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REPORTING PEAK EXPIRATORY FLOW IN OLDER PERSONS

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Abstract

Background—Peak expiratory flow ("peak flow") predicts important outcomes in older persons. Nevertheless, its clinical application is uncertain because prior strategies for reporting peak flow may not be valid. We thus determined the frequency distribution of peak flow by the conventional strategy of percent predicted (%predicted) and by an alternative method termed standardized residual (SR) percentile, and evaluated how these two metrics relate to health status in older persons.

Methods—Participants included 754 community-living persons aged ≥ 70 years. Data included chronic conditions, frailty indicators, and peak flow.

Results—Mean age was 78.4 years, with 63.7% reporting a smoking history, 17.4% chronic lung disease, and 77.1% having one or more frailty indicators. Peak flow ≥ 80 %predicted was recorded in 67.5% of participants, whereas peak flow ≥ 80^{th} SR-percentile was only noted in 15.9%. A graded relationship was observed between peak flow and health status, but %predicted yielded health risk at peak flows currently considered normal (80–100 %predicted), whereas SR-percentile conferred health risk only at severely reduced peak flows (< 50^{th} SR-percentile).

Conclusions—Peak flow expressed as SR-percentile attains a frequency distribution more consistent with the characteristics of our elderly cohort, and establishes health risk at more appropriate levels of reduced peak flow. These findings establish the need for longitudinal studies based on SR-percentile to further evaluate the use of peak flow as a risk assessment tool in older persons, and to determine if pulmonary function, in general, is better reported in older persons as SR-percentile, rather than as %predicted.

INTRODUCTION

Peak expiratory flow ("peak flow"), defined as the maximum flow achieved during expiration delivered with maximal force starting from maximal lung inflation (1), offers several advantages that warrant its consideration as a risk assessment tool in older persons. First, it is a simple, inexpensive, and readily available measure of pulmonary function (1). Second, in older persons, peak flow is cross-sectionally associated with health status and physical and cognitive function (2–5). Third, reduced peak flow in older persons predicts cognitive decline, institutionalization, and mortality (6–8). Fourth, in many cases, these associations persist even after adjustment for smoking status (2,4,5,8). The applicability of these findings to clinical practice and epidemiological research is limited, however, because peak flow was not appropriately compared to the predicted mean, i.e., the reference value in a normal population having similar anthropometric variables (1,9). Rather, peak flow was expressed either as a measured value, without comparison to the predicted mean (3,4,6,7), or as the residual difference between a measured and predicted value, which was neither standardized nor based on a correctly calculated predicted mean, i.e., relied on weight as a predictor variable (2,5,8).

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In contrast to height, age, gender, and ethnicity, weight is not an accepted variable to calculate the predicted mean, as it can adversely affect pulmonary function (1,9–12).

The reporting of peak flow, and pulmonary function in general, is further complicated by current recommendations that may not be applicable to older persons (1,9). Presently (11), pulmonary function is reported as percent predicted (%predicted), i.e., [(measured/predicted) * 100]. It has been customary to then equate 80 %predicted with the lower limit of normal (1,9–11). Two concerns are raised, however, regarding the use of %predicted among older persons. First, prior work suggests that the cutoff of 80 %predicted may not apply (1,9–11). Second, because the scatter of measured values about the predicted mean in older persons is independent of pulmonary function, there is no empirical basis to divide what is measured by that which is predicted (1,9). A fundamental issue thus arises, namely how peak flow should be reported in older persons.

To address these problems, peak flow may be reported by an alternative method termed standardized residual (SR) (1,9), i.e., [(measured–predicted)/(standard deviation of the residuals)]. In this equation, the numerator is referred to as the *residual*, while the denominator is a constant that quantifies the scatter of measured values about the predicted mean (1,9). Thereafter, percentiles based on the SR are computed or taken from published tables (9), e.g. SR=−1.64 is the 5th percentile, SR=0 is the 50th percentile, and SR=1.96 is the 97th percentile. Although endorsed by the European Respiratory Society in 1993, SR-percentiles were not mentioned in the 2005 recommendations of a combined American Thoracic Society and European Respiratory Society task force regarding the reporting of pulmonary function (9, 11). A potential impediment is the absence of evidence demonstrating that SR-percentiles are associated with measures of health status in older persons.

In the present study, we set out to compare the frequency distribution of peak flow when expressed as %predicted and SR-percentile, and to determine how these two metrics of pulmonary function relate to health status in older persons. Such findings may provide insight into the relevance of SR-percentile as a method to rigorously evaluate the use of peak flow as a risk assessment tool in older persons.

Methods

Study Population

Participants were members of an ongoing longitudinal study of 754 community-living persons, 70 years or older, who were nondisabled in four essential activities of daily living (ADL) - bathing, dressing, walking, and transferring from a chair (13). Exclusion criteria included significant cognitive impairment with no available proxy, inability to speak English, diagnosis of a terminal illness, and a plan to move out of the area during the next 12 months. Persons who scored greater than 10 seconds on the rapid gait test were oversampled to ensure a sufficient number of participants at increased risk for ADL disability (14,15). The participation rate was 75.2%. The study protocol was approved by the Human Investigation Committee.

Data Collection

At baseline, participants underwent an in-home assessment by a trained research nurse. Data were collected on demographics, smoking status, nine self-reported, physician diagnosed chronic conditions, five indicators of frailty, and cognitive status. Chronic lung disease was present if the participant answered “Yes” to – “Has a doctor ever told you that you have chronic lung disease such as chronic bronchitis, chronic obstructive pulmonary disease (COPD), asthma, or emphysema?” Frailty was operationalized based on three or more of the following indicators (16) - slow gait speed, weight loss, exhaustion, inactivity, and reduced grip strength;

while prefrailty was identified if only one or two of the frailty-related indicators were present. Cognitive status was evaluated by the Mini-Mental State Examination (17) with an abnormal score being < 24.

Peak flow was assessed via a Mini-Wright meter (Clement Clarke International; Essex, England), as described in the Text Box. The measured peak flow was recorded as the highest value achieved during three attempts (1). Of the 754 participants, 750 (99.5%) completed three peak flow readings, while three achieved at least one reading, leaving 753 in our study population. The peak flow test was largely performed standing (96%) and with good-to-excellent understanding (93%). Variability in effort was minimal with the intraclass correlation coefficient for the three peak flow readings being 0.92.

Statistical Analysis

Expressing peak flow as %predicted or SR-percentile requires comparison of a measured value with a predicted mean derived from "normal" subjects having similar anthropometrics (1,9–11). In the current study, a subgroup of normal subjects was defined as never-smokers who at study entry had no history of lung disease, myocardial infarction, congestive heart failure, stroke and cancer. Two regression models were fit, one for the "normal" male group and the other for the "normal" female group. In each model, a variable representing measured peak flow was regressed on prediction variables for height and age. The resulting predictive equations were used to calculate the predicted peak flow, and thereafter %predicted and SR-percentile according to methods previously described (1,9–11).

Next, we categorized measured peak flow based on current clinical practice. For example, the National Asthma Education and Prevention Program utilizes peak flow cut-points at 80 and 50% of one's personal best to define asthma severity (18). Similarly, the Global Initiative for Obstructive Lung Disease (GOLD) (19) has established a "staging" scheme for COPD based on the forced expiratory volume in 1 second (FEV1), with cut-points set at 80, 50, and 30 % predicted. While these spirometric cut-points have not been validated, they remain a standard of clinical practice (19), and are used in the current study. However, because a large number of participants had peak flow values below the 30th SR-percentile, we added a lower stage. Hence, our staging cut-points were 80, 50, 30, and 10, expressed as %predicted and SR-percentile.

To determine whether these two metrics of pulmonary function could discriminate differences in health status, we regressed select measures of health status on both %predicted and SR-percentile in unadjusted binomial regression models, yielding risk ratios as measures of association. Peak flow stages were treated as nominal categories, with the category representing best peak flow as the reference group. Measures of health status included chronic lung disease and frailty. Three indicators of frailty - slow gait, inactivity, and exhaustion, were specifically selected for analysis as they reflect endurance, an attribute that may decline with reductions in peak flow. SAS version 9.1.3 (SAS Institute; Cary, NC) was used for all analyses, and a p-value of 0.05 (two-sided) was used for all tests of statistical significance.

Results

As shown in Table 1, participants had a mean age of about 80 years, were largely female and white, and were not cognitively impaired. Smoking exposure was substantial with 8.4% and 55.3% being current or former smokers, respectively. About a quarter of participants were frail, with an additional 51.4% being prefrail. The five most prevalent chronic conditions were hypertension, arthritis, diabetes, myocardial infarction, and chronic lung disease.

Table 2 provides results of the multiple linear regression models and the resultant predictive equations for peak flow in “normal” participants. Of note, although age was not a significant coefficient in the male regression model, it was nevertheless retained, as it is a relevant determinant of pulmonary function across age groups.

Table 3 presents results for measured peak flow. When peak flow was expressed as percent predicted, 67.5% of the cohort was categorized as Stage 1, including 40% with %predicted values > 100. In contrast, when peak flow was expressed as a SR-percentile, participants were more equally distributed across the five stages, which included only 15.9% at Stage 1.

Table 4 provides risk ratios for chronic lung disease, frailty, and the three frailty indicators according to peak flow stage, expressed as %predicted. While a graded relationship was observed between worsening peak flow and increasing risk for all health status measures, these associations occurred at levels of peak flow currently considered normal or only mild-to-moderately reduced, i.e., at Stage 1 (80–100 %predicted) for chronic lung disease and slow gait, and Stage 2 (50–79 %predicted) for frailty, exhaustion, and inactivity.

The corresponding results for SR-percentile are noted in Table 5. A graded relationship was also observed between worsening peak flow and increasing risk for all health status measures. However, in contrast to %predicted, significant elevations in risk were only noted at more advanced stages of reduced peak flow, i.e., at Stage 3 (30–49 SR-percentile) for slow gait, Stage 4 (10–29 SR-percentile) for chronic lung disease, frailty, and inactivity, and Stage 5 (< 10 SR-percentile) for exhaustion.

Discussion

In a large cohort of community-living persons aged 70 years or older, we found that expressing peak flow as %predicted has serious limitations, while the alternative of SR-percentile is valid and offers clinical advantages. These findings establish the need for longitudinal studies based on SR-percentile to further evaluate the use of peak flow as a risk assessment tool in older persons, and to determine if pulmonary function, in general, is better reported in older persons as SR-percentile, rather than as %predicted.

As noted earlier, expressing pulmonary function as %predicted lacks an empirical basis in older persons (1,9). In fact, when applied specifically to peak flow, we found that the frequency distribution of %predicted is inconsistent with the clinical characteristics of our study population. For example, 40% of our elderly participants achieved a peak flow > 100 % predicted, despite a high prevalence of smoking-exposure, chronic lung disease, and indicators of frailty, all factors associated with reduced pulmonary function. Additionally, we found that risk for chronic lung disease and slow gait occurred at a peak flow of 80–100 %predicted, a range commonly interpreted as normal in clinical practice (1,9–11).

In contrast, the SR-method placed 46% of our cohort at a peak flow below the 30th SR-percentile, including 23% below the 10th SR-percentile – a distribution more consistent with the clinical characteristics of our study population. Further, participants were more equally distributed across the five stages of peak flow, with risk for chronic lung disease and slow gait only becoming significant at below the 50th SR-percentile for slow gait and below the 30th SR-percentile for chronic lung disease. Finally, the SR-method is empirically valid as it correctly standardizes peak flow to a constant, namely the standard deviation of the residuals (9).

Our observations are based on high quality data. Over 90% of participants completed, while standing, three peak flow readings with good-to-excellent understanding and minimal variability in effort. Within this context, our results suggest that the more valid approach of reporting peak flow is the SR-method, rather than %predicted.

Our predictive equations require comment. While the proportion of variance in peak flow that was accounted for by the predictor variables of height and age was low at 21% for females and 35% for males, these values, however, are similar to those reported in prior studies (5,20). Our findings thus suggest that peak flow variance is attributable to other factors beyond gender, height, and age.

Whether our findings for peak flow are applicable to other measures of pulmonary function is uncertain. The results from prior studies, however, have raised similar concerns about the use of %predicted as a basis for the spirometric diagnosis of pulmonary disorders in older persons (1,9,21,22).

In conclusion, among community-living older persons, peak flow is better reported as SR-percentile rather than %predicted. Longitudinal studies based on SR-percentile are needed to evaluate the use of peak flow as a risk assessment tool in older persons, and to determine if pulmonary function, in general, is better reported in older persons as SR-percentile, rather than as %predicted.

Text Box. Standardized protocol for measuring peak flow

- The assessor first demonstrates correct use of the peak flow meter.
- The assessor provides the following instructions:
  1. I would like you to perform the test three times.
  2. Stand up.
  3. Take as deep a breath as possible.
  4. Open your mouth and close your lips firmly around the outside of the mouth piece.
  5. Blow as hard and as fast as you can into the mouthpiece.
- The assessor records the participant’s posture (standing, sitting, lying) and understanding or compliance with the test (excellent, good, fair, poor, not applicable).

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Table 1

Baseline characteristics of study participants, N=753*

Characteristic	Mean (SD) or No. (%)
Age in years	78.4 (5.3)
Women	487 (64.7)
Non-Hispanic white	681 (90.4)
Education in years	12.0 (2.9)
Smoking Status	
Current	63 (8.4)
Former	416 (55.3)
Never	274 (36.4)
MMSE score	26.8 (2.5)
Frailty State†	
Nonfrail	171 (22.9)
Prefrail	386 (51.4)
Frail	193 (25.7)
Chronic Conditions	
Hypertension	416 (55.3)
Arthritis	227 (30.2)
Diabetes mellitus	137 (18.2)
Myocardial infarction	135 (17.9)
Chronic lung disease	131 (17.4)
Cancer (other than minor skin cancers)	124 (16.5)
Fracture other than hip since 50 years of age	98 (13.0)
Stroke	65 (8.6)
Congestive heart failure	48 (6.4)

*One of the 754 participants did not achieve a peak flow reading

†Two values were missing.

SD= standard deviation; MMSE= Mini-Mental State Examination (17)

Table 2

Multiple regression models for peak flow in a subgroup of "normal" participants*

Terms	**Male N=31**		**Female N=121**	
	Coefficient (SE)	**Mean**	**Coefficient (SE)**	**Mean**
Intercept (liters/min)	474.5 (16.3) $p < 0.001$	474.5	337.4 (6.7) $p < 0.001$	337.4
Height† (cm)	8.7 (2.7) $p = 0.003$	174.7	3.1 (1.1) $p = 0.005$	158.7
Age† (years)	−3.9 (3.5) $p = 0.273$	79.4	−5.57 (1.3) $p < 0.001$	78.6
Predictive Equations	474.52 + 8.69 (height) − 3.95 (age) SDR=87.78; $R^2 = 0.35$		337.40 + 3.09 (height) − 5.57 (age) SDR=73.29; $R^2 = 0.21$	

*SDR= standard deviation of the residuals; R^2= the square of the Pearson product moment correlation coefficient; SE= standard error.

†To enhance interpretability, each predictor variable was centered, i.e., for each participant, the mean value was subtracted from the measured value. The resulting intercepts equal the mean peak flow values for "normal" males and females, respectively. The *p* values refer to the significance of the terms within the regression model. Squaring the variables height and age did not improve the fit of the models, as denoted by the R^2 values.

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Table 3

Measured peak flow according to gender for all participants and never smokers

Peak Flow	All Participants			Never-Smokers		
	Total N=753	**Male N=266**	**Female N=487**	**Total N=274**	**Male N=52**	**Female N=222**
Raw values, liters/minute						
Median (IQR)	**350 (270–440)**	**460 (370–540)**	**310 (240–370)**	**340 (270–400)**	**450 (380–540)**	**325 (250–380)**
Percent predicted	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)
≥ 80 *Stage 1* *	508 (67.5) †	191 (71.8)	317 (65.1)	200 (73.0) ‡	39 (75.0)	161 (72.5)
50–79 *Stage 2*	190 (25.2)	60 (22.6)	130 (26.7)	60 (21.9)	12 (23.1)	48 (21.6)
30–49 *Stage 3*	50 (6.6)	14 (5.3)	36 (7.4)	13 (4.7)	1 (1.9)	12 (5.4)
10–29 *Stage 4*	2 (0.3)	1 (0.4)	1 (0.2)	0 (0)	0 (0)	0 (0)
< 10 *Stage 5*	3 (0.4)	0 (0)	3 (0.6)	1 (0.4)	0 (0)	1 (0.2)
SR-Percentile	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)
80–100 *Stage 1* *	120 (15.9)	50 (18.8)	70 (14.4)	44 (16.1)	8 (15.4)	36 (16.2)
50 –79 *Stage 2*	160 (21.3)	49 (18.4)	111 (22.8)	72 (26.3)	11 (21.2)	61 (27.5)
30–49 *Stage 3*	127 (16.9)	51 (19.2)	76 (15.6)	47 (17.2)	11 (21.2)	36 (16.2)
10–29 *Stage 4*	172 (22.8)	56 (21.0)	116 (23.9)	63 (23.0)	13 (25.0)	50 (22.6)
< 10 *Stage 5*	174 (23.1)	60 (22.6)	114 (23.4)	48 (17.5)	9 (17.3)	39 (17.6)

* By definition, SR-percentile cannot exceed 100, but percent predicted may – see text.

† 304 (40%) participants were at ≥ 100 percent predicted.

‡ 124 (45%) participants were at ≥ 100 percent predicted.

IQR= interquartile range; SR= standardized residuals.

Table 4

Risk ratios for health status measures according to percent predicted, N=753*

Peak Flow Percent Predicted	Chronic Lung Disease		Frailty		Slow Gait		Exhaustion		Inactivity	
	RR	CI	RR	CI	RR	CI	RR	CI	RR	CI
> 100	1.00		1.00		1.00		1.00		1.00	
80–100 *Stage 1*	1.76	1.03, 3.02	1.40	0.97, 2.01	1.44	1.13, 1.83	1.23	0.69,2.20	1.28	0.94, 1.75
50–79 *Stage 2*	4.15	2.62, 6.55	2.25	1.64, 3.10	2.02	1.63, 2.50	2.57	1.58,4.19	1.92	1.46, 2.53
30–49 *Stage 3*	6.91	4.24, 11.3	3.35	2.33, 4.81	2.28	1.75, 2.97	3.97	2.23,7.07	2.80	2.05, 3.84

*Participants with values greater than 100 percent predicted, denoting best peak flow, served as the reference group; risk ratios were not calculated for Stages 4 and 5 because of small cell sizes.

RR= risk ratio; CI= 95% confidence interval.

Table 5

Risk ratios for health status measures according to SR-percentile, N=753*

Peak Flow SR-percentile	Chronic Lung Disease		Frailty		Slow Gait		Exhaustion		Inactivity	
	RR	CI	RR	CI	RR	CI	RR	CI	RR	CI
80–100 *Stage 1*	1.00		1.00		1.00		1.00		1.00	
50–79 *Stage 2*	1.75	0.69, 4.42	0.94	0.55, 1.61	1.07	0.73, 1.56	1.22	0.52, 2.85	1.23	0.76, 1.97
30–49 *Stage 3*	1.89	0.73, 4.88	1.37	0.82, 2.29	1.46	1.02, 2.09	1.42	0.60, 3.35	1.59	1.00, 2.53 †
10–29 *Stage 4*	3.60	1.55, 8.37	1.71	1.07, 2.72	1.78	1.28, 2.47	2.01	0.93, 4.33	1.78	1.15, 2.74
< 10 *Stage 5*	7.82	3.51, 17.4	2.41	1.56, 3.74	2.22	1.62, 3.03	3.36	1.63, 6.94	2.51	1.66, 3.78

* Stage 1 is the reference group denoting best peak flow.

† $p = 0.051$

RR= risk ratio; CI= 95% confidence interval.