RESEARCH ARTICLE

Prediction for the maximum inspiratory pressure value from the thoracic expansion measurement in Indonesian healthy young adults

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Background: The diaphragm is the primary muscle responsible for breathing. Weakness in the diaphragm will result in breathing difficulties. The micro-RPM (respiratory pressure meter) is a non-invasive testing device to measure respiratory muscle strength, which is not always feasible, while thoracic expansion measurements are easy to do.

Aim: This study constructs a prediction formula for a maximal inspiratory pressure (MIP) value from thoracic expansion measurements.

Methods: This study was quantitative with a cross-sectional design. Participants were healthy adults aged 20–40 years, with normal Mini-Mental State Examinations, body mass index, spirometry, and moderate activity levels. The tests performed were MIP and thoracic expansion measurements at three levels: axilla (L1), the fourth intercostal space (L2), and at processus xiphoideus (L3). The data were analyzed using an unpaired *t*-test and multivariate.

Results: The mean MIP for males (81.51 ± 13.90 cmH_2O) was significantly greater than females (63.17 ± 15.89 cmH_2O) ($P = 0.0001$). These findings were not different with the Chinese, Indian, Mangalorean, and Malaysian populations because they are all of Asian ethnicity. Thoracic expansion L2 ($r = 0.463$, $P = 0.0001$) and L3 ($r = 0.502$, $P = 0.0001$) were moderately correlated with MIP, whereas thoracic expansion L2, L3 combined with gender had a weak effect on MIP. The prediction formula was: MIP = 56.802 + 2.387 + L2 + 13.904 + Gender * and MIP = 53.289+ 3.561 + L3 + 9.504 + Gender *, * 0 = female; 1 = male.

Conclusions: A prediction formula for MIP can be made using the thoracic expansion variable with gender as a determinant factor. A quick and easy measurement of thoracic expansion can be used as a mean of screening respiratory muscle strength in patient care.

Key Words: *diaphragm; maximal respiratory pressures; muscle strength; reference values; respiratory muscles*

INTRODUCTION

The diaphragm is the main respiratory muscle, responsible for 60%–70% of the inspiratory process [1]. Contraction of the diaphragm increases chest cavity volume, which can be observed by the increase in chest circumference [2]. Respiratory muscle weakness in systemic diseases is difficult to detect as there are no specific signs and symptoms; however, it can be found in neuromuscular, pulmonary, and several other diseases [3]. For instance, a study by Vander [4] in the United States found low female maximal inspiratory pressure (MIP) values of 54.8 ± 2.15 cmH_2O and male MIP values of 97.5 ± 27.2 cmH_2O for those with cardiovascular disease. In the United States, Sachs et al. [5] obtained low MIP values of 73 ± 26 cmH_2O for females and 97 ± 29 cmH_2O for males aged 45–84 years with atherosclerosis.

In Australia, Baumann's study [6] found that amyotrophic lateral sclerosis (ALS) subjects experienced respiratory muscle weakness with a MIP value of less than 70 cmH_2O. A study by Khalil et al. [7] in Cairo presented male subjects aged 56.8 ± 7.7 years old with chronic obstructive pulmonary disease (COPD) who experienced diaphragmatic muscle weakness with a MIP value of 43.6 ± 26.9 cmH_2O.

Respiratory muscle strength can be assessed volitionally or by the patient's active role. Volitional measurements can be made through trans-diaphragmatic pressure, i.e., measurement of the MIP using a micro-respiratory pressure meter (micro-RPM), spirometer, and chest circumference measurements [1, 2]. MIP is the maximum negative pressure in the upper airway, which can be generated through maximal inspiration from the functional residual capacity (FRC) or residual volume (RV). MIP measurements are fast, accurate, and non-invasive [1].

Direct measurement of diaphragmatic muscle strength using micro-RPM, an expensive device, is not always applicable because of limited availability. Meanwhile, measuring thoracic expansion to determine the strength of the respiratory muscles indirectly using a measuring tape is easy, inexpensive, and has a high-reliability value (intraclass correlation coefficients (ICC) = 0.81–0.91) [8].

This study aims to find a correlation between MIP values and thoracic expansion and then to construct a prediction formula. It is expected that there will be a correlation between the MIP and the thoracic expansion because of the mechanics of breathing or postural changes. If a correlation with MIP values is demonstrated, this quick and easy measurement of thoracic expansion can be used as a means of screening

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respiratory muscle strength in systemic diseases that do not directly involve the respiratory system [2].

METHODS

Participants were patients from Hasan Sadikin Hospital Bandung, selected and randomized based on the inclusion criteria were healthy males and females, aged 20–40 years, Mini-Mental State Examination 27-30, body mass index (BMI) between 18.5 kg/m^2 and 23 kg/m^2 with moderate activity levels on the Global Physical Activity Questionnaire. Exclusion criteria were the presence of thoracic, spinal, or upper limb deformities; limited range of motion in the upper extremities; active smokers; pregnancy; have had operative procedures of the lungs or heart or chest cavity in the last eight weeks; have had heart attacks such as acute myocardial infarction and angina pectoris within eight hours; and spirometer results of Forced Vital Capacity (FVC) <80% and Forced Expiratory Volume 1 second (FEV1) <80%.

This study already has ethical approval (Number LB.02.01/X. 6.5/240/2019) from the Dr. Hasan Sadikin Hospital Bandung health research ethics committee. Participants were given the study procedure and asked to sign an informed consent form. The study began with primary data collection (modified SF-36), physical examination, spirometry, thoracic expansion, and MIP measurements.

Spirometry was used to examine lung function. The participant was asked to sit upright and seal their mouth tightly around the mouthpiece, with a nose clamp on to ensure no air leakage. While on the mouthpiece, participant was asked to take two normal breaths followed by a deep, maximal inhalation on their third breath, with an immediate strong, forceful exhalation at maximal force until reaching residual capacity. The participants were given a 1-minute rest period in between measurements, which were repeated three times, with the highest score being recorded.

We used micro-RPM, equipped with a mouthpiece, to measure the MIP accuracy. The participant was asked to exhale normally, put the mouthpiece inside their mouth, close their lips tightly around the mouthpiece, take a deep inspiration, and hold their breath for at least 2 seconds. The participant was given a 1-minute rest period in between measurements, which were repeated three times. The highest score was taken.

The measurement of thoracic expansion was carried out with the participant standing in standard anatomical position, with their arms abducted and palms positioned behind the head. Chest expansion had three levels of measurement: axilla (L1), the fourth intercostal space (L2), and at processus xiphoideus (L3). The participant was asked to exhale completely, followed with a full inspiration and complete expiration. The measurement was conducted three times at each level, and the highest score was taken. Thorax expansion is a calculation of a participant's inspiration diameter subtracted from their expiration diameter.

This study was an analytic, quantitative, and observational study with a cross-sectional design. The data were processed using the SPSS version 24.0 for Windows. The correlation between MIP and thoracic expansion measurements was processed using the Pearson correlation test. Correlation analysis was continued with multiple linear regression analysis. The coefficient of determination is sought to see a linear relationship with the independent variable, while other variables explain the rest.

RESULTS

Characteristics of the subjects

Seventy-seven people participated in this study. The participants consisted of 35 males (45.5%) and 42 females (54.5%), with a mean age of 24.58 ± 4.33 years, height 162.21 ± 7.9 cm, body weight 55.03 ± 6.75 kg, MIP 71.51 ± 17.53 cmH2O, thoracic expansion L1 was 2.62 ± 0.67 cm, thoracic expansion L2 was 3.51 ± 1.3 cm, and thoracic expansion L3 was 3.90 ± 1.57 cm. Most participants were students who represented the healthy adult population.

Comparison of height, weight, and MIP between males and females

Table 1 shows the difference between males and females in height (168.57 ± 5.55 cm and 156.90 ± 5.18 cm, respectively) and body weight (60.20 ± 5.25 kg and 50.71 ± 4.44 kg, respectively) was statistically significant ($P < 0.01$). Similarly, the MIP between males and females (81.51 ± 13.90 cmH_2O and 63.17 ± 15.89 cmH_2O, respectively) showed a significant difference. From this result, we suggest that gender could influence the MIP result.

Relationship between MIP and thoracic expansion (L1, L2, and L3)

Table 2 shows the relationship between MIP and thoracic expansion for each level. This study found a moderate correlation between L2 (r = 0.463) and L3 (r = 0.502) to MIP which is statistically significant ($P < 0.01$). Meanwhile, L1 (r = 0.081) is not significantly correlated with MIP ($P > 0.01$), which may be caused by lesser expansion of the thoracic cage compared with the L2 and L3 at the lower part of the thoracic cage.

Construction of prediction formula based on gender, thoracic expansion L2, and L3 to MIP

Table 3 shows the simultaneous influence (coefficient of determination) of gender, thoracic expansion L2 to MIP was 0.290, whereas other effects of 0.710 were determined by variables that were not calculated in this study. Likewise, the simultaneous influence (coefficient of determination) of gender, thoracic expansion L3 to MIP was 0.313, whereas other effects of 0.687 were determined by variables not calculated in this study.

For the formula to predict MIP based on gender and thoracic expansion (L2 and L3) (Figure 1), this study used coefficients that were

TABLE 1

Comparison of height, weight, and maximum inspiratory pressure (MIP) between males and females

	Group		
Variable	Males, n = 35	Females, n = 42	P
Height (cm), Mean ± Std	168.57 ± 5.55	156.90 ± 5.18	0.0001**
Weight (kg), Mean ± Std	60.20 ± 5.25	50.71 ± 4.44	0.0001**
MIP (cmH_2O), Mean ± Std	81.51 ± 13.90	63.17 ± 15.89	0.0001**

** $P < 0.01$, which means significant or statistically significant.

TABLE 2

Relationship between maximum inspiratory pressure (MIP) and thoracic expansion (L1, L2, and L3)

Correlation MIP – thoracic expansion	r	P
L1	0.081	0.483
L2	0.463	0.0001**
L3	0.502	0.0001**

** $P < 0.01$, which means significant or statistically significant. r: correlation coefficient.

TABLE 3

The coefficient of determination between gender, thoracic expansion L2 and L3 related to maximum inspiratory pressure (MIP)

	Model summary[a]			
Model	r	r^2	Adjusted r^2	Std. error of the estimate
L2	0.539[b]	0.290	0.271	14.96272
L3	0.559[b]	0.313	0.294	14.72462

Note: r = coefficient of correlation; r^2 = coefficient of determination; Adjusted r^2 = the number of independent variables used for predicting the target variable.

[a]Dependent variable: MIP.

[b]Predictors: constant, gender, thoracic expansion.

FIGURE 1

Prediction formula between gender, thoracic expansion L2 (a), and thoracic expansion L3 (b) on maximum inspiratory pressure (MIP).

*0 = females; 1 = males.

a) MIP (L2) = 56.802+ 2.387 x thoracic expansion L2 (cm) + 13.904 x Gender*

b) MIP (L3) = 53.289+ 3.561 x thoracic expansion L3 (cm) + 9.504 x Gender*

TABLE 4

Formulas for the relation between gender, thoracic expansion L2 and L3 on maximum inspiratory pressure coefficients[a]

Model		Unstandardized coefficients		Standardized coefficients	
		B	Standard error	Beta	*P*
1	Constant	56.802	5.595		0.000
	Thoracic expansion (L2)	2.387	1.911	0.176	0.216
	Gender	13.904	4.938	0.398	0.006
2	Constant	53.289	5.423		0.000
	Thoracic expansion (L3)	3.561	1.775	0.318	0.049
	Gender	9.504	5.549	0.272	0.091

Note: *B*, unstandardized coefficients.

[a]Dependent variable: MIP.

calculated from the partial testing of gender and thoracic expansion (L2 and L3) to MIP (Table 4). This study found that gender and the thoracic expansion variable (L3) has a significant effect on MIP.

DISCUSSION

The mean height and weight of subjects in this study were in accordance with the average Indonesian population and similar to other Asian populations, such as Malaysia, the Philippines, and Thailand, but different from the European population [9–11]. Subjects involved in this study were healthy young adults expecting to show the highest MIP value, similar to findings in an Indian study that found high MIP values in adults aged 20–40 years [3].

Simões [12] noted that after 40 years of age, muscle strength and lung function decline, resulting in decreased ventilation as well as other intrinsic and extrinsic changes. Intrinsically, there is a change in the number and composition of the connective tissue components of the lung parenchyma, such as elastin, collagen, and proteoglycans, which affects vital capacity, RV, and FRC. Extrinsically, the chest wall becomes more inflexible due to the stiffness of connective tissue between the ribs and vertebrae, causing a decrease in thoracic expansion [12]. Simões [12] stated that the MIP value tends to be low in individuals with light activity levels. In this study, subjects with a moderate activity level were recruited as it is the most common level found in the general public. Therefore, it is expected that it will support the correlation between MIP and thoracic expansion in healthy adults.

Relationship between MIP, thoracic expansion, and gender

The MIP value for males (81.51 ± 13.90 cmH_2O) in this study did not differ much from the Chinese population (88.7 ± 32.5 cmH_2O, with a mean age of 40.8 ± 13.4 years, height 167.0 ± 7.0 cm and body weight 64.1 ± 9.8 kg), the Indian population (83.7 ± 30.0 cmH_2O, with a mean age of 39.1 ± 11.5 years, height 166.3 ± 6.4 cm and body weight 67.2 ± 11.6 kg), and the population of Malaysia (74.0 ± 22.7 cmH_2O, with a mean age of 37.3 ± 11.5 years, height 163.9 ± 6.3 cm and body weight 64.3 ± 11.3 kg). It did not differ much from the Mangalorean population (76.03 ± 18.05 cmH_2O), whose subjects tended to be the same age (with a mean age of 20–29 years, height 167.82 kg, and body weight of 63.28 kg) [3, 9].

The MIP values of females (63.17 ± 15.89 cmH_2O) in this study also did not differ much from the Chinese population (53.6 ± 20.3 cmH_2O, with a mean age of 38.9 ± 11.8 years, height 156.6 ± 5.5 cm, and body weight 53.6 ± 9.2 kg), the Malaysian population (50.7 ± 18.3 cmH_2O, with a mean age of 33.4 ± 9.6 years, height 154.8 ± 5.0 cm, and body weight of 57.8 ± 14.0 kg), and the Indian population (50.0 ± 15.2 cmH_2O, with a mean age of 35.1 ± 11.8 years, height 155.2 ± 6.5 cm, and body weight 55.7 ± 11.2 kg). The MIP value of Indonesian females was higher than the MIP value in the Mangalorean population (46.89 ± 16.45 cmH_2O, height 156.31 cm, and body weight 51.96 kg) whose subjects were approximate of the same age with this study [3, 9].

The MIP value of this study differs significantly from Caucasians (MIP of males is 125 cmH_2O and females is 90 cmH_2O) [13]. These differences in MIP value are caused by differences in height and weight of Caucasian males and females [3, 9]. The spirometry test is used to measure lung function, while the test results will be influenced by gender, age, and size. Similarly, respiratory muscle strength is also influenced by gender, age, and BMI [14]. This study recruited subjects with normal BMIs to measure optimized diaphragmatic function. According to their height and weight, muscle quality in individuals with normal BMI is better than in those with abnormal BMI [15]. The diaphragm movement and thoracic expansion are limited in an obese individual due to the accumulation of fat layers in the chest and abdominal cavities [16]. Underweight or low BMI was associated with poorer pulmonary function indicators such as FEV1, predicted FEV1 (percent), FVC, predicted FVC (percent), and peak expiratory flow (PEF). There are several reasons why being underweight is linked to poor pulmonary function. One of the possible causes is low muscle mass in underweight people. Several studies have linked a low pulmonary function to lower skeletal muscle mass. In an underweight population, diaphragmatic muscle mass has been found to be reduced. The reduction of intercostal and abdominal muscle mass could theoretically impact respiratory muscle strength and force [17].

MIP values for males were significantly higher than for females ($P < 0.01$), indicating that the diaphragm muscle strength of males was greater than females. This could be due to the average female diaphragm length being approximately 9% shorter than males, and the diaphragm length in the zone of apposition in females being smaller than in males. Lo-Mauro and Aliverti [18] found differences in the diaphragm length in males and females when measuring the total lung capacity, FRC, and RV. Smaller lung size and relatively narrow airways in the respiratory system of females, compared with males of the same age and height, also influenced muscle strength [19].

The MIP value in this study did not correlate with the thoracic expansion L1 ($r = 0.081$, $P > 0.01$), but was moderately correlated with thoracic expansion L2 and L3 ($r = 0.463$, $P < 0.01$ and $r = 0.502$, $P < 0.01$). Measurement of thoracic expansion was also carried out with arms abducted and the hands behind the head to fully elevate the shoulder girdle, pulling the rib cage upwards. It may explain the slight thoracic expansion at the L1 level, which does not correlate with the MIP value. Meanwhile, we found a positive correlation between the MIP value and the thoracic expansion at the L2 and L3 levels. The stronger the contraction of the diaphragm, the greater the thoracic expansion at the L2 and L3 levels. The L2 and L3 levels are relatively closer to diaphragm contraction. L2 level is located at the level of the fourth intercostal space, which is closer to the costal area of the diaphragm muscle. L3, located at the xiphoid process level, is adjacent to the diaphragm's sternal attachment location. Contraction of the diaphragm muscle will lift the lower ribs and expand the mediolateral diameter of the chest cavity, resulting in increased thoracic expansion [13]. During deep inspiration, contraction of the diaphragm is assisted by the external intercostal muscles and several other auxiliary muscles, including the latissimus dorsi muscle, which was not discussed in this study [20].

Based on previous research, the existing predictive formula for MIP involves weight, height, gender, with age having weak to moderate effect values [12, 21]. A study by Johan [9] in Singapore found a moderate correlation between body weight and height on MIP in Chinese males ($r = 0.405$) and a weak correlation in Chinese females ($r = 0.263$), Indian male ($r = 0.339$), Indian female ($r = 0.191$), Malaysian male population ($r = 0.219$), and Malaysia female population ($r = 0.144$) [12]. Pessoa's research in Brazil found a weak effect value between gender, body weight, and age ($r = 0.34$) [21]. The coefficient of determination 0.4–0.6 is indicating moderate effect and clinical value [22].

This study looked for a correlation between thoracic expansion and MIP, then found that L2 and L3 were moderately correlated with MIP. Since gender also affects MIP, the formula for predicting MIP must include gender, L2, and L3. If gender and L2 or L3 thoracic expansion were simultaneously used to predict MIP, the calculated effects were 0.290 and 0.313, indicating a weak effect ($r < 0.4$). The posture during the thoracic measurements may affect this low correlation value. Other muscle involvements and the airway opening pressure are not discussed in this study [23].

CONCLUSIONS

A prediction formula for MIP value can be garnered from thoracic expansion measurements. Gender and thoracic expansion values at L2 or L3 simultaneously can be used to predict MIP values with weak effects. This study has shown that a prediction formula for MIP can be made using the thoracic expansion variable with gender as a determinant factor. It is necessary to carry out further research that considers other factors, such as a wide age range; the position of the upper extremities; posture; height, weight; and ethnicity when measuring the expansion of the thoracic cage; the role of other muscles; and the airway opening pressure to obtain a strong correlation value between thoracic expansion and MIP. The diaphragm is the main muscle role in breathing, but breathing requires much motion from many segments that are assisted by many muscles. We must consider the sternocleidomastoid, scalenes, subclavian, pectoralis minor, serratus anterior, and intercostals; upper trapezius, rhomboids, and erector spinae; rectus abdominis, transverse abdominis, oblique abdominis, and pelvic floor; and maybe a few other muscles. Altogether those factors can influence thoracic expansion.

DISCLOURES

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Authors' contributions
DMS conceptualized and designed the study. TN collected the data and collaborated with MAM in the analysis and interpretation of the data. TN, DMS, and MAM contributed to writing the paper. MAM translated into English. All authors read and approved the final manuscript.

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Declaration of interest
None.

Ethical approval and consent to participate
The research ethics committee from the Faculty of Medicine Universitas Padjadjaran had approved this study (Ethics Number LB.02.01/X.6.5/240/2019). Written informed consent was obtained from the subjects.

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