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Original Article

Assessment of Inspiratory Muscle Endurance in Healthy Adults by Recording Breathing Characteristics

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Abstract

OBJECTIVE: Respiratory muscle function is considered as strength and endurance. Since respiratory muscles are used a submaximally in daily life, measurement of respiratory muscle endurance rather than respiratory muscle strength is a more functional assessment. Measurement of respiratory muscle endurance is recommended to be performed by controlling the respiratory frequency and recording the breathing parameters. The purpose of this study was to evaluate respiratory muscle endurance with the incremental threshold loading (ITL) test in healthy adults by recording breathing parameters.

MATERIAL AND METHODS: This observational, cross-sectional study included 112 healthy adult subjects aged between 18 to 35 years. The anthropometric characteristics (weight and height), pulmonary function testing including forced expiratory volume (FEV1), forced vital capacity (FVC), and maximal voluntary ventilation (MVV), maximum inspiratory pressure (MIP), and physical activity level (International Physical Activity Questionnaire-Short Form - IPAQ-SF) were evaluated. Inspiratory muscle endurance is assessed with ITL.

RESULTS: The inspiratory muscle endurance (*P*Imax) was 54.08±21.62 cmH_2O. Correlations between the *P*Imax showed weak positive results with height (r=0.392, $P < 0.001$), weight (r=0.382, $P < 0.001$), and FEV1 (r=0.386, $P < 0.001$), moderate positive results with FVC (r=0.446, $P < 0.001$) and MVV (%) (r=0.541, $P < 0.001$), while strong positive results with MIP (r=0.796, $P < 0.001$). According to the regression analysis results, the MIP and MVV% values explained 63% of *P*Imax.

CONCLUSION: Inspiratory muscle endurance in healthy adults can be explained with MIP and MVV. The ITL testing that is performed by recording respiratory mechanics, such as the inspiratory volume, inspiratory flow and work of breathing, can guide the determination of respiratory muscle training intensity.

KEYWORDS: Muscle endurance test, respiratory muscles, respiratory mechanics, inspiratory volume, inspiratory flow, inspiratory pressure

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INTRODUCTION

A comprehensive respiratory system assessment includes information on history, symptoms if present, physical examination, respiratory function, and respiratory muscle performance. The respiratory muscle performance, which is assessed as strength (maximum power generation capacity) and endurance (ability to continue a given task for a long time), should be part of a detailed and complete evaluation process. Measuring the strength of the respiratory muscles alone does not provide sufficient information regarding respiratory muscle function. The functional importance of respiratory muscle strength is controversial because maximal pressure is not reached often during the day. Moreover, in pathological conditions, respiratory muscles usually begin to weaken before clinical symptoms appear. Assessing the respiratory muscle strength alone may mask this weakness.[1,2] Even if the inspiratory muscles are of sufficient strength, a loss of endurance may have started in stages where such pathological conditions do not progress much. In other

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words, the measurement of respiratory muscle endurance also provides predictive information regarding respiratory function. Comprehensive assessment of respiratory muscle performance is essential before starting respiratory muscle training on time. For these reasons, the endurance of the respiratory muscles (especially the inspiratory muscles) also needs to be evaluated. However, the effect of the respiratory pattern on the outcome measurements, and the fact that a standardized measurement method has not been developed yet, prevent the routine measurement of inspiratory muscle endurance in the clinic.[3-6]

There are several methods of assessing respiratory muscle endurance (Figure 1). The incremental threshold loading (ITL) test is one of the most frequently used to determine inspiratory muscle endurance.[4] This measures a person's ability to sustain increased inspiratory load at regular intervals.[7,8] Gradually increasing the test, which starts with a low load, allows participants to develop strategies to tolerate high loads. However, as high loads increase, decreased inspiratory volume and inspiratory time make maintaining ventilation throughout the step difficult. This situation, which causes the participants to terminate the test early with a feeling of suffocation, can be prevented by measuring devices that provide conic flow resistive loading.[9-11]

The European Respiratory Society recommends evaluating the control of respiratory frequency and the recording of breathing parameters during the ITL test.[10] Conic flow resistive loading devices allow these recordings separately for each breath.[12] To the best of our knowledge, there has been no study generating prediction models with this recommendation in young adults. Therefore, the aim of the study is to evaluate respiratory muscle endurance with the ITL test in healthy adults by recording breathing parameters.

MATERIAL AND METHODS

For this cross-sectional observational study, healthy adults were recruited from June 2020 to July 2022. Since the study data were collected during the Coronavirus disease-2019 (COVID-19) pandemic period, triage was applied to each patient for COVID-19 before the test, considering the "Recommendations for Pulmonary Function Tests During and After the COVID 19 Pandemic" published according to the Expert Opinion Report of the Turkish Thoracic Society, to avoid any risk of transmission. According to the answers given to the screening questions in the triage form, the participants who were not considered at risk for the measurements were evaluated. After the measurements, the equipment and laboratory room were disinfected, and the room was ventilated. During the tests, a filtered mouthpiece was used to prevent bacterial and viral cross-contamination.[13] The study was approved by the Non-interventional Clinical Research Ethics Committee of Kütahya Health Sciences University (approval number: 2020/04-11, date: 25.02.2020). The study was conducted in accordance with the Declaration of Helsinki.

Participants

Participants between the ages of 18 and 35 years, who did not have any disease, did not regularly exercise, and did not smoke were included in the study. Adults with respiratory tract disease, heart disease, neuromuscular disease, scoliosis, previous thoracic surgery, and those who previously underwent a respiratory muscle endurance protocol were not included in the study.[14,15] Volunteer participants who met the inclusion criteria were randomly selected. Informed consent was obtained from all participants.

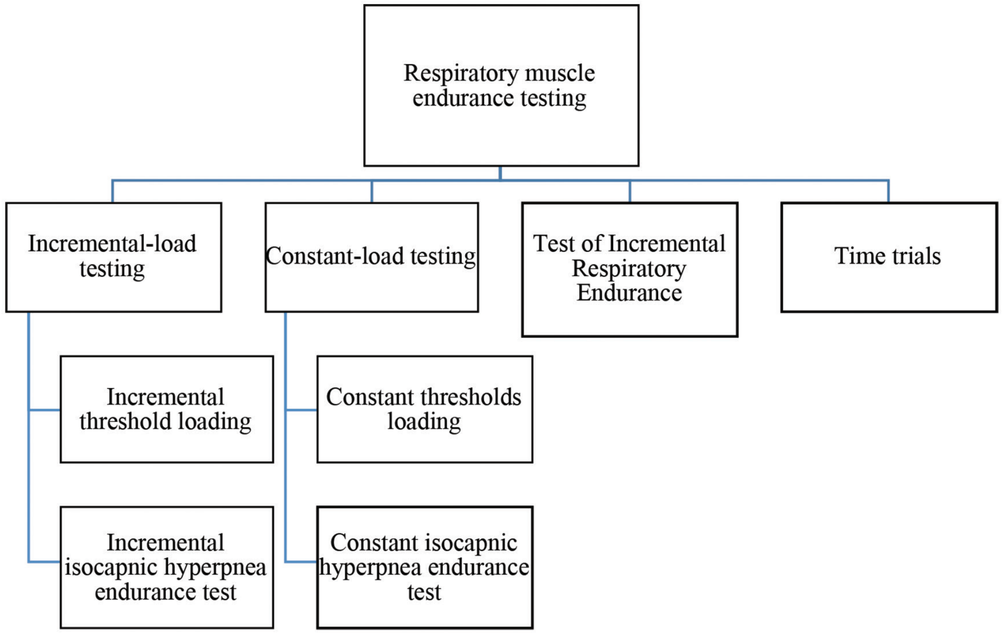

Figure 1. Respiratory muscle endurance assessment methods

Assessments

Firstly, anthropometric measurements of the participants were evaluated. Pulmonary function testing (PFT) measurements were then performed. After the inspiratory muscle strength measurement, participants took a rest break of 15 to 20 minutes. Then the inspiratory muscle endurance test was performed. Finally, the participants were asked to complete the International Physical Activity Questionnaire-Short Form (IPAQ-SF).

Experimental Design

The weight and height of the participants were evaluated. Weight was assessed using a digital scale in the orthostatic position, without shoes, with minimal clothing[16] (Tanita BC 730, Tokyo, Japan). Height was measured with the feet parallel and adjacent to each other, the arms extended by the body, and the head in a neutral position[17] (Seca 213, Hamburg, Germany).

PFT was performed using a spirometer (Cosmed Pony FX, Inc, Italy). Forced vital capacity (FVC), and forced expiratory volume (FEV1), were recorded.[18] For maximal voluntary ventilation (MVV) measurements, the participant was asked to breathe deeply and rapidly (90-110 breaths/min) for twelve seconds. The highest value from at least three technically acceptable maneuvers was expressed as the percentage of the predicted values in each test.[19]

IPAQ-SF was used to measure the physical activity level of the subjects. The physical activity score is calculated by converting the questionnaire score to the metabolic equivalent of task (MET) (MET min/week, 1 MET=3.5 mL/kg/min). Levels of moderate and intense physical activity, as well as the duration of walking and sitting, in the previous seven days were evaluated with the IPAQ-SF. The physical activity level was classified as ‘inactive’ for values lower than 600 MET-min/week, ‘minimally active’ for values of 600-3000 MET-min/week, and ‘active’ for values over 3000 MET-min/week.[20]

The inspiratory muscle strength was assessed with maximum inspiratory pressure (MIP), formed at the mouth (POWERbreathe KH2, POWERbreathe International Ltd., UK). The participants were asked to perform maximal inspiratory efforts; starting from the residual volume and sustaining it for at least one and a half seconds. The measurements were repeated nine times, at one-minute intervals, showing no more than a 10 cmH_2O or 10% difference between the results. The highest MIP value was used for inspiratory muscle endurance.[10,21]

The inspiratory muscle endurance was evaluated with the ITL test. In a preliminary study, the reproducibility of the test was evaluated with thirty of the participants. The test-retest reliability of the ITL was found to be excellent (intraclass correlation coefficient: 0.979; $P < 0.001$). There was no significant difference between the breathing parameters, rate of perceived exertion (RPE), or the duty cycle of the test and retest.[22] An eight-step test was started with 30% of the MIP, and the pressure was increased by 10% at one-minute intervals. Breathing frequency was fixed at fifteen breaths per minute by metronome. In the last ten seconds of each load level, the subjects were requested to RPE using the modified Borg Scale.[23] This scale is used to assess the severity of perceived fatigue, with a scoring range from 0 to 10. The individual indicates a value between 0-10 according to their perceived fatigue. It means “0: None” and “10: Most severe. The test was terminated when the participant was too tired to continue or was unable to open the valve three consecutive times. The outcome measure, called sustained maximal inspiratory pressure (*P*Imax), was defined as the highest load in percentage of MIP sustained for a full minute. The parameters of work of breathing (WOB), inspiratory volume, inspiratory pressure, and inspiratory flow rate were recorded for each step. In addition, the ratio of the inspiratory time to the total respiration time (duty cycle) was calculated for each breath.[10,24]

Statistical Analysis

Data analysis and calculations were performed using the IBM Statistical Package for the Social Sciences (SPSS) statistics 26.0 software package (IBM SPSS statistics for Windows, version 26.0; IBM, Armonk, New York). Data were expressed as frequency, percentages, and mean±standard deviation. The normality of the data was checked using the Shapiro-Wilk test. The Mann-Whitney U test was used to compare the continuous data of the paired groups determined by measurement. A comparison of the parameters in the first and last steps of the test was performed with the Wilcoxon paired-sample test. Correlations between the ITL and variables were evaluated using Spearman correlation analysis. In the correlation analysis, the correlation coefficient (ρ [rho]) 0.00-0.19 was considered as indicating no relationship or an insignificantly weak relationship; 0.20-0.39 as a weak relationship; 0.40-0.69 as a moderate relationship; 0.70-0.89 as a strong relationship; and 0.90-1.00 as a very strong relationship.[25] Multiple linear regression analysis was applied to determine the variables predicting the *P*Imax, and the stepwise method was preferred. A priori power analysis using G-power (a G-power 3.1.9 package program) demonstrated a minimum sample size of 109 with a medium effect size and power of 80% according to eight predictors. The level of significance was $P < 0.05$.

Main Points

- This paper provides objective data from the evaluation of inspiratory muscle endurance (IME) with the incremental threshold loading test recording breathing characteristics in healthy subjects.
- IME in healthy adults can be explained by maximal inspiratory pressure and maximal voluntary ventilation.
- Respiratory mechanics recorded during testing can be helpful in determining respiratory muscle exercise intensity.
- The pressure threshold at which work of breathing, inspiratory volume, and flow are high may help to increase the benefits of training.

RESULTS

One hundred sixteen healthy non-smoking adult subjects aged between 18 and 35 years participated in the study. Three of the participants declared their cold, flu, and cough complaints in the 'COVID-19 Screening Form before the Respiratory Function Test'. One participant was excluded from the study due to a lack of cooperation during the test. Data from 112 participants were analyzed.

The physical and demographic characteristics of the subjects are given in Table 1. According to the ITL test results, *P*Imax was 54.08±21.62 cmH_2O. The duty cycle was 0.52±0.06. The mean respiratory muscle endurance value was 60.64±14.97% of MIP. The RPE was 6.55±2.22 according to the modified Borg Scale. No subject completed all the steps of the test.

Table 1. Characteristics of the subjects

	n = 112 (mean±SD)
Age (years)	24.92±5.3
Gender (M/F)	56/56
Height (cm)	168.92±9.19
Weight (kg)	70.63±16.20
Body mass index (kg/m²)	24.60±4.56
Pulmonary function testing	
FEV1 (L)	3.56±0.76
(% predicted)	93.94±9.39
FVC (L)	4.17±0.90
(% predicted)	95.59±9.51
MVV (L/min)	111.86±29.26
(% predicted)	84.35±16.89
Respiratory muscle strength	
MIP (cmH_2O)	88.91±26.49
(% predicted)	108.02±17.89

M: male, F: female, FEV1: forced expiratory volume, FVC: forced vital capacity, MVV: maximal voluntary ventilation, MIP: maximal inspiratory pressure, SD: standard deviation

The weekly energy consumption of the participants was calculated in MET-min and classified into physically inactive, low physical activity level, and adequate physical activity level according to the IPAQ-SF. There was no significant difference in the values of respiratory muscle strength and endurance according to the physical activity levels of the participants ($P > 0.05$) (Table 2).

Breathing parameters, such as inspiratory volume, inspiratory pressure, inspiratory flow, and WOB, recorded during the ITL test are shown in Table 3. The mean of inspiratory volume, inspiratory flow and WOB reached during the test was 1.26±0.4, 0.73±0.34 and 58.05±33.4, respectively. The difference between the breathing parameters in the first step and in the last step was statistically significant. In the last step of the test, the inspiratory volume and inspiratory flow decreased, while the inspiratory pressure and WOB increased ($P < 0.05$). The highest inspiratory volume, inspiratory flow, and WOB reached during the test were 43.7%, 46.12%, and 48.67% of MIP, respectively.

The difference between the *P*Imax values, RPE levels, and breathing parameters of the female and male participants was statistically significant ($P < 0.05$). There was no significant difference between the physical activity levels of the women and men according to the IPAQ-SF results ($P = 0.22$) (Table 4).

Correlations of the inspiratory muscle endurance with descriptive variables are shown in Table 5. A stepwise model was used in multiple regression analysis to identify possible predictors of the respiratory muscle endurance value. Gender did not influence the model. MIP and MVV % values explained 63% of *P*Imax.

*P*Imax = -15.991 + 0.586*(MIP) + 0.213*MVV (%)

R^2=0.629.

A strong positive correlation was demonstrated (ρ = 0.80; $P < 0.001$) when correlating the values predicted by the proposed equation with the absolute values of the ITL (Figure 2).

Table 2. Inspiratory muscle performance according to physical activity level

Inspiratory muscle strength and endurance	Physical activity level				
	Inactive (n = 42) Mean±SD	Minimally active (n = 60) Mean±SD	Active (n = 10) Mean±SD	χ^2	*P*
MIP (cmH_2O)	82.21±3.82	92.58±3.56	95.06±7.38	4.700	0.095
*P*Imax (cmH_2O)	49.04±3.39	57.18±2.79	56.66±5.59	4.722	0.094
Perceived exertion (modified Borg Scale)	6.10±0.30	6.75±0.28	7.30±1.03	4.291	0.117
i/i+e	0.52±0.01	0.51±0.01	0.51±0.02	0.149	0.928

SD: standard deviation, χ^2: Kruskal-Wallis test chi-square value, *P*Imax: inspiratory muscle endurance value, MIP: maximal inspiratory pressure, i/i+e: inspiration time/inspiration and expiration time

Table 3. Breathing characteristics

	First step of test Mean±SD	Last step of test Mean±SD	z	*P*
Breathing parameters				
Inspiratory volume (L)	1.33±0.55	1.09±0.51	-4.839	**<0.001***
Inspiratory pressure (cmH_2O)	16.95±5.20	33.35±12.23	-9.103	**<0.001***
Inspiratory flow (L/s)	0.72±0.37	0.63±0.33	-3.004	**0.003***
WOB (Joules)	43.19±24.43	57.52±42.94	-3.883	**<0.001***

*$P < 0.05$, z: Wilcoxon paired two-sample test value, WOB: work of breathing, SD: standard deviation

Table 4. Respiratory muscle endurance value, test parameters and physical activity level according to gender

	Gender		z	*P*
	Female (n = 56) Mean±SD	Male (n = 56) Mean±SD		
Variables				
*P*Imax (cmH_2O)	45.31±2.42	62.85±2.86	-4.606	**<0.001***
RPE (modified Borg Scale)	7.29±0.28	5.82±0.28	-3.414	**<0.001***
i/i+e	0.51±0.01	0.52±0.01	-0.869	0.385
Inspiratory volume (L)	1.51±0.07	1.01±0.04	-5.418	**<0.001***
Inspiratory pressure (cmH_2O)	22.31±0.91	28.70±1.13	-3.945	**<0.001***
Inspiratory flow (L/s)	0.56±0.03	0.89±0.045	-5.562	**<0.001***
WOB (Joules)	36.34±2.72	73.75±4.48	-6.133	**<0.001***
IPAQ-SF (METs/min/week)	995.71±941.80	1274.16±1227.89	-1.237	0.216

z: Mann-Whitney U test value, *$P < 0.05$, *P*Imax: respiratory muscle endurance, i/i+e: duty cycle, WOB: work of breathing, IPAQ-SF: International Physical Activity Questionnaire Short Form, RPE: rate of perceived exertion

Table 5. The relationship between the ITL test and descriptive data

		Age (years)	Height (cm)	Weight (kg)	BMI (kg/m²)	FVC (L)	FEV1 (L)	MVV (L)	MIP (cmH_2O)
***P*Imax**	***P***	-0.024	0.392	0.382	0.247	0.446	0.386	0.541	0.796
	P	0.801	**<0.001***	**<0.001***	0.009	**<0.001***	**<0.001***	**<0.001***	**<0.001***

*$P < 0.05$, ρ: Spearman correlation analysis value (rho), *P*Imax: respiratory muscle endurance, MIP: maximal inspiratory pressure

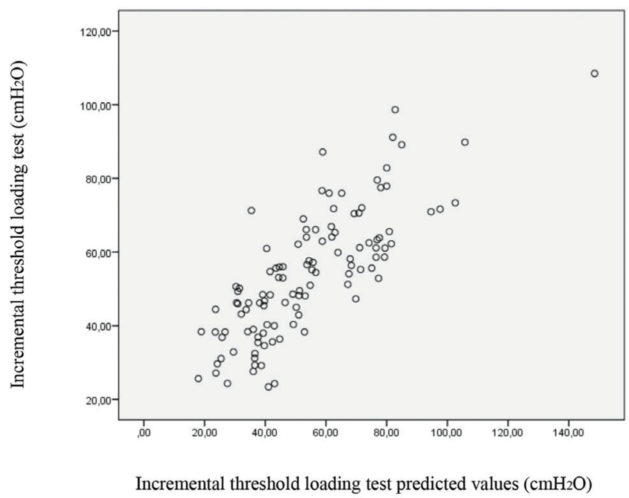

Figure 2. Correlations between the absolute values of ITL with the values predicted by the proposed equations

DISCUSSION

This study presents the multiple linear regression model for the ITL, examining the relationship between the main independent variables and inspiratory muscle endurance prediction. As a result of regression analysis, MIP and MVV values were the variables that best explained *P*Imax. In fact, one of the factors reflecting respiratory muscle performance is inspiratory muscle strength and the other is inspiratory muscle endurance. Therefore, it is possible to predict this relationship. The MVV is used for the evaluation of respiratory muscle endurance in both athletes and patients where the airway is affected.[26,27] The MVV is not recommended as a respiratory muscle endurance assessment method because the test period is not long enough to evaluate endurance. In addition, since it is affected by the airways, it does not provide precise information whether the test result reflects only the endurance of the respiratory muscles. Therefore, it is recommended not to use the MVV as a respiratory muscle endurance assessment method.[10] In line with the results obtained in the current study, it was concluded that the MVV is related to the respiratory muscles and should be evaluated with alternative methods.

The independent variables differ in studies that create a regression model for respiratory muscle endurance in the literature. Woszezenki et al.[14] in their study with healthy children aged 4-18 years, 66% of the *P*Imax value was explained in the regression model with the MIP and age variables for the ITL. Neder et al.[28] included one hundred healthy participants aged 20-80 years in their study. Age and anthropometric measurements explained 56% of the MVV. Fiz et al.[29] found a significant relationship between the *P*Imax value and FEV1, MIP, age and height in their study with ninety-nine healthy individuals aged 20-70 years. Variation in independent factors associated with respiratory muscle endurance between studies may be due to the population participating in the study, the age range of the subjects, sample size, and test type. While age and SFT were among the possible factors predicting respiratory muscle endurance value in studies with a wide age range, the MIP value was included in the regression formula in studies where the test procedure was determined using the MIP measurement.

It has been reported that for a well-controlled endurance test to contribute to a standardized evaluation program, it is not only sufficient to keep the respiratory frequency constant during the test but also to control the respiratory parameters. Several authors have reported that using a device that continuously records flow, volume, and pressure variables during measurement makes respiratory muscle endurance assessment more standardized.[9,10] A device that can record respiratory parameters was used in this study, whose validity and reliability studies were performed working with the principle of conic flow resistive loading.[9,12] The flow, volume, pressure, and WOB parameters recorded for each breath of each step of the test were analyzed. The inspiratory volume was found to be higher in the first steps of the test. The inspiratory flow increased as the pressure increased, but reached its peak before the end of the test. It is one of the strategies used to increase the flow rate by reducing the inspiratory volume during the test, to meet the threshold pressure load and create greater power. In this case, considering the incremental nature of the test, increasing the inspiratory pressure causes the volume to decrease and the flow rate to increase at each step.[11,30] In the current study, the inspiratory volume did not decrease enough to cause an increase in the flow rate. The use of a conical flow resistance device and fixation of inspiration and expiration times may have contributed to this result. Devices working with the principle of conic flow resistive loading allow inspiratory flow after the pressure threshold is exceeded and therefore prevent the tidal volume from falling.[31] In the systematic review and meta-analysis of Beaumont et al.[32] it was reported that optimal settings should be adjusted in respiratory muscle training to have a positive effect on dyspnea. The studies included in this meta-analysis use a classical inspiratory muscle training device. The advantage of devices working with the principle of conic flow resistive loading over classical muscle training devices is that they allow inspiratory flow after the pressure threshold is exceeded, and thereby increase tidal volume and vital capacity.[12] For this reason, determining the appropriate exercise intensity by considering the volume and flow values together with the inspiratory pressure may enhance the effect of respiratory muscle training and reduce dyspnea. The ITL performed with a device that measures respiratory parameters can be used to determine the appropriate training intensity.

In this study, the mean value of the WOB was greater than the values in both the first and the last steps. It has been suggested that the WOB value may be the most important determinant of respiratory muscle endurance, independent of the breathing pattern. The peak WOB reached during the test may be an indicator of the dynamic capacity of the respiratory muscles. It has been reported in the literature that the WOB during ITL reaches its peak in the first steps and decreases rapidly before reaching the last step of the test. This indicates that the ability to generate inspiratory flow and inspiratory volume is also high during the high WOB stage.[10] The current study shows that, in parallel with the literature, the respiratory workload reached its peak value before reaching the last step of the test. At the same time, the peak steps of the volume, flow, and WOB were close and were in the range of 40-50% of the MIP. This value corresponded to the second and third steps of the test. In the literature, the intensity of respiratory muscle training varies between 30-80% of the MIP. After an individual evaluation, choosing the level with a high WOB, and inspiratory volume and flow as the training intensity can help increase the benefits of training.

In the present study, both inspiratory muscle strength and endurance of male participants were significantly higher than those of female participants. The perceived exertion level of women at the end of the test was also significantly higher than that of men. The difference in respiratory muscle performance may be due to the lower muscle mass of women compared to men.[33] Although there was a difference between the respiratory muscle strength of men and women, no difference was found in respiratory muscle endurance. The authors stated that this situation was due to insufficient sample size, high variability of outcome measurements and unknown factors.[29,34,35] In this study, the number of groups was equal, the sample size was sufficient to show sex differences, the respiratory frequency was fixed during the measurement, and the standardization provided by controlling the respiratory parameters made the test more sensitive in showing the change between the groups. With the combination of these factors, the current study, unlike other studies in the literature, showed the change in respiratory muscle strength and endurance according to gender.

This study has some limitations. The age range of the participants included in the study is limited. Conducting the study in a wider age range may explain the age-related changes in respiratory muscle endurance. In the present study, a self-report scale is used to measure the level of physical activity. None of the participants included in the study had regular physical activity habits. However, according to the scale results, 8.92% of the participants seem to have sufficient physical activity levels. Evaluating the physical activity level using a more objective method, such as accelerometers and pedometers rather than self-reported activity, will contribute to a more accurate interpretation of the results. There is also a need for studies evaluating the response of the ITL to respiratory muscle training with a device operating based on the principle of conical flow resistive loading.

CONCLUSION

Respiratory muscle function is evaluated as strength (maximum power generation capacity) and endurance (ability to continue a given task for a long time). Respiratory muscle strength provides information about respiratory muscle function. However, evaluation of respiratory muscle strength and endurance is more effective in determining respiratory muscle dysfunction. As a result of the regression analysis, the analysis showed that the variables that best explained the *P*Imax value were the values of MIP and MVV (%). MIP and MVV could account for 63% of the *P*Imax value. Anthropometric values, gender, FEV1, and FVC values were other independent variables that were related to the ITL but were not included in the regression formula. Respiratory workload and inspiratory flow parameters peaked during the test and decreased before reaching the last step of the test. Considering that the effect of standard respiratory muscle training in increasing ventilation has not been demonstrated, evaluating these parameters may enhance respiratory muscle training. In a measurement where respiratory muscle endurance is evaluated by ITL, the pressure where the inspiratory volume, inspiratory flow, and WOB (considered an indicator of the dynamic capacity of the respiratory muscles) are high can guide the determination of the intensity of respiratory muscle training.

Ethics

Ethics Committee Approval: The study was approved by the Non-interventional Clinical Research Ethics Committee of Kütahya Health Sciences University (approval number: 2020/04-11, date: 25.02.2020).

Informed Consent: Informed consent was obtained from all participants.

*The study has clinical trial registration (ClinicalTrials.gov identifier: NCT05237427).

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Footnotes

Authorship Contributions

Surgical and Medical Practices: S.O-G., Concept: S.O-G., Ö.A., Design: S.O-G., Data Collection or Processing: S.O-G., Analysis or Interpretation: S.O-G., Ö.A., Literature Search: S.O-G., Ö.A., Writing: S.O-G.

Conflict of Interest: No conflict of interest was declared by the authors.

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REFERENCES

1. Larribaut J, Gruet M, McNarry MA, Mackintosh KA, Verges S. Methodology and reliability of respiratory muscle assessment. *Respir Physiol Neurobiol.* 2020;273:103321. **[Crossref]**
2. Troosters T, Gosselink R, Decramer M. Respiratory muscle assessment. *Eur Respir Monogr.* 2005;31-57. **[Crossref]**
3. Eastwood PR, Hillman DR, Morton AR, Finucane KE. The effects of learning on the ventilatory responses to inspiratory threshold loading. *Am J Respir Crit Care Med.* 1998;158(4):1190-1196. **[Crossref]**
4. Hill K, Jenkins SC, Philippe DL, Shepherd KL, Hillman DR, Eastwood PR. Comparison of incremental and constant load tests of inspiratory muscle endurance in COPD. *Eur Respir J.* 2007;30(3):479-486. **[Crossref]**
5. Basso-Vanelli RP, Di Lorenzo VAP, Ramalho M, et al. Reproducibility of inspiratory muscle endurance testing using PowerBreathe for COPD patients. *Physiother Res Int.* 2018;23(1). **[Crossref]**
6. Gokcen S, Inal-Ince D, Saglam M, et al. Sustainable inspiratory pressure and incremental threshold loading for respiratory muscle endurance in chronic obstructive pulmonary disease: a pilot study. *Clin Respir J.* 2021;15(1):19-25. **[Crossref]**
7. McElvaney G, Fairbarn MS, Wilcox PG, Pardy RL. Comparison of two minute incremental threshold loading and maximal loading as measures of respiratory muscle endurance. *Chest.* 1989;96(3):557-563. **[Crossref]**
8. Johnson PH, Cowley AJ, Kinnear WJ. Incremental threshold loading: a standard protocol and establishment of a reference range in naive normal subjects. *Eur Respir J.* 1997;10(12):2868-2871. **[Crossref]**
9. Langer D, Jacome C, Charususin N, et al. Measurement validity of an electronic inspiratory loading device during a loaded breathing task in patients with COPD. *Respir Med.* 2013;107(4):633-635. **[Crossref]**
10. Laveneziana P, Albuquerque A, Aliverti A, et al. ERS statement on respiratory muscle testing at rest and during exercise. *Eur Respir J.* 2019;53(6):1801214. **[Crossref]**
11. Martyn JB, Moreno RH, Paré PD, Pardy RL. Measurement of inspiratory muscle performance with incremental threshold loading. *Am Rev Respir Dis.* 1987;135(4):919-923. **[Crossref]**

12. Van Hollebeke M, Poddighe D, Gojevic T, et al. Measurement validity of an electronic training device to assess breathing characteristics during inspiratory muscle training in patients with weaning difficulties. *PloS One*. 2021;16(8):0255431. **[Crossref]**
13. Gemicioğlu B, Börekçi Ş, Dilektaşlı AG, et al. Turkish thoracic society experts consensus report: recommendations for pulmonary function tests during and after COVID 19 pandemic. *Turk Thorac J.* 2020;21(3):193. **[Crossref]**
14. Woszezenki CT, Heinzmann-Filho JP, Vendrusculo FM, Piva TC, Levices I, Donadio MV. Reference values for inspiratory muscle endurance in healthy children and adolescents. *PloS One*. 2017;12(1):0170696. **[Crossref]**
15. Silva AC, Neder JA, Chiurciu MV, et al. Effect of aerobic training on ventilatory muscle endurance of spinal cord injured men. *Spinal Cord.* 1998;36(4):240-245. **[Crossref]**
16. Roongjiraroj T, Siriwan C, Suwannahitatorn P. PSUN114 correlation of percent body fat from two-electrode bioelectric impedance analysis and dual-energy x-ray absorptiometry. *J Endocr Soc.* 2022;6(Suppl 1):A22. **[Crossref]**
17. Baharudin A, Ahmad MH, Naidu BM, et al. Reliability, technical error of measurement and validity of height measurement using portable stadiometer. *Pertanika J Sci Technol.* 2017;25(3):675-686. **[Crossref]**
18. Stanojevic S, Kaminsky DA, Miller MR, et al. ERS/ATS technical standard on interpretive strategies for routine lung function tests. *Eur Respir J.* 2022;60(1):2101499. **[Crossref]**
19. Miller K, Mayer OH. Pulmonary function testing in patients with neuromuscular disease. *Pediatr Pulmonol.* 2021;56(4):693-699. **[Crossref]**
20. Saglam M, Arikan H, Savci S, et al. International physical activity questionnaire: reliability and validity of the Turkish version. *Percept Mot Skills.* 2010;111(1): 278-284. **[Crossref]**
21. Black LF, Hyatt RE. Maximal respiratory pressures: normal values and relationship to age and sex. *Am Rev Respir Dis.* 1969;99(5):696-702. **[Crossref]**
22. Gokcen S, Aras O. Test-retest reliability of inspiratory muscle endurance testing in healthy adults. *Ann Clin Anal Med.* 2023;14(8):681-685. **[Crossref]**
23. Borg GA. Psychophysical basis of perceived exertion. *Med Sci Sports Exerc.* 1982;14:377-381. **[Crossref]**
24. American Thoracic Society. ATS/ERS Statement on respiratory muscle testing. *Am J Respir Crit Care Med.* 2002;166(4):518-624. **[Crossref]**
25. Cohen J. Statistical power analysis. *Curr Dir Psychol Sci.* 1992;1(3):98-101. **[Crossref]**
26. Andrello AC, Donaria L, Castro LA, et al. Maximum voluntary ventilation and its relationship with clinical outcomes in subjects with COPD. *Respir Care.* 2021;66(1):79-86. **[Crossref]**
27. Tiller NB. Pulmonary and respiratory muscle function in response to marathon and ultra-marathon running: a review. *Sports Med.* 2019;49(7):1031-1041. **[Crossref]**
28. Neder JA, Andreoni S, Lerario MC, Nery LE. Reference values for lung function tests: II. Maximal respiratory pressures and voluntary ventilation. *Braz J Med Biol Res.* 1999;32(6):719-727. **[Crossref]**
29. Fiz JA, Romero P, Gomez R, et al. Indices of respiratory muscle endurance in healthy subjects. *Respiration.* 1998;65(1):21-27. **[Crossref]**
30. Eastwood PR, Hillman DR, Finucane KE. Ventilatory responses to inspiratory threshold loading and role of muscle fatigue in task failure. *J Appl Physiol.* 1994;76(1):185-195. **[Crossref]**
31. Charususin N, Gosselink R, Decramer M, et al. Inspiratory muscle training protocol for patients with chronic obstructive pulmonary disease (IMTCO study): a multicentre randomised controlled trial. *BMJ Open.* 2013;3(8):003101. **[Crossref]**
32. Beaumont M, Forget P, Couturaud F, Reychler G. Effects of inspiratory muscle training in COPD patients: A systematic review and meta-analysis. *Clin Respir J.* 2018;12(7):2178-2188. **[Crossref]**
33. Bassett AJ, Ahlmen A, Rosendorf JM, Romeo AA, Erickson BJ, Bishop ME. The biology of sex and sport. *JBJS Reviews.* 2020;8(3):0140. **[Crossref]**
34. Chen HI, Kuo CS. Relationship between respiratory muscle function and age, sex, and other factors. *J Appl Physiol.* 1989;66(2):943-948. **[Crossref]**
35. Reiter M, Totzauer A, Werner I, Koessler W, Zwick H, Wanke T. Evaluation of inspiratory muscle function in a healthy Austrian population–practical aspects. *Respiration.* 2006;73(5)590-596. **[Crossref]**