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Correlates of Peak Expiratory Flow Lability in Elderly Persons*

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Objective: **To determine the correlates of the lability of peak expiratory flow (PEF) in the elderly.**
Methods: **A community sample of 4,581 persons ≥ 65 years old from the Cardiovascular Health Study completed an asthma questionnaire and underwent spirometry. During a follow-up examination of the cohort, 1,836 persons agreed to measure PEF at home twice daily for 2 weeks, and 90% successfully obtained at least 4 days of valid measurements. PEF lability was calculated as the highest daily (PEF maximum − PEF minimum)/mean PEF.**
Results: **Mean PEF measured at home was accurate when compared to PEF determined by spirometry in the clinic. Mean PEF lability was 18% in those with current asthma (n = 165) vs 12% in healthy nonsmokers (upper limit of normal, 29%). Approximately 26% of those with asthma and 14% of the other participants had abnormally high PEF lability (> 29%). After excluding participants with asthma, other independent predictors of high PEF lability included black race, current and former smoking, airway obstruction on spirometry, daytime sleepiness, recent wheezing, chronic cough, emphysema, and wheezing from lying in a supine position. Despite having a lower mean PEF, those reporting congestive heart failure (n = 82) did not have significantly higher PEF lability.**
Conclusions: **Measurement of PEF lability at home is highly successful in elderly persons. PEF lability ≥ 30% is abnormal in the elderly and is associated with asthma.**
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Key words: airway lability; asthma; elderly; peak expiratory flow

Abbreviations: ANOVA = analysis of variance; ATS = American Thoracic Society; CHS = Cardiovascular Health Study; PEF = peak expiratory flow; ULN = upper limit of normal

The Cardiovascular Health Study (CHS) is a prospective study of a general population sample designed to study the epidemiology and risk factors associated with cardiovascular disease in the elderly.[1] The 1993–1994 CHS examination provided comprehensive measures of cardiovascular disease and risk factors from a representative sample of elderly persons from four US communities, as well as spirometry and standardized questions regarding asthma symptoms and triggers. Ambulatory peak flow monitoring was also done in a subset. Previous studies of peak expiratory flow (PEF) lability did not include large numbers of elderly persons,[2,3] included only patients,[4] or did not carefully characterize cardiovascular comorbidity.[5] The goal of this report is to provide reference values and correlates of PEF lability in older adults.

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†A list of participants is shown in the Appendix.
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Materials and Methods

Recruitment

Participants in the CHS were selected using a Medicare eligibility list provided by the US Health Care Financing Administration for the four participating communities: Forsyth County, NC; Pittsburgh, PA; Sacramento County, CA; and Washington County, MD (all close to sea level). These communities are diverse in proportion of minorities, education and income levels, degrees of urbanization, death rates, and availability of medical care. Stratified sampling of the communities was done in order to include a 60:40 female/male ratio in each of four age groups, with

oversampling of younger age groups to produce similar numbers of cardiovascular events in each age and sex stratum. In order to improve follow-up rates, the spouse of each eligible subject was also encouraged to join the study.

Fifty-seven percent of eligible subjects agreed to participate. The initial study cohort of 5,201 participants (≥ 65 years old) was recruited and examined in 1989–1990, as described in detail elsewhere.[1,6] Because the original cohort included only 5% minority subjects, an additional 687 black participants were recruited, also using Health Care Financing Administration enrollment lists, and examined in 1992–1993 using the same methods as in the original cohort. Both cohorts underwent repeat examination in 1993–1994, including spirometry and PEF lability, from which all data in this report are derived.

The following were exclusion factors for the CHS: institutionalization; terminal illness; unable to walk, communicate, or give informed consent; or likelihood of moving from the area during the next 3 years. Enrolled CHS participants were younger, more educated, and more likely to be married and white than those who refused or were ineligible. The CHS design and recruitment are described in detail elsewhere.[1,6] The research protocol was reviewed and approved by the institutional review board for human studies of each clinical center, and a complete informed consent was obtained from all participants.

Interview and Clinical Examination

Spirometry and other examination components were scheduled throughout the morning of the examination, which included seated BP, resting 12-lead ECG, and a physical examination. Anthropometric measurements included standing height without shoes, sitting height, weight, and hip and waist circumferences. Trained interviewers completed a subset of the standardized American Thoracic Society (ATS) DLD-78 Respiratory Questionnaire.[7] Additional asthma-specific questions were taken from the European Community Respiratory Health Survey questionnaire[8,9] and the Tucson Airways Specialized Center of Research questionnaire.[10] Supplemental dyspnea questions were obtained from Guyatt and coworkers.[11] Participants brought their prescription medication containers to the clinic, where interviewers transcribed the drug name, strength, and dosing instructions from the medication labels.[12]

Current asthma for the purposes of this report was defined as positive responses to all three of these questions: "Have you ever had asthma? Do you still have it? Was it confirmed by a doctor?" *Chronic bronchitis* and *emphysema* were also defined as a self-report of the disease, confirmed by a doctor.

Spirometry Testing

A water-sealed spirometer was connected to a personal computer using software that assisted the pulmonary technician with quality control of maneuvers, calculated the pulmonary function variables, and compressed the results for transmission to the pulmonary function reading center. Details of the spirometry methods and resulting reference equations have been previously published.[13,14]

Ambulatory Peak Flow

Immediately following spirometry testing, participants were asked to participate in an optional study of peak flow lability. If they agreed, they were instructed how to use a PEF meter (Personal Best; Respironics; Kenilworth, NJ). This model was independently tested in Salt Lake City, UT, using 26 standard flow-time waveforms, and found to meet the 1994 ATS recommendations for PEF meter accuracy and repeatability.[15] Unlike some other models, this PEF meter does not overestimate PEF with "snappy" maneuvers (when the rise time to peak flow is short).[16]

The trained technician coached them to perform three maneuvers and recorded the highest value.[17] Participants were given a diary sheet with instructions on the reverse. The highest PEF from three maneuvers was recorded by filling in a circle corresponding to the reading on the PEF meter on the diary sheet, which was designed for automated optical mark reading. Participants were instructed to keep the PEF meter next to the bathroom sink and to perform three maneuvers as soon as they got out of bed in the morning and at dinner time (from 4 PM to 6 PM). After 7 days of use at home, participants returned the PEF meters and diaries in postage-prepaid, padded envelopes to the clinic. The accumulated PEF diaries were scanned using optical mark reading software (Paper Keyboard EZ; Datacap; Tarrytown, NY) using a scanner (Hewlett Packard Scan Jet; Hewlett Packard; Andover, MA).

Statistical Methods

The ambulatory PEF results were analyzed from subjects who completed at least 6 days of PEF data with both morning and evening results. PEF data from the day of the clinic visit and the following day were excluded due to learning effects. The daily PEF lability (PEF maximum − PEF minimum/mean PEF) was determined from each of the remaining valid test days (minimum, 4 days). The largest daily PEF lability was selected to represent PEF lability for the monitoring period. Of the 1,836 participants who returned PEF diaries, a valid PEF lability could be calculated from 1,628 participants (90%).

The demographic characteristics of those subjects who did and did not have valid PEF data were compared using χ^2 tests. Those who did not have valid PEF data included those who did not agree to participate as well as those who did not successfully complete at least 6 full days of measurements. The mean PEF values obtained from the diaries were also compared with PEF values obtained during spirometry testing at the clinic visit by estimating Pearson's correlation coefficient.

The bivariate associations between PEF lability and demographics, disease history, medication use, and respiratory symptoms were determined. Statistical comparisons for demographic variables were made using *t* tests. Results were adjusted for age, gender, black race, standing height, and ever-smoking, using an analysis of variance (ANOVA) model.

In order to obtain a set of reference equations for PEF and PEF lability, we defined a "healthy" subset of the cohort. Following ATS guidelines,[18] we excluded subjects with the following factors: current smoking, current asthma or use of asthma medications, history of chronic bronchitis or emphysema, chronic cough, history of congestive heart failure, and wheezing in the past year or with exercise.

The remaining healthy subset was used to construct reference equations for PEF and PEF lability. Initially, one linear model was fit (for each of the two outcomes separately), which forced age, gender, black race, and standing height into the model. A stepwise search was then made of all two-way interactions. For each model, the distribution of the residuals was examined (observed minus predicted value) to check for departures from the linearity assumption. For PEF, we calculated the lower limit of normal to be the fifth percentile of this distribution. For PEF lability (for which larger values indicate disease), we calculated the upper limit of normal (ULN) to be the 95th percentile. All statistical analyses were performed using software (SPSS for Windows, version 7.5; SPSS; Chicago, IL).

Results

Of the 4,581 CHS participants with a clinic visit during the 1993–1994 follow-up year, only 40% elected to attempt to measure their PEF lability at home for 1 week. Approximately 90% of those were successful in providing at least 4 days of valid readings twice per day (n = 1,628). Those with valid PEF lability results (when compared to those who elected not to perform the test) were significantly more likely to be male, white, with a higher family income, < 75 years old, and less likely to have a history of asthma (or receiving medications for asthma), and less likely to have chronic bronchitis, hay fever, emphysema, and congestive heart failure (Table 1). Also, participants from the Sacramento, CA, clinic (University of California, Davis) had a much lower rate of providing PEF lability measurements (n = 113, 6.9%) when compared to those at the other three clinics (26.4 to 36.5% per clinic). This may have been due to unusual time constraints at that clinic.

Table 1—*Comparison of Subjects With Valid PEF Data to Those With Missing PEF Data***

Risk Factors	Valid PEF Measurement? Yes (n = 1,628)	No (n = 2,953)	p Value
Male gender	709 (43.6)	1160 (39.3)	0.005
Black race	193 (11.9)	545 (18.5)	< 0.001
Family income < $12,000	309 (20.0)	780 (28.4)	< 0.001
Less than high school education	420 (25.8)	808 (27.4)	NS
Fair or poor health	250 (15.4)	735 (24.9)	< 0.001
Age group, yr			< 0.001
65–70	104 (6.4)	177 (6.0)	
71–75	806 (49.5)	1153 (39.0)	
76–80	434 (26.7)	839 (28.4)	
81–85	233 (14.3)	499 (16.9)	
> 85	51 (3.1)	285 (9.7)	
Smoking status			NS
Never	722 (44.5)	1376 (47.0)	
Former	760 (46.9)	1279 (43.7)	
Current	139 (8.6)	272 (9.3)	
Clinic			< 0.001
Bowman Gray	490 (30.1)	696 (23.6)	
Davis	113 (6.9)	1144 (38.7)	
Hopkins	595 (36.5)	399 (13.5)	
Pittsburgh	430 (26.4)	714 (24.2)	
History of disease			
Congestive heart failure	82 (5.0)	235 (8.0)	< 0.001
Chronic bronchitis (BL)	69 (4.3)	162 (5.7)	0.045
Emphysema (BL)	48 (3.0)	134 (4.6)	0.007
Hay fever	334 (21.0)	754 (26.4)	< 0.001
Chronic cough	177 (10.9)	385 (13.1)	0.033
Childhood respiratory disease	142 (8.8)	223 (7.7)	NS
Current asthma	49 (3.0)	130 (4.4)	0.020
Asthma medications			
Oral sympathomimetic	40 (2.5)	118 (4.0)	0.006
Oral theophylline	35 (2.2)	122 (4.1)	< 0.001
Oral corticosteroids	43 (2.6)	91 (3.1)	NS
Inhaled steroids	18 (1.1)	58 (2.0)	0.029

*Data are presented as No. (%); NS = not significant; BL = baseline. All p values are based on a χ^2 test for independence between the risk factor and presence/absence of valid PEF data.

As a check of the internal validity of the PEF values obtained by the participants at home using the peak flowmeters, we compared them to the PEF values measured during spirometry testing done during the clinic visit (just before the week of testing at home), coached by a study technician. Figure 1 plots the difference between the mean home PEF values (from days 3 to 7, both morning and evening) and the maximum forced expiratory flow from the best spirometry maneuver, per the recommendations of Bland and Altman.[19] For clarity, the plot includes only a randomly selected 25% of the points. The mean PEF results from home monitoring were slightly higher than those measured from the spirometer during the clinic visit, but the two measures were highly correlated ($r = 0.80$). The mean absolute difference was 60 L/min, with a 95th percentile of 162 L/min.

In bivariate analyses, statistically significantly higher PEF lability was seen in participants who were black, and those who were current or former smokers (Table 2). There was no association with family income, education, or age group. After adjusting for age, gender, race, height, and smoking status, those with a history of current asthma, chronic cough, and emphysema had higher PEF lability, but there was no association with congestive heart failure, hay fever, or a history of childhood respiratory disease (Table 3). Participants who had current

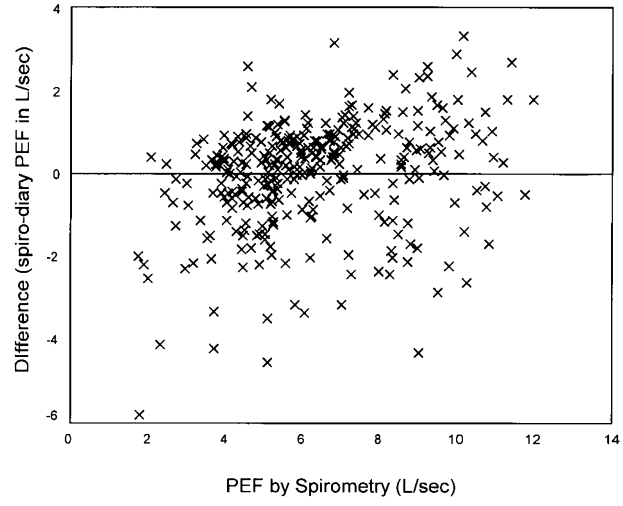

Figure 1. Comparison of PEF from home measurements (diary) and from spirometry performed in the clinic. Note that units of peak flow on the horizontal axis are liters per second (not liters per minute).

Table 2—*Association of Mean PEF Lability and Demographics

Demographics	No.	PEF Lability	p Value
Gender			
Male	709	12.52 (9.4)	NS
Female	919	13.38 (9.1)	
Race			
Nonblack	1,435	12.71 (9.0)	< 0.001
Black	193	15.19 (10.8)	
Income			
< $12,000	309	13.30 (9.2)	NS
≥ $12,000	1,239	12.90 (9.18)	
Education			
< High school	420	13.32 (9.4)	NS
≥ High school	1,205	12.88 (9.2)	
Age group, yr			
65–70	104	14.45 (10.4)	NS
71–75	806	12.39 (8.3)	
76–80	434	13.65 (10.3)	
81–85	233	13.49 (9.5)	
> 85	51	12.06 (9.1)	
Smoking status			
Never	722	12.39 (8.5)	0.046
Former	760	13.58 (10.0)	
Current	139	13.08 (8.8)	

*Data are presented as mean (SD) unless otherwise indicated. All p values are based on a two-way ANOVA model comparing mean PEF lability across the levels of each demographic variable. See Table 1 for expansion of abbreviation.

Table 3—*Associations of Mean PEF Lability With History of Disease and Asthma Medications

Variables	No.	PEF Lability Adjusted Mean	p Value
History of disease			
Current asthma			
No	1,572	12.86	< 0.001
Yes	49	17.65	
CHF			
No	1,539	12.94	NS
Yes	82	14.31	
Chronic bronchitis (BL)			
No	1,533	13.01	NS
Yes	69	13.05	
Emphysema (BL)			
No	1,559	12.89	0.001
Yes	48	17.35	
Current hay fever			
No	1,249	12.84	NS
Yes	333	13.65	
Chronic cough			
No	1,440	12.81	0.016
Yes	176	14.61	
Childhood respiratory disease			
No	1,458	12.86	NS
Yes	142	13.70	
Asthma medications (asthmatics only)			
Sympathomimetics			
No	27	14.22	0.028
Yes	22	22.08	
Theophylline			
No	36	17.22	NS
Yes	13	19.23	
Oral corticosteroids			
No	38	15.26	0.008
Yes	11	26.34	
Inhaled steroids			
No	35	15.20	0.019
Yes	14	24.14	

*All p values and adjusted means are based on an ANOVA model with PEF lability as the response, adjusting for age, gender, black race, standing height, and ever-smoking. Variables that were only measured at study entry are labeled BL (baseline). See Table 1 for expansion of abbreviation.

asthma and were receiving medications for asthma (probably a marker for more severe asthma) had higher PEF lability than those with asthma who were not receiving asthma medications.

After excluding persons with asthma and adjusting for age, gender, black race, height, and ever-smoking, ANOVA models were used to determine additional (statistically significant) independent predictors of high PEF lability (Table 4). These included trouble breathing, chronic cough, wheezing in the last year, wheezing from lying in a supine position, and a low FEV_1. Wheezing related to other factors, dyspnea on exertion, and the presence of a dog or cat at home were not associated with PEF lability, and the presence of wall-to-wall carpeting in the home was weakly associated with lower PEF lability.

Reference Values

In order to provide reference values of PEF and PEF lability that may be used for clinical purposes, a healthy subset of participants was obtained by excluding those with factors found to be significant predictors of low PEF or high PEF lability. In the healthy subgroup with valid PEF results, there were 61 black women, 511 white women, 44 black men, and 390 white men. Demographic predictor variables offered to each regression model of healthy participants included height, age, race, and gender interaction terms. Predicted values for PEF (the mean of home measurements) and the lower limit of the normal range (fifth percentile) were then calculated using the significant predictor variables. Table 5 shows the gender-specific reference equations for PEF. Healthy, elderly black participants had significantly higher age- and height-corrected PEF values when compared to the healthy white participants (mean, 21 L/min higher). Sitting height was not determined. Figure 2 shows the linear decline in mean PEF in healthy elderly CHS participants, stratified by gender and race.

The only significant predictors of PEF lability

Table 4—*Associations of PEF Lability and Respiratory Symptoms (Excluding Asthmatics)

Symptoms	No.	PEF Lability Adjusted Mean	p Value
Ever have trouble breathing?			
No	1,384	12.60	0.003
Yes	186	14.77	
Chronic cough?			
No	1,406	12.68	0.020
Yes	161	14.46	
Daytime sleepiness?			
No	1,278	12.61	0.025
Yes	290	13.97	
Wheezing in last year?			
No	1,286	12.60	0.040
Yes	279	13.93	
Wheezing from colds/flu?			
No	1,378	12.76	NS
Yes	187	13.53	
Wheezing from animals?			
No	1,509	12.79	NS
Yes	56	14.23	
Wheezing from dust/smoke/ fumes?			
No	1,470	12.74	NS
Yes	95	14.51	
Wheezing from exercise?			
No	1,515	12.80	NS
Yes	50	13.73	
Wheezing from lying flat?			
No	1,516	12.70	0.001
Yes	49	16.87	
Short of breath with activity?			
No	846	12.50	NS
Yes	726	13.27	
Short of breath while walking quickly?			
No	801	12.56	NS
Yes	679	12.99	
Short of breath while walking on level?			
No	1,502	12.82	NS
Yes	65	13.80	
Short of breath while resting in chair?			
No	1,552	12.85	NS
Yes	20	13.46	
Wall-to-wall carpeting?			
No	411	13.89	0.044
Yes	1,210	12.71	
Exposure to vapors/fumes?			
No	1,125	13.23	NS
Yes	492	12.47	
Dog or cat at home?			
No	1,329	13.01	NS
Yes	292	13.00	
FEV_1 < 69% predicted?			
No	1,416	12.67	0.004
Yes	205	15.28	

*All p values and adjusted means are based on an ANOVA model with PEF lability as the response, adjusting for age, gender, black race, standing height, and ever-smoking, and excluding asthmatics. See Table 1 for expansion of abbreviation.

Table 5—*Reference Equations for PEF

Terms	PEF (r^2 = 0.58) Coefficient	SE	p Value
Intercept	194.269	121.17	0.109
Age†	− 3.533	0.84	< 0.001
Gender	58.405	185.23	0.753
Black race	21.339	9.15	0.020
Height‡	2.322	0.60	< 0.001
Gender times age	− 2.871	1.25	0.022
Gender times height	1.802	0.90	0.045

*PEF measured in liters per minute. Reference equations (determined from above): female patients, PEF = 194 − (3.533 age) + (2.322 height) − 109 for lower limit of normal; male patients, PEF = 253 − (6.404 age) + (4.124 height) − 180 for lower limit of normal (add 21 L/min if black race).
†Measured in years.
‡Measured in centimeters.

were height and race. Because height only explained 3% of the variance in the model, we recommend the use of race-specific ULNs (based on the 95th percentile). The mean PEF lability for the 901 healthy white participants was 12%, and ULN was 28.6%. The mean PEF lability for the 105 healthy blacks was 15%, and ULN was 4.5%.

Discussion

PEF Lability Correlates

Increased PEF lability is common in patients with asthma and is moderately associated with nonspecific bronchial hyperresponsiveness, as measured by methacholine or histamine challenge[20–22]; therefore, the correlates of PEF lability should be similar to those of bronchial hyperresponsiveness. Our article[23]

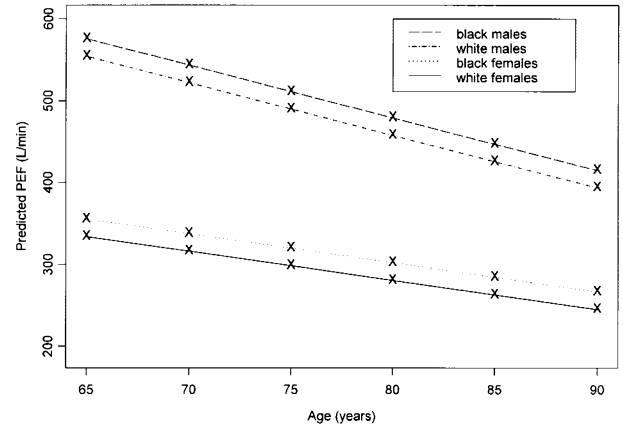

Figure 2. Predicted PEF by age, gender, and race from healthy older adults. The results were evaluated at the average height for men (174 cm) and women (159 cm).

describing the prevalence and correlates of asthma in the CHS cohort, and this current analysis showed that those with asthma had increased PEF lability. In other population samples of younger adults, even after excluding those with asthma or COPD due to cigarette smoking, increased PEF lability was associated with respiratory symptoms like wheezing (apart from colds), nocturnal dyspnea, exertional dyspnea, seasonal rhinitis, and chronic cough (but not with chronic phlegm).[2,3,5,20,24] In these studies, increased PEF lability was also associated with positive allergy skin test results, use of over-the-counter bronchodilators, current cigarette smoking, and pack-years of smoking. Apart from those with diagnosed asthma, the correlates of PEF lability that we found in this cohort of elderly persons are similar to those of studies of middle-aged persons: wheeze, airways obstruction, dyspnea, and chronic cough.

We found a 90% success rate in completion of the PEF diary in the subset of participants who agreed to try it, a rate similar to the 91% compliance from a population of Dutch adults,[3] and better than the 62% compliance from a study[22] of English adults. Optical mark coding of the diary saved data entry time and was probably easier for the participants to "blacken the eggs" instead of writing down the PEF numbers. However, the very recent availability of inexpensive handheld electronic spirometers that store the FEV_1 and PEF for > 30 days will make measurements of PEF lability even more sensitive, accurate, and efficient.[25,26] Changes in FEV_1 are more sensitive and more repeatable when compared to changes in PEF when bronchoconstriction occurs.[27]

The mean PEF values recorded without supervision at home were highly correlated with the values obtained from the automated volume spirometers operated by the technicians during the clinic visit. The differences are probably due to PEF meters being much less accurate than spirometers,[15] vigorous coaching by the technicians during spirometry performed during clinic visits, and the inclusion of morning dips in the mean PEF measured at home.

The mean PEF lability (12%) and ULN of PEF lability (28%) in the healthy subset of our cohort was very similar to that found in studies of middle-aged persons.[2,10,28] One large study[28] found that the overall test performance for detecting asthma was optimal at a cutoff of 30%. We chose a PEF lability index that emphasized sensitivity. Only one morning of bronchoconstriction during the monitoring period will increase the PEF lability for that individual for the entire monitoring period (approximately 1 week). Our PEF lability will be somewhat higher than studies in which the reported PEF lability was computed as the mean daily PEF lability.[10] A study[29] of children previously validated our approach when compared to methacholine challenge results and respiratory symptoms.

Previous studies did not include black subjects. Further studies of PEF lability are needed in minority populations since we cannot explain the reason for the higher PEF lability found in our subset of healthy elderly black participants.

Measurement of PEF lability may be useful for clinical purposes. In patients presenting with symptoms suggesting asthma, measurement of PEF lability may help to confirm a diagnosis of asthma, since a high PEF lability ($> 30\%$) will increase the clinician's estimated pretest probability of asthma,[4] but the sensitivity is low when compared to methacholine challenge testing.[28]

Our reference equations for PEF values in the elderly using PEF meters differ somewhat from

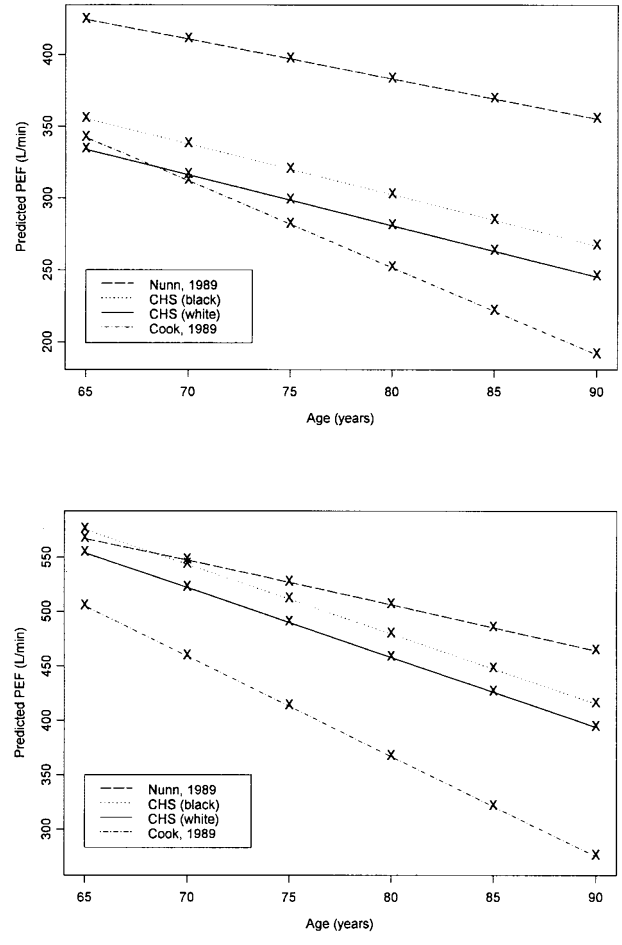

FIGURE 3. A comparison of PEF predicted values from studies of healthy older adults. CHS = this study, Nunn and Gregg[30] in 1989, and Cook et al[31] in 1989. The results were evaluated using an average height of 159 cm for elderly women and 174 cm for elderly men. For the equations of Cook et al[31] (which use body weight), average weights of 150 lb for women and 178 lb for men were used.

those published by other investigators (Fig 3). Our mean values and our age coefficient for elderly men are slightly higher than those from the study of Nunn and Gregg.[30] The study of Cook and coworkers[31] gives much lower values due to a much larger age coefficient, but they probably included more persons in their "healthy" subset who had factors that reduce lung function. Our mean PEF values for women fall midway between Nunn and Gregg[30] and Cook and coworkers.[31] Differences in instruments, measurement techniques, age distributions, and inclusion and exclusion criteria probably account for these differences. This suggests that single PEF values from individual elderly patients should be interpreted with considerable caution. Spirometry should be used to diagnose airflow limitation, since the instruments are much more accurate, quality control checks are possible, and predicted values are more accurate when compared to using PEF meters.

Limitations of our study include the fact that PEF testing was optional, and those who elected to perform the test were in better health. This reduced the power of our analyses to detect associations of PEF lability with various symptoms and diseases. The PEF lability of those taking medications for asthma is not a good index of their inherent PEF lability, since we did not ask them to withhold treatment with their asthma medications during the 2 weeks of PEF home monitoring. Asthma medications reduce PEF lability by improving lung function in the morning hours.

In summary, older adults are highly successful in recording PEF in their homes. Elderly patients with asthma or emphysema and those with airways obstruction have increased PEF lability.

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Appendix: Participating Institutions and Principal Staff of the Cardiovascular Health Study Research Group

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