

PHYSIOLOGY

A Curvilinear Nomogram of Peak Expiratory Flow Rate for the Young

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Objective. Peak expiratory flow rates (PEFRs) differ among populations and between times. The new EU scale of the mini-Wright flow-meter has been introduced since 2004. This study updated the PEFR nomograms with the new scale for Chinese children and adolescents (aged 6–19 years) in Hong Kong. **Methods.** A convenience sample was recruited from 34 primary care practices (patients' companions/children) and four schools. Standardization workshops were run for the physicians, and the proper use of the flow-meter was demonstrated to students prior to the data collection. Brand new meters were used. For each sex, the linear regression model was used to determine the relationship between PEFR and the variables of age and body height. The open-source software PyNomo was used to generate the nomograms. **Results.** After excluding 66 participants with past/current history of respiratory tract diseases, heart disease, incomplete data, and poor effort, PEFRs were collected from 798 males and 794 females. The PEFR had a linear relationship with age but a curvilinear relationship with height. The regression equations for predicted PEFR were $\ln(\text{PEFR}) = 1.810256 \cdot \ln(\text{height}) + 0.038297 \cdot \text{age} - 3.734139$ for males and $\ln(\text{PEFR}) = 1.525509 \cdot \ln(\text{height}) + 0.033275 \cdot \text{age} - 2.368592$ for females. The corresponding nomograms were constructed. They were tested with 230 patients in primary care; 9.6% (12 males and 10 females) had PEFR less than the predicted value by $\geq 20\%$. **Conclusion.** The body height was a stronger determinant than age for PEFR. The predicted PEFR with these determinants bear a curvilinear relationship.

Keywords adolescents, asthma, children, nomogram, peak expiratory flow rate

INTRODUCTION

Although the spirometry is preferred to the peak expiratory flow rate (PEFR) in the diagnosis of asthma (1, 2), the spirometer is not widely available in primary care. The primary care physician often uses the mini-Wright flow meter, and PEFR is accepted as an aid in the diagnosis and monitoring of airway limitation by the Global Initiative for Asthma (3). The predicted PEFR varies among different ethnic populations (4–7); hence, different populations construct their own PEFR nomograms. Even for a specific population, the reported prediction equations could vary over time (8–11). Consequently, the PEFR nomograms need to be updated periodically.

Since Year 2004, the mini-Wright flow meter has used a new scale (EN 13826 or EU scale). The old Wright scale was found to overrepresent changes in the mid-range of PEFR and underrepresent the low and high ranges. The manufacturer of the new meter publishes for reference the pediatric normal values that correlate only with body height without further subdivision into sex and age (12). These reference values are definitely not adequate for clinical practice as PEFR differs significantly between the sexes and among different ages. As the old mini-Wright flow meters are obsolete, more new nomograms for specific populations are forthcoming.

We report here our approach to construct the PEFR nomograms of children and adolescent residents, aged 6–19 years, in Hong Kong, using the new EU scale mini-Wright meters. We believe that this could serve as a reference for researchers to construct or update their population-specific nomograms.

METHODS

This was part of the larger study of the predicted PEFR of residents aged 6–65 years who had been residing for at least one year in Hong Kong; the study was previously reported (13). We invited by letters the primary care doctors in private practice throughout the 18 electoral districts of Hong Kong to collect PEFR from at least 100 persons in their practices (caregivers or companions of patients but not the consulting patients). The 34 doctors who agreed to participate attended a standardization workshop for taking the PEFR and body heights. Each doctor received two brand new meters, one with standard range EU scale and one with low-range EU scale, and disposable mouthpieces. They were periodically reminded on the progress with emails or telephone contacts.

We also recruited students from two primary and two secondary schools. We made a digital video with the help of the Multimedia Group of one secondary school on the purpose of the survey and how to use the peak flow meter. This video was shown to the students before the day of data collection, and the technique was demonstrated again before the actual tests at their schools. The best PEFR after three

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attempts while standing was taken as the student's PEFR. All the PEFR were obtained in the afternoons by trained assistants and clinic nurses, together with the authors on site. The body height was measured with each student standing with the bare feet close together and heels on the ground. The knees, legs, and back were held straight, and the level of the external auditory meatus horizontal to that of the lower rim of the orbit. The body weight was taken with the participant in light clothing and without shoes.

The inclusion criteria were the written consents from the parents/guardians and the ability to use the peak flow meter after instruction. We excluded people with the history of chronic respiratory or heart diseases, concurrent infectious diseases of the respiratory tract, or oral/musculoskeletal conditions affecting the respiratory system. We also excluded the PEFR reading if the participants had obviously not blown into the meter with the maximum effort.

We used the linear regression model to analyze the association of PEFR with other factors and the coefficient of determination, R^2 , to determine the final model. The R^2 is a measure of how well the future outcome is likely to be predicted by the regression model. Separate models were used for boys and girls. The association of PEFR with individual factors (age, height, weight, etc.) was first tested. All the factors with significant association with PEFR were entered into the regression model to see which combination of factors was significant. We then tested different transformations of the factors (e.g., age, age², age³, and natural logarithm (ln) age). The model with the least amount of factors and the largest R^2 was adopted. All the statistical tests were done with the *R* statistical packages, taking $p < .05$ as the significant level. The nomograms were generated with the free open-source software PyNomo (14) that was developed in 2007 and updated in 2009 (PyNomo is open source and free software licensed under the GNU GPL Version 3. Copyright © 2007–2009 Leif Roschier).

The nomograms were then sent to five primary care doctors for the clinical test. The purpose was to test the performance of the nomograms. We did not validate the regression equation because the nomograms would mainly be used in clinical practice for patients. Because of this reason, we were less stringent with the exclusion criteria and excluded only the asthmatic and the patients who consulted for upper/lower respiratory tract symptoms. The observed PEFR were compared against the predicted values from the nomograms.

Ethics approval was granted by the Institutional Review Board of The University of Hong Kong/Hospital Authority Hong Kong West Cluster.

RESULTS

Recruited Children and Adolescents

We recruited 1658 children and adolescents aged 6–19 years, of whom 66 were excluded due to history of asthma (23), history of respiratory diseases other than asthma (24), heart diseases (2), physical weakness caused

TABLE 1.—Body heights (cm) of the recruits compared with another local survey (15).

Age	Male		Female	
	This study (<i>n</i> = 798)	2005/6 study (<i>n</i> = 7311)	This study (<i>n</i> = 794)	2005/6 study (<i>n</i> = 7189)
6	115.2 ± 5.8	117.9 ± 4.5	110.8 ± 5.6	117.3 ± 5.0
7	121.7 ± 5.5	122.9 ± 5.8	120.8 ± 9.6	120.8 ± 5.3
8	128.0 ± 7.2	127.9 ± 5.9	127.6 ± 5.8	127.2 ± 5.5
9	130.3 ± 7.5	133.1 ± 5.7	129.9 ± 5.2	132.7 ± 6.3
10	148.4 ± 11.9	138.5 ± 6.5	146.7 ± 10.3	138.4 ± 6.8
11	147.5 ± 9.5	143.5 ± 7.2	145.9 ± 9.0	145.4 ± 7.0
12	155.1 ± 9.7	151.0 ± 8.1	153.9 ± 7.1	151.5 ± 6.4
13	160.4 ± 9.5	158.2 ± 8.5	154.6 ± 8.4	155.2 ± 6.0
14	167.2 ± 10.8	164.2 ± 7.6	158.7 ± 6.3	157.0 ± 5.3
15	170.2 ± 8.5	167.9 ± 6.0	159.8 ± 5.9	157.9 ± 5.2
16	171.5 ± 7.2	170.6 ± 5.5	157.6 ± 5.4	158.4 ± 5.4
17	171.9 ± 6.2	171.4 ± 5.9	159.3 ± 4.5	158.7 ± 5.4
18	172.8 ± 6.4	171.7 ± 5.5	159.7 ± 4.8	158.7 ± 5.7
19	171.7 ± 5.3	—	158.5 ± 6.8	—

by current illnesses (5), oral diseases (1), poor voluntary effort (2), and incomplete data (9). Of the final sample of 1592 participants, 798 were male and 794 female.

The body heights of our sample were similar to the much larger sample in a local growth survey in years 2005/6 (15) (Table 1), except for the subgroup of age 6 (due to the smaller sample size in this study). Seven males were smokers while none of the females reported smoking.

Predicted PEFR

The observed PEFR had a linear relationship with age but a curvilinear one with body height (Figure 1). We transformed the PEFR and height into their natural logarithms (ln) so that the relationship became linear. Age, height, weight, and body mass index were tested in the regression model against PEFR, using different transformations. We finally arrived at the model that involved ln(PEFR), ln(height), and age. The regression equations are:

For males:

$$\ln(\text{PEFR}) = 1.810256 * \ln(\text{height}) + 0.038297 * \text{age} - 3.734139$$

$$R^2 = 0.7778, r = 0.88, p < .001$$

For females:

$$\ln(\text{PEFR}) = 1.525509 * \ln(\text{height}) + 0.033275 * \text{age} - 2.368592$$

$$R^2 = 0.5955, r = 0.77, p < .001$$

If body mass index was included in the regression model, the R^2 improved slightly to 0.7802 for males and 0.6150 for females. Opting for a simple procedure in a busy clinic, we exclude body mass index in our prediction equations for

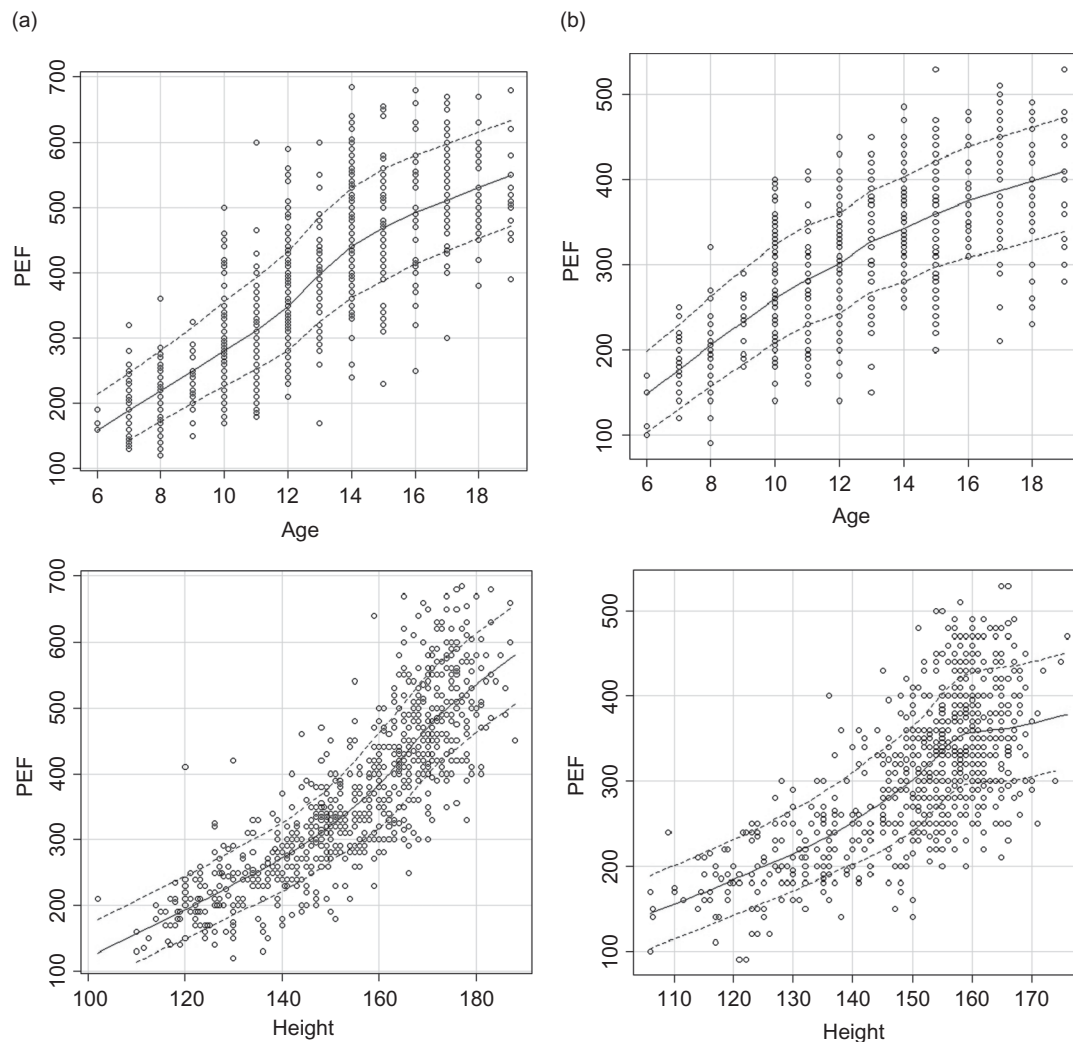


FIGURE 1.—(a) Scatterplots of PEFR against age and height in the male (with smoothed 0.25, 0.5, and 0.75 percentile curves of PEFR). (b) Scatterplots of PEFR against age and height in the female (with smoothed 0.25, 0.5, and 0.75 percentile curves of PEFR).

PEFR. The resulting PEFRs have a curvilinear relationship with age together with height as exemplified in Figure 2.

Construction of the Nomograms

The regression equation for males was arranged into:

$$\ln(\text{PEFR}) - 1.810256 * \ln(\text{height}) + (3.734139 - 0.038297 * \text{age}) = 0$$

This equation was in the format of the “type 1 basic block” for the construction of nomogram by the PyNomo software. The nomogram for each sex was generated with putting these three parameters into the source code. These are presented in Figures A1 and A2.

Clinical Test of the Nomograms

The five primary care physicians recruited 236 patients, of whom six were excluded due to current upper respiratory tract diseases. Of the remaining 230 patients, the mean PEFR-difference ((predicted – observed)/predicted) was $4.3 \pm 11.22\%$ (ranging from -23.7% to 34.0%). Overall,

in 9.6% of the patients (12 males and 10 females), the observed PEFR were less than the predicted by $\geq 20\%$. All the six excluded patients had PEFR lower than the predicted by more than 24.2%.

DISCUSSION

We approached 34 primary care physicians and four schools to recruit children and adolescents (well without current illnesses) for the collection of PEFR. For each sex, we used a linear regression model for the prediction equation of the natural logarithm of PEFR against age and the natural logarithm of height. The final nomograms were constructed with the open-source software PyNomo and were tested on a separate set of patient-recruits. This approach was inexpensive both in monetary and human resources.

To our best knowledge, these are the first PEFR nomograms with the new mini-Wright flow meters in EU scale. The pediatric “normal values” published by the manufacturer of the mini-Wright are very limited in clinical use. For example, for the height of 140 cm, the predicted PEFR

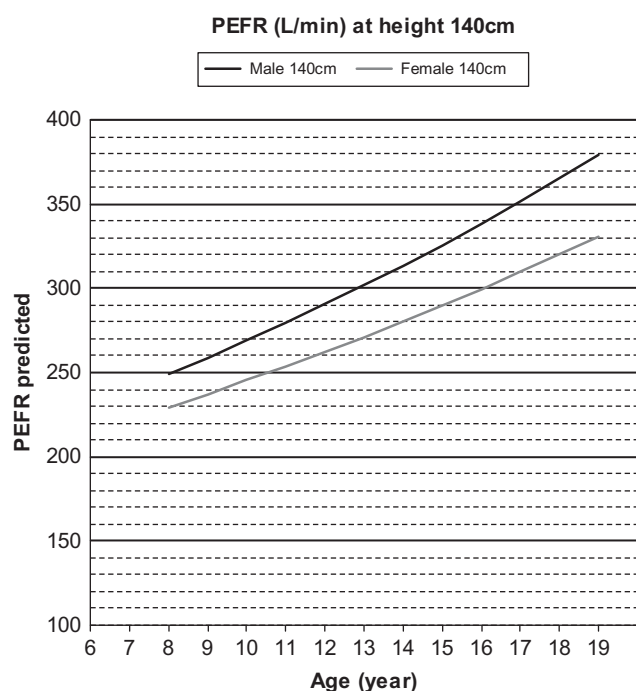


FIGURE 2.—Predicted PEFR (L/min) for a boy or a girl of height 140 cm.

value from the manufacturer is 254 L/min. Such a PEFR applies to a 9-year-old boy or 11-year-old girl of the same height in our sample population.

It is not possible at present to compare with similar nomograms from other populations. The previous PEFR in Hong Kong was constructed in 1982 with the old mini-Wright meter (16). On comparing the body heights of their recruits and ours, the boys and girls in this study were much taller, up to more than 10 cm in the age-group of 9–15 years. Apart from the different scales, the previous nomograms are not applicable for the present young generation. This observation suggests that nomograms need to be revised from time to time to be consistent with the secular changes in anthropometry.

This study is apparently the first one to report a curvilinear relationship between PEFR and body height and a logarithmic transformation for the prediction equations of PEFR. In the literature, the previously reported prediction equations for PEFR with the mini-Wright meters in children and adolescents were mostly linear (7, 10, 17–20). Hsu et al in United States adopted the power transformation of height (21). Pistelli, using the spirometer instead of the mini-Wright, arrived at a regression model with the logarithmic transformation of the predicting variables (22).

It is uncertain if the new EU scale has any contribution to this curvilinear relationship. However, it is likely due to the curvilinear relationship between age and height in this age group. Children have a rapid height increase (cm/year) around the ages 11–12 which become the turning point for the curvilinear height–age curve. As PEFR is determined by height and age, such curvilinear relationship is extrapolated to the prediction equation. The cause of this

rapid increase is uncertain though probably related to the hormonal changes around puberty.

We had a good experience in working with the students' multimedia interest group of a secondary school. The production of the video-CD to explain the purpose of our study, the meaning of the PEFR, and the proper use of the peak flow meter stimulated not only the students' interest and cooperation in the survey, but also the awareness of asthma. The survey served as a chance for health education to the young. The students with the history of asthma were given their PEFR readings after the survey.

For the clinical test of the nomograms, 142 (61.7%) patients had PEFRs lower than the predicted value, although only 22 (9.6%) patients with a difference $\geq 20\%$. This could be explained by the fact that we only excluded patients who consulted for upper/lower respiratory tract infections; the patients' current illness (e.g., painful conditions) could have diminished their effort in blowing into the flow meter. Strictly speaking, we only validated the use of the nomogram in primary care practice rather than the prediction equation for the general population. The recruits for the predication equation (people feeling well) and for the test of the nomogram (people with illness) were not exactly comparable. The nomograms were tested not at their optimal performance but for their practical use.

Limitations

The study population was a convenience sample. However the height distribution of our recruits and the rapid increase in height around the ages 11–12 years were consistent with the recent study of body heights of the local children (15). The latter study was a two-stage cluster randomized sample of all school children in Hong Kong. This consistency suggested that our study population was similar to the general population of the same age range.

In the clinical test of the nomograms, we did not pursue further with the 9.6% of patients whose PEFRs were less than the predicted by $\geq 20\%$. Whether they had airways limitation or not was uncertain, although the medical records showed that they had no past history of respiratory diseases. A better validation of the prediction equations could be done with a separate recruit of school children.

We collected PEFR from the school children in the afternoon but there is a circadian variation in PEFR. Henderson and Carswell reported two peaks of PEFR in children (one in the morning and one in the afternoon) (23), but Hetzel and Clark reported a peak around 3:30 pm in children and adults (24). Others reported a peak in the afternoon in adults (25, 26), and PEFR taken in the afternoon could minimize the effect of the circadian rhythm (26, 27). The time of data collection in this study was feasible to obtain PEFR close to the peak and for the schools to arrange an extra-curricular activity.

CONCLUSION

PEFR nomograms of children and adolescents in Hong Kong were constructed for the EU scale of the mini-Wright

flow meter. Age and height were the significant determinants of PEFR for each sex in the regression model. The PEFR had a curvilinear relationship with body height.

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DECLARATION OF INTEREST

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APPENDIX

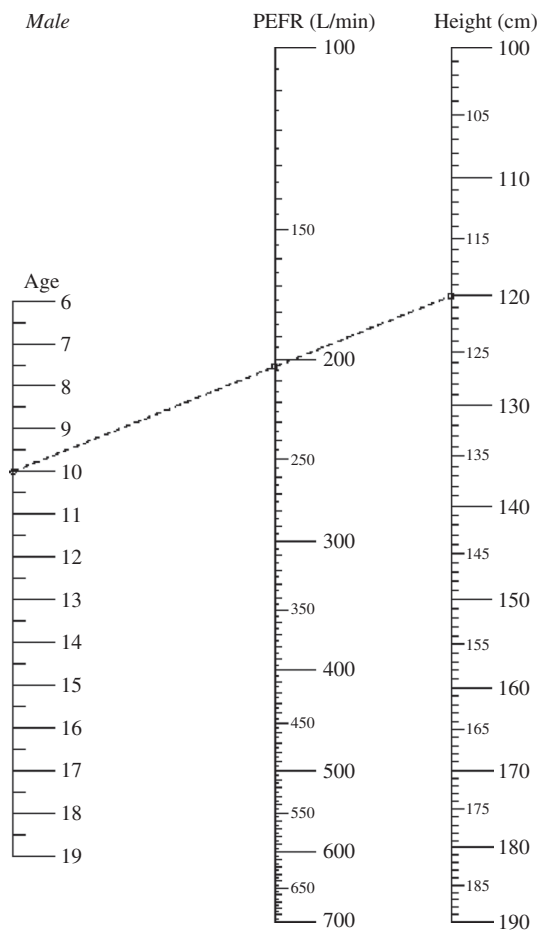


FIGURE A1.—PEFR nomogram for males aged 6–19 years.

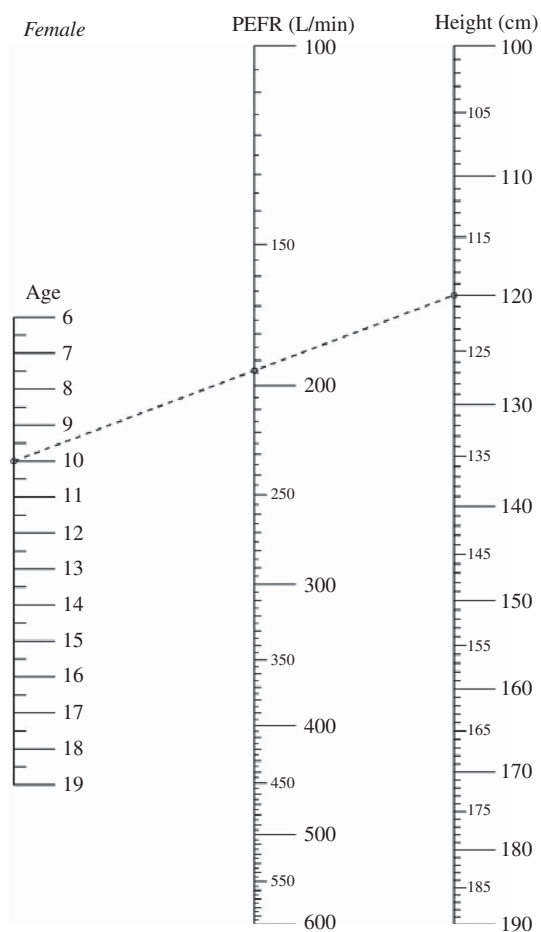


FIGURE A2.—PEFR nomogram for females aged 6–19 years.