

Correlation and Predicted Equations of MIP/MEP from the Pulmonary Function, Demographics and Anthropometrics in Healthy Thai Participants aged 19 to 50 Years

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ABSTRACT

OBJECTIVE: To identify the correlations and possible predicted equations of maximal inspiratory (MIP) and expiratory mouth pressure (MEP) values from pulmonary function test (PFT), demographics, and anthropometrics.

METHODS: This study involved 217 healthy participants (91 males and 126 females) aged 19 to 50 years. The PFT (forced vital capacity; FVC, forced expiratory volume in 1 second; FEV1, maximal mid-expiratory flow; MMEF, and peak expiratory flow; PEF) was performed by spirometry, whereas MIP and MEP were evaluated by a respiratory pressure meter. Pearson correlation and multiple linear regression, with the stepwise method, were used for statistical analysis.

RESULTS: The MIP and MEP had a significant positive correlation with weight, height, body mass index (BMI), and waist circumference. MIP had a significant positive correlation with FVC (%) and PEF (L/s and %), as well as a negative correlation with FEV1/FVC (ratio and %) and MMEF (%). Whereas, MEP showed a significant positive correlation with PEF (L/s and %) and negative correlation with FEV1/FVC (ratio and %) and MMEF (L/s). Finally, the predicted MIP and MEP equations were $103.988 - 97.70 \times \text{FEV1/FVC} + 31.292 \times \text{Sex}$ (male = 1 and female = 0) + $0.662 \times \text{PEF}$ (%) and $47.384 + 3.603 \times \text{PEF}$ (L/s) - $9.514 \times \text{MMEF}$ (L/s) + $30.458 \times \text{Sex}$ (male = 1 and female = 0) + $0.534 \times \text{PEF}$ (%), respectively.

CONCLUSION: The respiratory muscle strengths can be predicted from the pulmonary function test, and gender data.

KEYWORDS: Anthropometrics, demographics, predicted MIP and MEP equations, pulmonary function test

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Introduction

Background knowledge on the impairment of respiratory muscle function has been reported in various diseases such as cardiovascular,¹ pulmonary,² and neuromuscular³ conditions, rheumatoid arthritis,⁴ and post radiotherapy in breast cancer,⁵ relating to impairment in ventilation, gas exchange, and oxygen delivery to tissue.⁶ Therefore, respiratory muscle strength in either inspiratory or expiratory muscles is related to quality of life for many people; for example, the elderly with Parkinson's disease,⁷ or adolescent and child patients with asthma,⁸ and patients with cervical spinal cord injury,⁹ etc.

The maximal pressure for either maximal inspiratory mouth pressure (MIP) or maximal expiratory mouth pressure (MEP) must be evaluated by following the standard maneuvers¹⁰ under the American Thoracic Society/European Respiratory Society (ATS/ERS) protocol.⁶ In order to evaluate the MIP or MEP with special devices either a portable capsule-sensing pressure gauge,¹¹ which is noninvasiveness, and light weight, or being a

digital pressure gauge, portable autospirometer,¹² and MicroRPM meter.¹³ Although, the evaluation of the respiratory muscle strength is a critical importance, it is not carried out successfully because of unavailable devices from high cost as the routine spirometry test in general hospitals in Thailand. Therefore, finding the predicted equation for MIP and MEP from the routine pulmonary function test is very interesting. Previous studies found that age,^{14,15} and anthropometrics¹⁶ correlated with predicted MIP and MEP values. In addition, a previous report suggested that the male gender, younger age, obesity, higher FVC (L), and shorter height were associated strongly and independently with higher values of MIP in relatively healthy adults.¹⁷ In contrast to a previous study in which MIP and MEP were evaluated in chronic obstructive pulmonary disease (COPD) patients, showed that age, height, weight, and BMI did not correlate with MIP, whereas their weight and BMI had slightly correlation with MEP.¹⁸ Therefore, aims of this study were to identify the correlation and predicted MIP



or MEP equations from the parameters of routine pulmonary function test, demographics and anthropometric data.

Materials and Methods

Study subjects

This study comprised 217 healthy non-smoking participants aged 19 to 50 years old (91 males), who were not athletic or doing exercise less than 3 times per week, but had normal BMI ($18.5\text{--}24.9\text{ kg}\cdot\text{m}^{-2}$),¹⁹ as well as normal PFT under ATS/ERS guideline protocol. Standardized pulmonary function testing ($\text{FEV}_1 \geq 80\%$ and $\text{FEV}_1/\text{FVC} > 0.7$) followed the protocol guideline, and interpretation of the Global Initiative for Chronic Obstructive Pulmonary Disease (GOLD)²⁰ was included in this study. All of the participants had no history of previous illness reported or recorded from hospital data; for example, asthma, COPD, pneumothorax, hemoptysis, chest wall deformity, previous rib fracture, thoraco-abdominal surgery or aneurysm, angina chest pain, and cardiovascular disease.²¹ In addition, current extra-vitamin supplement intake was exclusion criteria. All of the participants signed a consent form before the program started.

Experimental design

This study was a cross-sectional design and the research protocol was approved ethically by the Ethic Committee at the Faculty of Associated Medical Sciences, Chaing Mai University, Chiang Mai, Thailand (Study Code: AMSEC-61EX-096). This study aimed to identify the correlations and possible predicted equations of maximal inspiratory (MIP) and expiratory mouth pressure (MEP) values from pulmonary function test, demographics (age and sex) and anthropometrics (weight, height, BMI, and waist circumference) data. The sample size for this study was calculated by G*Power program (version 3.0.10) was used to analyze F-tests (Multiple regression; Omnibus (R^2 deviation from zero). The effect size $f^2 = 0.15$, α err prob = 0.05, Power ($1 - \beta$ err prob) = 0.95, and Number of predictors = 9 (FVC, FEV₁, peak expiratory flow (PEF), age, sex, height, BMI, and waist circumference) were used to calculate the MIP and MEP. Therefore, at least sample size of 200 healthy participants (100 males and 100 females) aged 19 to 50 years old should be collected. Moreover, to prevent insufficient sample size, 20 participants (10%) were added, therefore, total 220 participants were recruited.

Anthropometric evaluation

Data collection of all parameters was performed in a quiet laboratory which controlled temperature at 24°C to 26°C. Before anthropometric evaluation, participants were asked to wear light clothing and wearing barefoot. Body weight was registered using a digital scale (TANITA Corporation, Tokyo,

Japan). Height was measured using a stadiometer (Health O meter® Physician, AD Medical, Inc., USA) with resolution in millimeters. BMI was calculated as weight by height squared ($\text{kg}\cdot\text{m}^{-2}$). Waist circumference (inches) was determined with a non-stretch tape measure horizontally placed at navel level during expiration.²²

Pulmonary function test

The pulmonary function parameters; FVC (L and %), FEV₁ (L and %), FEV₁/FVC (absolute value and %), MMEF (L/s and %) and PEF (L/s and %) were evaluated by spirometry (Easy on-PC Spirometry, nnd Medical Technologies, Zurich, Switzerland) under the prediction referred on the Thai population.²³ The spirometry evaluation was performed under the standard American Thoracic Society (ATS) guideline protocol²⁴ and interpretation followed the GOLD guideline.²⁰

Maximal respiratory pressures

MIP and MEP were evaluated by a respiratory pressure meter (MicroRPM) (CareFusion, UK 232 Ltd, United Kingdom) under the standardized guideline of the ATS/ERS Statement of Respiratory Muscle Testing (2002).⁶ The participants were placed in a sitting position with their back supported and instructed to wear a nasal clip and hold a flanged mouthpiece tightly in their mouth in order to prevent air leakage in all maneuvers. In determining MIP, the participants were asked to give maximal inspiratory effort after starting from residual volume (RV), or maximal exhalation, whereas MEP was measured after starting from total lung capacity (TLC) or after maximal inhalation. The highest value of maximal pressure (cmH_2O) from at least 3 efforts (for at least 2 seconds and sustained for 1 second without leakage) was acceptable and recorded if the values did not exceed the previous effort or the highest value by 10%.²⁵ A one-minute rest was allowed between each maneuver and 5 minutes between MIP and MEP assessments, in accordance with previous instruction.

Statistical analysis

Continuous variables of demographics (eg, age and sex), anthropometrics (weight, height, BMI, and waist circumference) and pulmonary function test (ie, FVC, FEV₁, FEV₁/FVC, MMEF, and PEF) were rechecked for normal distribution by the Kolmogorov-Smirnov test before reporting the mean \pm standard deviation (SD), and categorical variable as sex (defined as 1 for male and 0 for female). The equations for predicting MIP and MEP from the PFT, demographics and anthropometrics were analyzed using multiple linear regression (MLR). After rechecking data with normal distribution, the correlation between MIP and MEP to all characteristics and PFT result was interpreted using the Pearson's correlation test under the

Table 1. Demographics, anthropometrics, pulmonary function and maximal respiratory muscle pressures.

	MALES	FEMALES	TOTAL	P
Demographics and anthropometrics				
Number	91	126	217	
Age (years)	28.32 ± 9.57 (19-50)	30.65 ± 9.57 (20-50)	29.70 ± 9.63 (19-50)	.075
Weight (kg)	65.09 ± 7.41 (48-87)	53.12 ± 5.65 (39-67)	58.14 ± 8.74 (39-87)	.000
Height (m.)	1.72 ± 0.06 (1.60-1.86)	1.59 ± 0.05 (1.43-1.72)	1.64 ± 0.09 (1.43-1.86)	.000
BMI (kg.m ⁻²)	21.56 ± 1.21 (18.59-22.89)	20.89 ± 1.41 (18.50-22.89)	21.18 ± 1.36 (18.50-22.89)	.000
Waist circumference (inches)	31.73 ± 3.57 (23.6-42.0)	28.82 ± 3.06 (22.0-37.0)	30.04 ± 3.58 (22.0-42.0)	.000
Pulmonary function				
FVC (L)	4.05 ± 0.54 (2.91-5.22)	2.86 ± 0.39 (1.97-3.88)	3.36 ± 0.75 (1.97-5.22)	.000
FVC (%)	95.18 ± 11.45 (80-133)	97.58 ± 10.94 (80-123)	96.58 ± 11.20 (80-133)	.120
FEV1 (L)	3.68 ± 0.49 (2.66-4.92)	2.55 ± 0.35 (1.76-3.55)	3.02 ± 0.69 (1.76-4.92)	.000
FEV1 (%)	101.95 ± 11.15 (80-135)	96.43 ± 9.89 (80-124)	98.75 ± 10.72 (80-135)	.000
FEV1/FVC	0.92 ± 0.55 (0.8-1.0)	0.87 ± 0.06 (0.8-1.0)	0.90 ± 0.06 (0.8-1.0)	.040
FEV1/FVC (%)	103.02 ± 6.05 (81.5-113.8)	101.39 ± 8.40 (81.0-122.5)	102.08 ± 7.53 (81.0-122.5)	.118
MMEF (L/s)	4.73 ± 1.00 (2.22-7.21)	3.29 ± 0.81 (1.54-5.40)	3.90 ± 1.14 (1.54-7.21)	.000
MMEF (%)	106.78 ± 21.37 (69-169)	101.81 ± 21.51 (56-154)	103.89 ± 21.54 (56-169)	.094
PEF (L/s)	9.10 ± 1.69 (4.33-13.72)	5.98 ± 1.25 (1.56-8.68)	7.29 ± 2.11 (1.56-13.72)	.000
PEF (%)	97.11 ± 17.74 (60-174)	96.09 ± 17.62 (56-141)	96.52 ± 17.64 (56-174)	.677
Maximal respiratory muscle pressures				
MIP (cmH ₂ O)	110.44 ± 26.07 (55-187)	80.19 ± 20.04 (41-147)	92.87 ± 27.19 (41-187)	.000
MEP (cmH ₂ O)	117.45 ± 28.87 (62-206)	88.90 ± 23.78 (46-157)	100.8 ± 29.54 (46-206)	.000

Abbreviations: BMI, body mass index; FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity; MEP, maximal expiratory mouth pressure; MIP, maximal inspiratory mouth pressure; MMEF, maximal mid-expiratory flow; PEF, peak expiratory flow.

Data presents the mean ± standard deviation (min-max).

P value was statistical analyzed with independent paired t-test between sex (male and female group).

rule of thumb for interpreting the size of correlation coefficient as very low (0.00-0.30), low (0.31-0.50), moderate (0.51-0.70), high (0.71-0.90), and very high (0.91-1.00).²⁶ Then, linearity and heteroscedasticity were analyzed with a P-P Plot of standardized residual regression, and autocorrelation was determined using the Durbin-Watson Statistic Test.²⁷ The multicollinearity of variables that affected to the predicted equation was analyzed from the variation inflation factor (VIF) and Tolerance values. Finally, summary of a possible model for equating MIP or MEP were computed with all independent factors as pulmonary function (FVC, FEV1, FEV1/FVC, MMEF, and PEF) data, age, sex (male=1 and female=0), weight, height, BMI, and waist circumference of all participants by the stepwise regression method.^{28,29} All data were analyzed using the statistical package for social sciences software (SPSS) version.10.0 (SPSS Inc, Chicago, IL, USA) for Windows.

Results

The data of all 217 healthy participants (91 males and 126 females) were analyzed. As calculated, 91 male participants was recruited, and 9 were excluded from the analysis due to inability to perform MIP and MEP during collected and 26 female participants were added for data analyzed due to volunteered. Data of all participants showed mean ± SD (min-max) of characteristics, and pulmonary function that fell within the inclusion criteria (Table 1). The results showed significant difference between groups in the most variables, except for age, FVC (%), FEV1/FVC (%), MMEF (%), and PEF (%).

The correlation coefficient (*r*) for results of the Pearson correlation analysis in all 217 participants are presented in Table 2. The results of MIP correlation showed various significant positive sizes: very low correlation with BMI, FVC (%), FEV1 (%),

Table 2. Correlation coefficient (*r*) between MIP and MEP with the demographics, anthropometrics, and pulmonary function of 217 participants.

PARAMETERS	MIP (CMH ₂ O)	MEP (CMH ₂ O)
Demographics and anthropometrics		
Age (years)	0.044	0.121
Weight (kg)	0.436*	0.381*
Height (m.)	0.354*	0.278*
BMI (kg.m ⁻²)	0.260*	0.246*
Waist circumference (inches)	0.342*	0.298*
Pulmonary function		
FVC (L)	0.493*	0.390*
FVC (%)	0.192*	0.149*
FEV1 (L)	0.433*	0.332*
FEV1 (%)	0.297*	0.203*
FEV1/FVC	-0.104	-0.128
FEV1/FVC (%)	-0.046	-0.095
MMEF (L/s)	0.245*	0.151*
MMEF (%)	0.020	-0.048
PEF (L/s)	0.622*	0.564*
PEF (%)	0.425*	0.418*

Abbreviations: FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity; MEP, maximal expiratory mouth pressure; MIP, maximal inspiratory mouth pressure; MMEF, maximal mid-expiratory flow; PEF, peak expiratory flow. **P* < .05 from Pearson correlation test.

and MMEF (L/s); low correlation with weight, height, waist circumference, FVC (L), FEV1 (L), and PEF (%); and moderate correlation with PEF (L/s). The MEP correlation coefficient results also showed various significant positive sizes: very low correlation with height, BMI, waist circumference, FVC (%), FEV1 (%), and MMEF (L/s); low correlation with weight, FVC (L), FEV1 (L), and PEF (%); and moderate correlation with PEF (L/s).

The results of multiple linear regression model with stepwise regression analysis on MIP and MEP are shown in Tables 3 and 4. When the linearity of all independent and dependent variables (MIP and MEP) was proved, the graphs showed a straight line (Figure 1A and B). Results of the heteroscedasticity test by P-P Plot of regression standardized residual are presented in Figure 2A and B. The scatter plot shows random residuals in predicted values of both MIP and MEP dependent variables. There was no systematic pattern.

The model summary of predicting MIP in Table 3 shows 5 models with different independent variables. The equations for 5 models were as follows:

$$\text{Model 1 MIP(cmH}_2\text{O)} = 34.655 + 7.985 \times \text{PEF(L/s)}$$

$$\text{Model 2 MIP(cmH}_2\text{O)} = 122.997 + 8.575 \times \text{PEF(L/s)} \\ - 102.742 \times \text{FEV1/FVC ratio}$$

$$\text{Model 3 MIP(cmH}_2\text{O)} = 132.022 + 6.655 \times \text{PEF(L/s)} \\ - 102.472 \times \text{FEV1/FVC ratio} \\ + 11.285 \times \text{Sex(female} = 0, \text{male} = 1)$$

$$\text{Model 4 MIP(cmH}_2\text{O)} = 106.177 + 1.801 \times \text{PEF(L/s)} \\ - 100.885 \times \text{FEV1/FVC ratio} + 25.837 \\ \times \text{Sex(female} = 0, \text{male} = 1) + 0.556 \times \text{PEF}(\%)$$

$$\text{Model 5 MIP(cmH}_2\text{O)} = 103.988 - 97.700 \\ \times \text{FEV1/FVC ratio} + 31.292 \\ \times \text{Sex(female} = 0, \text{male} = 1) \\ + 0.662 \times \text{PEF}(\%)$$

The results of stepwise regression analysis on MEP are shown in Table 4. There were 4 models with different independent variables, as in the following equations:

$$\text{Model 1: MEP(cmH}_2\text{O)} = 43.559 + 7.861 \times \text{PEF(L/s)}$$

$$\text{Model 2: MEP(cmH}_2\text{O)} = 55.797 + 10.694 \times \text{PEF(L/s)} \\ - 8.431 \times \text{MMEF(L/s)}$$

$$\text{Model 3: MEP(cmH}_2\text{O)} = 72.989 + 8.44 \times \text{PEF(L/s)} \\ - 10.496 \times \text{MMEF(L/s)} \\ + 17.303 \times \text{Sex (female} = 0, \text{male} = 1)$$

$$\text{Model 4: MEP(cmH}_2\text{O)} = 47.384 + 3.603 \times \text{PEF(L/s)} \\ - 9.514 \times \text{MMEF(L/s)} + 30.458 \\ \times \text{Sex (female} = 0, \text{male} = 1) \\ + 0.534 \times \text{PEF}(\%)$$

In the results of MIP and MEP analysis, the highest fitting model for predicting MIP value, when recruiting both sexes (female and male), was in Model 5, which related to FEV1/FVC ratio ($\beta = 0.223$, $P < .01$), sex ($\beta = 0.569$, $P < .01$), and PEF (%) ($\beta = 0.429$, $P < .01$); and the MEP value in Model 4 related to PEF (L/s) ($\beta = 0.258$, $P < .01$), MMEF (L/s) ($\beta = 0.368$, $P < .01$), Sex ($\beta = 0.510$, $P < .01$), and PEF (%) ($\beta = 0.319$, $P < .01$). In addition, the values of all tolerance were not less than 0.2 or 0.1 and VIF values were less than 10 as same as the Durbin Watson of MIP (1.838) and MEP (1.898),

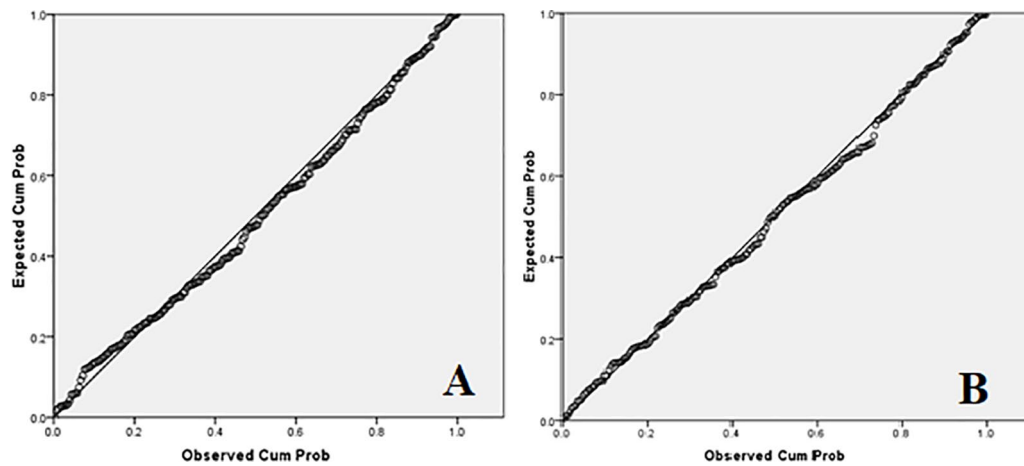


Figure 1. The linearity of MIP (A) and MEP (B) dependent variable between Observed Cum Prob and Expected Cum Prob of all 217 participants.

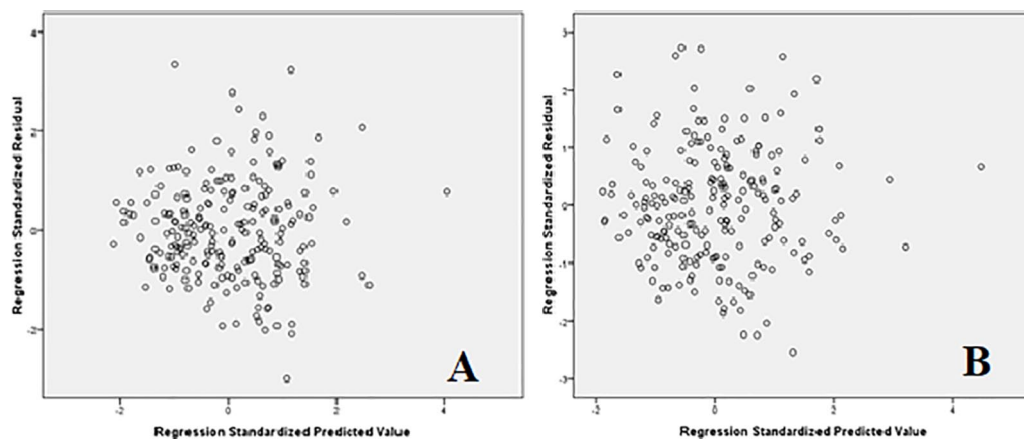


Figure 2. The scatter plot between regression standardized predicted value and regression standardized residual of MIP (A) and MEP (B) dependent variables of all 217 participants.

these showed independent correlation of individual variables in each equation. By comparing all models of MIP predicted, Model 5 was better than the others for fitting the data, with the higher value of R^2 and adjusted R^2 and significant result of all parameters. Whereas, of all models of MEP predicted, Model 4 was better than the others for fitting the data, with the higher value of R^2 and adjusted R^2 .

Discussion

This preliminary study evaluated the possible use of data from the routine PFT by spirometry to predict maximal respiratory mouth pressures; MIP or MEP, because the maximal respiratory muscle pressure meter is limited in general urban hospitals in Thailand, especially in Chiang Mai province. For PFT, MIP, and MEP presented correlation with some parameters of PFT, but they did not correlate with FEV1/FVC, FEV1/FVC (%), or MMEF (%). Results of PEF (L/s) and PEF (%) correlated with MIP, whereas PEF (L/s) correlated with MEP.

From the total of 217 participants, weight, height, BMI, and waist circumference correlated significantly with MIP and MEP. This result was similar to that in a previous review meta-analysis study, which found a significant correlation of MIP and MEP with age, weight, and height.³⁰ Moreover, a previous study showed that BMI correlated with MIP,¹⁷ that this is consistency with the results in this study. Furthermore, a study of 250 Indian adults aged 18 to 70 years showed that MIP and MEP had very low and low correlation, respectively, with age in males and height in females.¹⁶ Although characteristics such as age, weight, height, BMI, and waist circumference showed different results between gender groups, all of them correlated with MIP and MEP when calculated from the total participants. This indicated that these characteristics affect MIP and MEP values.

Studies on correlation between parameters from the PFT and MIP or MEP had been performed previously. There was report found that 99 male COPD patients showed low correlation of MIP and MEP with FEV1/FVC (%), which was the

Table 3. Model summary, coefficients and collinearity statistic results of MIP in all participants (n=217).

MODEL		UNSTANDARDIZED COEFFICIENTS		STANDARDIZED COEFFICIENTS			COLLINEARITY STATISTIC	
		B	STANDARD ERROR	BETA	T	SIG.	TOLERANCE	VIF
1	(Constant)	34.655	5.203		6.660	.000		
	PEF (L/s)	7.985	0.685	.622	11.650	.000	1.000	1.000
	<i>R</i> = .622, <i>R</i> ² = .387, Adjusted <i>R</i> ² = .384, SEE = 21.343							
	<i>F</i> = 135.718, Sig = .000							
2	(Constant)	122.997	20.249		6.074	.000		
	PEF (L/s)	8.575	0.670	.668	12.806	.000	0.962	1.040
	FEV1/FVC	-102.742	22.825	-.235	-4.501	.000	0.962	1.040
	<i>R</i> = .663, <i>R</i> ² = .440, Adjusted <i>R</i> ² = .435, SEE = 20.446							
<i>F</i> = 84.069, Sig = .000								
3	(Constant)	132.022	20.196		6.537	.000		
	PEF (L/s)	6.655	0.953	.518	6.986	.000	0.461	2.171
	FEV1/FVC	-102.472	22.471	-.234	-4.560	.000	0.962	1.040
	Sex	11.285	4.041	.205	2.792	.006	0.470	2.130
	<i>R</i> = .678, <i>R</i> ² = .460, Adjusted <i>R</i> ² = .452, SEE = 20.129							
<i>F</i> = 60.425, Sig = .000								
4	(Constant)	106.177	19.635		5.408	.000		
	PEF (L/s)	1.801	1.282	.140	1.405	.161	0.226	4.431
	FEV1/FVC	-100.885	21.166	-.231	-4.766	.000	0.961	1.040
	Sex	25.837	4.692	.470	5.506	.000	0.309	3.237
	PEF (%)	0.556	0.105	.361	5.304	.000	0.486	2.059
	<i>R</i> = .723, <i>R</i> ² = .523, Adjusted <i>R</i> ² = .514, SEE = 18.958							
<i>F</i> = 58.123, Sig = .000								
5	(Constant)	103.988	19.618		5.301	.000		
	FEV1/FVC	-97.700	21.093	-.223	-4.632	.000	0.973	1.028
	Sex	31.292	2.640	.569	11.852	.000	0.980	1.020
	PEF (%)	0.662	0.074	.429	8.989	.000	0.991	1.009
	<i>R</i> = .720, <i>R</i> ² = .519, Adjusted <i>R</i> ² = .512, SEE = 19.001							
<i>F</i> = 76.489, Sig = .000, Durbin Watson = 1.833								

Abbreviations: FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity; MIP, maximal inspiratory mouth pressure; PEF, peak expiratory flow; *R*, multiple correlation coefficient; *R*², multiple coefficients of determination; SEE, standard error of the estimate; VIF, variation inflation factor.

All models were analyzed using multiple linear regression and stepwise method.

F and Significant values were analyzed from ANOVA assay.

same as a moderate correlation with FEV1 (%) and FVC (%).¹⁷ However, the results in this study showed the significant correlation of FVC (L and %) with MIP and MEP, which was similar to a previous report suggesting that the male gender, younger age, obesity, higher FVC (L) and shorter height were associated strongly and independently with higher values of

MIP in relatively healthy adults.¹⁸ Interestingly, results of weak FEV1 (L and %) correlations with MIP and MEP were not identified previously. In addition, the results of PEF (L/s and %) in all 217 participants or each sex showed low positive correlation with MIP and MEP. These results also were not declared or shown before. This possibly implied that the FEV1

Table 4. Model summary, coefficients and collinearity statistic results of MEP in all participants (n=217).

MODEL		UNSTANDARDIZED COEFFICIENTS		STANDARDIZED COEFFICIENTS			COLLINEARITY STATISTIC	
		B	STANDARD ERROR	BETA	T	SIG.	TOLERANCE	VIF
1	(Constant)	43.559	5.963		7.305	.000		
	PEF (L/s)	7.861	0.786	.564	10.007	.000	1.000	1.000
	<i>R</i> = .564, <i>R</i> ² = .318, Adjusted <i>R</i> ² = .315, SEE = 24.460							
	<i>F</i> = 100.145, Sig = .000							
2	(Constant)	55.797	6.239		8.943	.000		
	PEF (L/s)	10.694	0.957	.767	11.179	.000	0.613	1.633
	MMEF (L/s)	-8.431	1.772	-.326	-4.758	.000	0.613	1.633
	<i>R</i> = .619, <i>R</i> ² = 0.383, Adjusted <i>R</i> ² = .377, SEE = 23.315							
<i>F</i> = 66.431, Sig = .000								
3	(Constant)	72.989	7.720		9.454	.000		
	PEF (L/s)	8.44	1.120	.606	7.538	.000	0.423	2.365
	MMEF (L/s)	-10.496	1.817	-.406	-5.777	.000	0.553	1.813
	Sex	17.303	4.800	.290	3.605	.000	0.423	2.365
	<i>R</i> = .647, <i>R</i> ² = .419, Adjusted <i>R</i> ² = .410, SEE = 22.687							
<i>F</i> = 51.102, Sig = .000								
4	(Constant)	47.384	9.420		5.030	.000		
	PEF (L/s)	3.603	1.539	.258	2.342	.020	0.206	4.844
	MMEF (L/s)	-9.514	1.758	-.368	-5.413	.000	0.543	1.842
	Sex	30.458	5.491	.510	5.547	.000	0.297	3.362
	PEF (%)	0.534	0.121	.319	4.400	.000	0.478	2.092
	<i>R</i> = .684, <i>R</i> ² = 0.467, Adjusted <i>R</i> ² = .457, SEE = 21.768							
<i>F</i> = 46.470, Sig = .000, Durbin Watson = 1.898								

Abbreviations: MEP, maximal expiratory mouth pressure; MMEF, maximal mid-expiratory flow; PEF, peak expiratory flow; *R*, multiple correlation coefficient; *R*², multiple coefficients of determination; SEE, standard error of the estimate; VIF, variation inflation factor.

All models were analyzed using multiple linear regression and stepwise method.

F and Significant values were analyzed from ANOVA assay.

and PEF maneuver was performed fast and forced, and possibly relates to MIP and MEP values. It was noticeable that the correlation value of PEF (L/s) and MIP or MEP showed higher correlation values and whether they indicated a better parameter for predicting the MIP or MEP value, which must be studied further and confirmed in a larger sample size.

The results of the multiple regression model analysis showed different model summaries in 217 participants. The results of standard error of estimate (SEE) in both MIP and MEP in all models showed approximately 20. This value presents the accuracy of predictions in the regression model and is a very important indicator of how precise an estimate of the independent variables is on dependent variables.^{29,31}

From the results in Figure 1 and 2 of P-P plots and scatter plots showed the linearity and heteroscedasticity which no

systematic pattern or higher powers of test than lower powers of curvature pattern.³² Therefore, the models that predict MIP and MEP can be run continuously without data transformation. Furthermore, the results of multicollinearity, a VIF value should be less than 5³³ that indicated no autocorrelation or controlled variables in any model of predicted MIP or MEP. Results of the MIP and MEP model in this study showed respective values of the Durbin-Watson test at 1.833 and 1.898 that was less than 2.0 in all of the participants. Thus, the results showed no autocorrelation.³⁴ In this study, all possible model equation summaries were presented, which showed multiple *R*², multiple *R* and adjusted *R*², including *F*-value and a significant data. A previous report showed that higher *R*² gives a good result on model fitting only if the model is fulfilled.³⁵ Previous study showed a moderately negative correlation of age

with MIP and MEP and anthropometric data of 500 male and female Indian people.¹⁶ Moreover, this study result was partially consistent with previous evidence in that age group. PEF (L/s) and weight (kg) could predict the MIP in 139 healthy males in the Baltimore Longitudinal Study of Aging (BLSA), and consistency was the same in the age, height, PEF (L/s), and weight (kg) in 128 BLSA females aged 20 to 90 years old.¹⁵ In addition, interesting result of a previous study in Brazil population (124 men and 229 women) that separated gender population and various BMI categories (normal to obesity groups) showed the predicted P_{Imax} and P_{E_{max}} equation models with added BMI and weight variables.³⁶ However, both variables did not statistically added into the MIP and MEP equation models in this study, this is possibly due to normal BMI and weight criteria, and small sample size. Therefore, it is very challenge to conduct more study in Thai population in the future. The reason for using the PEF (L/s) and MMEF (L/s) correlation with MIP and MEP is still unclear in predicting equations. There is no evidence to confirm whether high respiratory muscle forces affect PEF (L/s) or MMEF (L/s), but a previous study found that PEF (L/s) was reduced significantly, in the same way as the MIP and MEP after open cholecystectomy.³⁷ In addition, PEF (L/s) increased after inspiratory muscle training.³⁸ Therefore, this may support that respiratory muscle strength involves peak flow rate in both MIP and MEP.

Conclusion, Limitation, and Suggestions

Parameters such as FEV₁/FVC, sex and PEF can be included for MIP equation, and PEF, MMEF and sex can be included for MEP equation for all people aged between 19 and 50 years old. Although, this study performed in local Chiang Mai province, Thailand, and 217 healthy participants that is possibly the limitation to generalized application. Therefore, these equations in a healthy cohort in this study possibly cannot be applied to other ages, other races, or various diseases. Moreover, the application in participants who have co-confounding factors, such as other BMI or waist circumference, obstructive or restrictive lung and neuromuscular pathology, or non-successful communication may not possibly performed by using these equations, thus must be future studied.

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REFERENCES

- Meyer FJ, Borst MM, Zugck C, et al. Respiratory muscle dysfunction in congestive heart failure: clinical correlation and prognostic significant. *Circulation*. 2001;103:2153-2158.
- Wijkstra PJ, Van der Mark TW, Boezen M, Van Altna R, Postma DS, Koëter GH. Peak inspiratory mouth pressure in healthy subjects and in patients with COPD. *Chest*. 1995;107:652-656.
- Mehta S. Neuromuscular disease causing acute respiratory failure. *Respir Care*. 2006;51:1016-1021.
- Weber FM, Lop RR, Shiratori AP, Domenech SC, Júnior NG, da Silva Gevaerd M. Reduction of respiratory muscle strength in subjects with rheumatoid arthritis. *Acta Fisiatr*. 2014;21:183-188.
- Suesada MM, Carvalho HA, Albuquerque ALP, Salge JM, Stuart SR, Takagaki TY. Impact of thoracic radiotherapy on respiratory function and exercise capacity in patients with breast cancer. *J Bras Pneumol*. 2018;44:469-476.
- American Thoracic Society/European Respiratory Society. ATS/ERS. Statement on respiratory muscle testing. *Am J Respir Crit Care Med*. 2002;166:518-624.
- Alves WM, Alves TG, Ferreira RM, et al. Strength training improves the respiratory muscle strength and quality of life of elderly with Parkinson's disease. *J Sports Med Phys Fitness*. 2019;59:1756-1762.
- Reimberg MM, Castro RA, Selman JP, et al. Effects of a pulmonary rehabilitation program on physical capacity, peripheral muscle function and inflammatory markers in asthmatic children and adolescents: student protocol for a randomized controlled trial. *Trials*. 2015;16:346.
- Berlowitz DJ, Tamplin J. Respiratory muscle training for cervical spinal cord injury. *Cochrane Database Syst Rev*. 2013;23:CD008507.
- Evans JA, Whitelaw WA. The assessment of maximal respiratory mouth pressures in adults. *Respir Care*. 2009;54:1348-1359.
- Jalan NS, Daftari SS, Retharekaar SS, Rairikar SA, Shyam AM, Sancheti PK. Intra- and inter-rater reliability of maximum inspiratory pressure measured using a portable capsule-sensing pressure gauge device in healthy adults. *Can J Respir Ther*. 2015;51:39-42.
- Ohya T, Hagiwara M, Chino K, Suzuki Y. Maximal inspiratory mouth pressure in Japanese elite female athletes. *Respir Physiol Neurobiol*. 2017;238:55-58.
- Dimitriadis Z, Kapreli E, Konstantinidou I, Oldham J, Strimpakos N. Test/retest reliability of maximal mouth pressure measurements with the MiroRPM in healthy volunteers. *Respir Care*. 2011;56:766-782.
- Wilson SH, Cooke NT, Edwards RH, Spiro SG. Predicted normal values for maximal respiratory pressure in Caucasian adults and children. *Thorax*. 1984;39:535-538.
- Harik-Khan RI, Wise RA, Fozard JL. Determinants of maximal inspiratory pressure. *Am J Respir Crit Care Med*. 1998;158:1459-1464.
- Nambiar VK, Ravindra S. Maximal respiratory pressures and their correlations in normal Indian adult population: a cross-sectional study. *Int J Physiother Res*. 2015;3:1188-1196.
- Sachs MC, Enright PL, Hinckley Stukovsky KD, Jiang R, Barr RG. Multi-ethnic study of atherosclerosis lung study. Performance of maximum inspiratory pressure tests and maximum inspiratory pressure reference equations for 4 race/ethnic groups. *Respir Care*. 2009;54:1321-1328.
- Nambiar VK, Ravindra S, Kumar BS. Maximal inspiratory and expiratory pressures in men with chronic obstructive pulmonary disease: a cross-sectional study. *Indian J Respir Care*. 2018;7:88-92.
- Nuttall FQ. Body mass index. *Nutr Today*. 2015;50:117-128.
- Vogelmeier CF, Criner GJ, Martinez FJ, et al. Global strategy for the diagnosis, management, and prevention of chronic obstructive lung disease 2017 report. GOLD executive summary. *Am J Respir Crit Care Med*. 2017;195:557-582.
- Wilde M, Nair S, Madden B. Pulmonary function tests-a review. *Care Crit Ill*. 2007;23:173-177.
- Camhi SM, Bray GA, Bouchard C, et al. The relationship of waist circumference and BMI to visceral, subcutaneous, and total body fat: sex and race differences. *Obesity (Silver Spring)*. 2011;19:402-408.
- Dejsomritrutai W, Nana A, Maranetra KN, et al. Reference spirometric values for healthy lifetime nonsmokers in Thailand. *J Med Assoc Thai*. 2000;83:457-466.
- Culver BH, Graham BL, Coates AL, et al. Recommendations for a standardized pulmonary function report. An Official American Thoracic Society Technical Statement. *Am J Respir Crit Care Med*. 2017;196:1463-1472.
- Souza RB. Pressões respiratórias estáticas máximas. *J Pneumol*. 2002;28:S155-S165.
- Hung M, Bounsanga J, Voss MW. Interpretation of correlations in clinical research. *Postgrad Med*. 2017;129:902-906.
- Andy F. *Discovering Statistics Using SPSS: (And Sex, Drugs and Rock "n" Roll)*. SAGE; 2005.
- Ismail B, Manjula S. Estimation of linear regression model with correlated regressors in the presence of autocorrelation. *Inter J Stat Appl*. 2016;6:35-39.
- Ghani IMM, Ahmad S. Stepwise multiple regression method to forecast fish landing. *Procedia Soc Behav Sci*. 2010;8:549-554.
- Verma R, Chiang J, Qian H, Amin R. Maximal static respiratory and sniff pressures in healthy children. A systemic review and meta-analysis. *Ann Am Thorac Soc*. 2019;16:478-487.
- Mary L. Standard error; meaning and interpretation. *Biochem Med*. 2008;18:7-13.
- Mosteller F, Tukey JW. *Data Analysis and Regression: A Second Course in Statistics*. Addison-Wesley; 1977.

33. Daoud JI. Multicollinearity and regression analysis. *J Phys Conf Ser.* 2017;949:012009.
34. Smith DP. Durbin-Watson statistics for model life tables. *Asian Pac Cens Forum.* 1983;9:7-9.
35. Cameron AC, Windmeijer FAG. An R-squared measure of goodness of fit for some common nonlinear regression models. *J Econom.* 1997;77:329-342.
36. Sanchez FF, Araujo da Silva CD, de Souza Pereira Gama Maciel MC, Rebouças Demóstenes Marques J, Brosina de Leon E, Lins Gonçalves R. Predictive equations for respiratory muscle strength by anthropometric variables. *Clin Respir J.* 2018;12:2292-2299.
37. Miranda AS, Novaes RD, Ferreira AE, Neves MP, Corrêa CL, Mendonça VA. Assessment of respiratory muscle strength, peak expiratory flow and pain after open cholecystectomy. *Acta Gastroenterol Latinoam.* 2009;39:38-46.
38. Lima EV, Lima WL, Nobre A, Santos AM, Brito LM, Costa MD. Inspiratory muscle training and respiratory exercise with asthma. *J Bras Pneumol.* 2008;34:552-558.