung Study enrolled 3,965 participants in 2004 through 2006, of 4,484 eligible participants who were sampled randomly among MESA participants who consented to genetic analyses, underwent baseline measures of endothelial function, and attended study examination 3 or 4 (99%, 89%, and 88% of the cohort, respectively).

Instruments and Training

The same mechanical pressure gauge and testing techniques used by the Cardiovascular Health Study was used for this study.[3] The methods were consistent with American Thoracic Society guidelines.[8] The accuracy of each pressure gauge was checked using a mercury manometer

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This research was partly funded by National Heart, Lung, and Blood Institute contracts N01-HC-95159 through N01-HC-95165, N01-HC95169, and grant R01-HL077612. A full list of participating the Multi-Ethnic Study of Atherosclerosis (MESA) investigators and institutions can be found at http://www.mesa-nhlbi.org. This manuscript has been reviewed by the MESA Investigators for scientific content and consistency of data interpretation with previous MESA publications and important comments have been incorporated prior to submission for publication.

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at 50 cm H_2O and verified to be within 5%. A manual of procedures was written and distributed to the 6 field centers. At the beginning of the study, technologists from the 6 field centers were centrally trained and certified for spirometry and MIP testing.

Maximum Inspiratory Pressure Test Methods

Each participant was asked to perform 5 MIP maneuvers, with a goal of matching the highest 2 within 10 cm H_2O. MIP was recorded to the nearest 5 cm H_2O using a differential pressure gauge fitted with a disposable cardboard mouthpiece. The patient was seated for the test. The technologist first demonstrated the correct maneuver. The participant was instructed to exhale slowly and completely, seal lips firmly around the new mouthpiece, and then "pull in hard, like you are trying to suck up a thick milkshake." The technologist noted the largest negative pressure sustained for at least one second on the pressure gauge. The participant was allowed to rest for about one minute, and then repeated the maneuver 5 times. The pressure gauge has minor tick marks at 5 cm H_2O increments, so results were rounded to the nearest 5 cm H_2O.

We repeated MIP measurements on a 5% random quality-control sample of participants to confirm reproducibility of the measurements in this study.

Covariate Information

Age, self-identified race/ethnicity, subjective health status, and smoking status were assessed via questionnaires. Pack-years was calculated as the number of years smoked times the average number of cigarettes per day divided by 20. Height and weight were measured by trained technicians using a stadiometer and a balancing scale, respectively. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Wheeze with dyspnea was defined as a positive response to the item, "In the last 12 months, have you had an attack of wheezing or whistling in the chest that has made you feel short of breath?" Participants were asked what language they speak at home. If the technician who performed the MIP examination was fluent in that language, then they were classified as language concordant.

Spirometry was measured following and meeting American Thoracic Society standards,[9] as previously described.[10] Predicted values were calculated using Hankinson reference equations for whites, African Americans, and Hispanics,[11] which we have previously validated for use in this cohort.[10] We used a correction factor of 0.88 for Chinese Americans (using reference equations for forced expiratory volume in the first second [FEV_1] and FVC for whites), which we found to be superior to other approaches for this cohort.[10]

Statistical Analyses

We defined MIP difference as the difference between the highest and second highest MIP values. The MIP quality goal was defined as completion of exactly 5 MIP maneuvers with the MIP difference less than 10 cm H_2O (adequate repeatability). Using a logistic regression model with generalized estimating equations, we examined the relationship between MIP test success and age, sex, ethnicity, education, income, study site, height, BMI, smoking status, pack-years of smoking, asthma, FVC, FEV_1, FEV_1/FVC ratio, wheeze with dyspnea, subjective health status, technician language concordance, and systolic blood pressure. Age and sex adjusted models were fit first, followed by a multivariate model, which included the terms that were significant at the $P < .10$ level in the age and sex adjusted models. Family income and educational attainment were included in the model to better control for potential confounding of race/ethnicity by socioeconomic status. Generalized estimating equations were used to account for within-site correlation at the level of the technician.[12] There were 35 technologists who administered one or more MIP tests.

We defined the maximum MIP for each participant as the largest MIP from each participant's test session for participants who achieved the quality goal. Using a linear regression model, we examined the relationship between maximum MIP and age, height, BMI, race/ethnicity, study site, smoking status, FVC, systolic blood pressure, wheezes with dyspnea, and self-reported subjective health status. We developed sex-specific models using generalized estimating equations to account for the correlation within technician.[12] The standard errors are based on the empirical covariance estimates. For a graphical evaluation, maximum MIP was plotted versus age in years, with a fitted Lowess curve.

Since the overall sample included smokers and some patients with lung disease, we performed secondary analyses of race/ethic differences restricted to "healthy" participants, as previously defined.[3] Analyses were performed using statistical software (SAS version 9.1, SAS Institute, Cary, North Carolina; R version 2.2.1, R Foundation for Statistical Computing, Vienna, Austria).

Results

The characteristics of the 3,849 participants in the MESA Lung Study who attempted MIP measures are shown in Table 1. Mean age was 66 years, 51% were women. Chinese Americans were over-sampled, such that the final cohort was 35% white, 26% African American, 23% Hispanic, and 16% Chinese American. Half had smoked cigarettes, and 60% reported their health as "better than average." Mean ± SD MIP was 85 ± 30 cm H_2O.

Table 2. Multivariate Odds Ratios for Achieving the Maximum Inspiratory Pressure Test Quality Goal*

	OR	95% CI	*P*
Age, per 10 y	1.08	1.00–1.18	.05
Female	1.28	1.08–1.51	.01
Race/ethnicity			.03
Non-Hispanic white	1.00	Reference group	
African American	0.70	0.55–0.89	
Chinese American	0.79	0.61–1.02	
Hispanic	0.86	0.70–1.06	
Study site			.001
Winston-Salem	0.62	0.35–1.09	
New York	0.46	0.31–0.69	
Baltimore	0.75	0.46–1.22	
Minneapolis	0.42	0.24–0.71	
Chicago	0.55	0.37–0.80	
Los Angeles	1.00	Reference group	
FEV_1/FVC	0.22	0.07–0.71	.01
Wheeze with dyspnea in last 12 months	0.77	0.62–0.96	.02

* Adjusted for the variables in the table, health status, income and educational attainment.
OR = odds ratio
CI = confidence interval
FEV_1 = forced expiratory volume in the first second
FVC = forced vital capacity

Achievement of Quality Goal

Eighty-three percent of those who attempted MIP testing successfully achieved the quality goal. Of the remaining 17%, 2 participants were unable to complete the required 5 tests, and the remainder had a difference of the highest 2 measurements of MIP of greater than 10 cm H_2O.

Table 2 shows the multivariate correlates of achieving the quality goal for the MIP test of 5 MIP maneuvers with the highest and second highest MIP values within 10 cm H_2O. In age and sex adjusted analyses, older age, female sex, race/ethnicity, study site, low FEV_1/FVC ratio, wheeze, and worse health status were associated with successful achievement of the quality goal. In multivariate analyses, female sex, race/ethnicity, study site, low FEV_1/FVC ratio, and wheeze with dyspnea were independently associated with achievement of the quality goal. (Older age was of borderline significance.)

In order to further evaluate differences in quality by site, we examined the intra-class correlation coefficient in the 5% quality-control sample in whom MIP was repeated. The intra-class correlation coefficient is the ratio of the between-subject variance of MIP to the total variance. Intra-class correlation coefficients did not vary significantly by site in the quality-control sample. The intra-class correlation coefficients were 84%, 89%, 86%, 88%, 89%, and 86% at Winston-Salem, New York, Baltimore, Minneapolis, Chicago, and Los Angeles, respectively. An intra-class correlation coefficient greater than 80% demonstrates excellent reproducibility.

Correlates of Maximum Inspiratory Pressure

The distributions of MIP for men and women were both unimodal and approximately symmetric. Strong, linear associations were observed between MIP and age, BMI, and FVC in both sexes, with the exception that the relationship between MIP and BMI flattened at a BMI of about 30 kg/m^2 in men. The relationship between age and MIP is shown in Figure 1.

The mean ± standard deviation MIP was 73 ± 26 cm H_2O for women who achieved the quality goal. The multivariate correlates of MIP among women are shown in Table 3. The independent correlates of MIP among women from the multivariate model were younger age, race/ethnicity, study site, shorter height, higher BMI, higher FVC, and higher systolic blood pressure. The magnitude of the observed association between MIP and blood pressure was small, as a 10-unit difference in MIP was associated with only a 1-unit increase in systolic blood pressure, adjusting for the other covariates. Higher MIP was correlated with higher height in age-adjusted analyses but with lower height in multivariate analyses. Race/ethnicity was significant in age-adjusted and multivariate analyses among women; however, the statistical significance was due to an observed difference principally among Chinese Americans in age-adjusted analyses, and small differences among African Americans and Hispanics in multivariate analyses.

Among men who achieved the quality goal, the mean ± standard deviation MIP was 97 ± 29 cm H_2O, which was significantly higher than the mean MIP among women ($P < .001$). The multivariate correlates of MIP among men are shown in Table 4. The independent correlates of MIP among men from the multivariate model were younger age, study site, shorter height, higher BMI, higher FVC, and health status. Similar to among women, higher MIP was correlated with taller height in age-adjusted analyses and shorter height in multivariate analyses among men. No statistically significant or clinically important differences in MIP were observed among men by race/ethnicity in age-adjusted or multivariate models.

Maximum Inspiratory Pressure Reference Equations

We repeated the analyses of MIP and race/ethnicity among non-smoking participants in good health. We excluded those who failed to achieve the quality goal, current smokers, those with any respiratory illness, and those with $FEV_1 < 65\%$ of predicted, as suggested by a previous study.[4] 872 men and 883 women remained in the healthy subgroup. The lower limits of the normal range for men

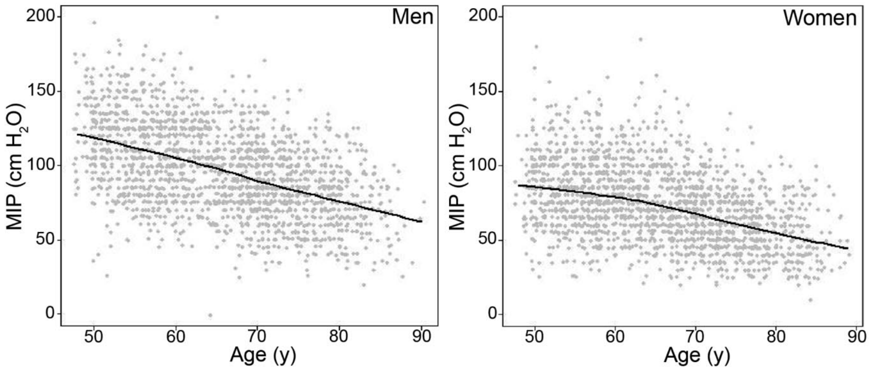

Fig. 1. The association of maximum inspiratory pressure (MIP) with age, in adult men and women, from the Multi-Ethnic Study of Atherosclerosis Lung Study. Solid lines are Lowess smooths.

Table 3. Multivariate Correlates of Maximum Inspiratory Pressure in Women*

	Mean Difference in MIP Per Unit Change*	95% CI	*P*
Age (y)	−0.70	−0.88 to −0.53	< .001
Race			< .001
White	Reference group	Reference group	
African-American	3.55	1.07 to 6.02	
Chinese	−1.74	−4.65 to 1.17	
Hispanic	−5.25	−9.13 to −1.38	
Site			< .001
Winston-Salem	3.97	−4.69 to 12.62	
New York	7.13	1.07 to 13.20	
Baltimore	−3.25	−5.60 to −0.90	
Minneapolis/St Paul	2.35	−5.20 to 9.90	
Chicago	1.91	−3.45 to 7.27	
Los Angeles	Reference group	Reference group	
Height (cm)	−0.18	−0.33 to −0.03	.022
BMI (kg/m^2)			< .001
< 18.5	−5.15	−12.67 to 2.38	
18.5–25	Reference group	Reference group	
25–30	4.20	1.35 to 7.06	
30–35	9.08	5.06 to 13.10	
> 35	13.03	8.97 to 17.09	
FVC (L)	12.09	9.70 to 14.48	< .001
Systolic blood pressure (mm Hg)	0.07	0.03 to 0.12	.002

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* Adjusted for variables in table.
MIP = maximum inspiratory pressure
CI = confidence interval
BMI = body mass index
FVC = forced vital capacity

Table 4. Multivariate Correlates of Maximum Inspiratory Pressure in Men*

	Mean Difference in MIP Per Unit Change*	95% CI	*P*
Age (y)	−1.08	−1.23 to −0.93	< .001
Site			< .001
Winston-Salem	1.13	−5.27 to 7.53	
New York	3.48	−0.48 to 7.43	
Baltimore	−4.40	−8.13 to −0.67	
Minneapolis/St Paul	3.22	−1.10 to 7.54	
Chicago	2.54	−5.63 to 10.71	
Los Angeles	Reference group	Reference group	
Height (cm)	−0.33	−0.49 to −0.17	< .001
BMI (kg/m$^{2)}$			< .001
< 18.5	−13.23	−19.96 to −6.51	
18.5–25	Reference group	Reference group	
25–30	9.75	7.07 to 12.43	
30–35	10.84	6.33 to 15.35	
> 35	9.93	4.78 to 15.08	
FVC (L)	9.98	7.69 to 12.26	< .001
Health			.025
> normal	1.25	−1.25 to 3.75	
Same	Reference group	Reference group	
Worse	−5.67	−13.18 to 1.84	

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* Adjusted for variables in table.
MIP = maximum inspiratory pressure
CI = confidence interval
BMI = body mass index
FVC = forced vital capacity

and women from our study were very similar to the lower limits of the normal range from previous large studies of adults (Fig. 2). No significant differences or interactions with race/ethnicity were found in the multivariate models. The sex-specific reference equations from our study are shown in Table 5.

Discussion

Male sex, younger age, obesity, higher FVC, and shorter height were strongly and independently associated with higher values of MIP in relatively healthy adults in 4 race/ethnic groups. In contrast, differences in MIP by race/ethnicity were of small magnitude and inconsistent statistical significance in the overall cohort, and were

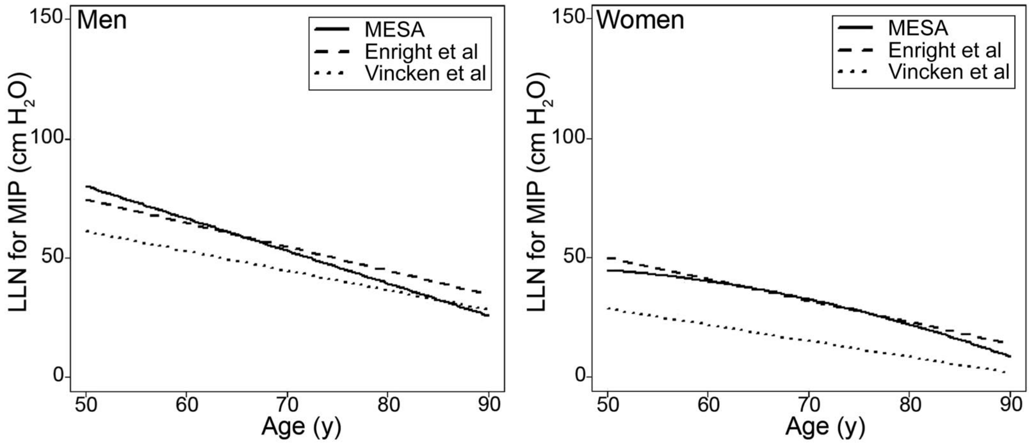

Fig. 2. Comparison of the maximum inspiratory pressure (MIP) lower limit of the normal (LLN) range from other studies,[3,13] stratified by sex, using average height (172 cm for men, 158 cm for women) and weight (177 lbs for men, 150 lbs for women). MESA = Multi-Ethnic Study of Atherosclerosis.

Table 5. Sex-Specific Maximum Inspiratory Pressure Reference Equations*

Coefficient	Age	Age^2	Weight	$Weight^2$	Age × Weight	Height	$Height^2$	LLN	r^2
Men = +9.8	–0.31	0	1.47	−0.0026	−0.0059	0	0	40	0.27
Women = −388	1.77	−0.014	0.41	0	−0.0041	4.69	−0.014	36	0.21

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* Maximum inspiratory pressure in cm H_2O; weight in pounds; height in centimeters. To obtain the lower limit of the normal (LLN) range for men, subtract 40 from the predicted maximum inspiratory pressure (subtract 36 for women).

nonsignificant among the subset of non-smoking participants in good health. These results suggest that race/ethnic-specific reference equations for MIP are not warranted.

This is the first study of which we are aware to evaluate correlates of MIP in a multi-ethnic sample, and is unique in avoiding site-by-race confounding by enrolling multiple ethnicities at all sites. The main correlates of higher values of MIP observed across the 4 race/ethnic groups in the present study, including male sex, younger age, obesity and higher FVC, are consistent with prior studies of MIP in whites and African Americans.[3-6] We observed linear relationships between advancing age and lower MIP, similar to results from the Atherosclerosis Risk in Communities (ARIC) study, the largest study to date.[6] The relationship of height to MIP was positive in age-adjusted analyses in both the current study and ARIC. After multivariate adjustment for BMI and other correlates, height became nonsignificant among women in ARIC and inverse in the current study. Similar to ARIC, we observed a non-linear relationship of BMI to MIP among men, which was positive in the normal-to-overweight range and was flat or slightly inverse in obesity. Among women, higher BMI was associated with higher MIP values among normal weight, overweight, and obese women in both studies.

In contrast to other measures of lung function,[10] values of MIP did not vary appreciably by race/ethnic group. There was no statistically significant difference in MIP by race/ethnicity among men in models controlling for multiple potential confounders. Mean MIP was higher among African American women (+3.6 cm H_2O) and lower among Hispanic women (−5.2 cm H_2O), when compared to white women; however, these differences were small relative to the differences between men and women (23 cm H_2O), between technologists (up to 10 cm H_2O), or with advancing age (−10 cm H_2O per 10 years), and thus of little clinical importance. Restriction to non-smoking participants in good health, as has been previously used for the derivation of reference equations,[4] yielded no significant differences by race/ethnicity. Neither of 3 prior studies that included whites and African Americans observed a difference in MIP by race/ethnicity, although 2 were potentially limited by small numbers of African Americans[3,5] and the other by site-by-race confounding.[6]

We did not observe a significant relationship of current smoking and lower MIP, which has been noted in some[3,5] but not other[13,14] prior studies. The negative association probably would have been significant had the MESA enrolled more current smokers.

The best index of quality is the repeatability of the MIP tests completed, as measured by the difference between the highest and second highest value for test sessions with at least 2 non-zero MIP measurements. However, meeting the quality goal does not necessarily mean that the subject's effort was maximum.[15] Differences in the MIP quality measure by site, for example, did not correspond to differences in maximum MIP by site. Furthermore, intraclass correlation coefficients in the 5% quality-control replicate sample also did not vary by site.

About 83% of our participants met the quality goal of a 10 cm H_2O match, a success rate similar to that of Cardiovascular Health Study participants.[3] MIP measurements depend greatly on patient effort; thus, the technologist must be an enthusiastic coach. Many patients (both children and adults) exhibit a rather large learning effect, so that their best values during a test session are often obtained after several maneuvers, even up to 15.[16,17] However, most MIP reference studies were done using 5 maneuvers, so most clinical laboratories follow the same procedure.[8] However, up to 3 additional maneuvers should be done if the last value was the highest or if the second highest value is not at least 90% of the highest value.

Achieving the quality goal was associated with female sex, older age, race/ethnicity, study site, low FEV_1/FVC ratio, and wheeze with dyspnea. The quality of MIP has previously been found to be related to both participant and technician factors.[18,19] Our results for sex, age, and airway obstruction match prior studies. Although African American participants achieved the quality goal less frequently than did white participants, mean MIP values for African Americans were slightly higher than for whites, as noted above.

The impact of the technician can be large. We therefore used generalized estimating equations in our multivariate modeling to account for the potential technician clustering effect and adjusted all analyses by study site. There were 35 technicians who administered at least one MIP test. Study site remained a significant correlate of both achievement of the quality goal and mean MIP in multivariate models, as has been noted in prior studies.[3,6]

Limitations of our study include possible residual site-by-ethnicity confounding. For example, the majority of the Chinese Americans were recruited from the Chicago site. Since mean MIP varies by technologist skills, the slightly lower mean MIP values for Chinese Americans (when compared to other ethnic groups) could have been due to slightly less effort provided by the technologists in Chicago. The body habitus and nutrition of various ethnic groups within mainland China vary markedly, and we did not ascertain the location of birth and childhood within China of our study participants. Application of our study results is limited by the age range of our participants (45–84 years), which did not include children or young adults.

Conclusions

In conclusion, male sex, younger age, and shorter height, obesity and higher FVC were strongly and independently associated with higher values of MIP in this large multi-ethnic cohort study. Unlike other measures of pulmonary function, no large or consistently significant differences in MIP were observed between whites, African Americans, Hispanics, and Chinese Americans. This finding suggests that race-specific reference equations for MIP are unnecessary and that previously published reference values for MIP in healthy white adults[3,13] are appropriate for patients in these 4 race/ethnic groups.

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Chest physician Richard V Ebert
with patient performing a spirogram
Photograph taken for cover
of *Modern Medicine*, 1966
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