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Assessment of Airway Resistance in Normal Trained and Fat Untrained Adolescent Boys Influenced by Exercise Experiences

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Background: Overweight and obese children are at increased risk of a wide range of health conditions including respiratory diseases. In addition, inactivity can decrease pulmonary function.
This study assessed the effect of obesity and inactivity on pulmonary function impairment in adolescents.

Materials and Methods: This study was conducted on 80 adolescents. Subjects were divided into two groups. Group I included 40 untrained (VO_2max= 29.30±4.20) fat adolescents (UO). Group II included 40 healthy trained (VO_2max= 58.11±2.23) normal weight adolescents (TN). Body mass index (BMI), body fat percentage and waist to hip ratio (WHR) were calculated and pulmonary function tests were carried out according to the standard protocols. Data were analyzed using student's "t" test and Pearson's correlation coefficient.

Results: UO had significantly lower pulmonary function values than the TN group. They also showed lower FEV1/FVC ratio when compared to TN group ($P<0.05$). In UO group, BMI, body fat percentage and WHR had a significant negative correlation with pulmonary function whereas in TN group only BMI had significant negative correlation with pulmonary function. A significant decrease in FEV1 was observed in the two groups, which led to a decrease in FEV1/FVC% after the exercise compared to before. Thus, exercise test induced airway resistance in both groups.

Conclusion: untrained obese adolescents have more respiratory symptoms than their normal weight trained peers, and these factors are recommended to be used as a predictor of pulmonary function in assessment of obese children in epidemiological studies. In addition, obesity and inactivity can surcharge pulmonary function abnormalities in adolescents.

Key words: Airway resistance, Pulmonary function, BMI, WHR, Fat percentage

INTRODUCTION

In recent years, obesity has become an increasingly important medical problem among adolescents and children (1). Globally, approximately 1.1 billion adults are over weight, out of which 312 million are clinically obese (2). The global epidemic of obesity is often called 'globosity'(3). Excessive accumulation of fat resulting in generalized body mass is defined as obesity (3, 4) and can compromise health (2, 3, 5). Thus, being overweight or obese increases the risk of many diseases and health conditions, such as respiratory problems (1). Thus, obesity has some effects on lung function and can reduce respiratory well-being, even in the absence of specific respiratory diseases, and may also exaggerate the effects of existing airway conditions (6).

The causes of childhood obesity are manifold and include lack of regular exercise (7), sedentary habits (2), over consumption of high calorie foods (8), genetics, and prenatal and early life factors (7).

BMI is the simplest and most widely used index of adiposity (1) predicting body fatness in different age, gender and racial groups. It has been demonstrated to predict disease and it has been proposed as an overall indicator of mortality as well (3, 5). BMI between 25 and 30 kg/m2 should be viewed as medically significant and worthy of therapeutic intervention especially in the presence of risk factors (8-10).

Association between BMI and pulmonary function has been previously examined (1, 8, 10- 12)and BMI has been reported to be negatively associated with values for dynamic lung volumes including forced vital capacity (FVC) and forced expiratory volume in first second (FEV1)(3, 12, 13), as well as increased respiratory symptoms, even in Individuals without airway obstruction (14). However, there have been very few studies investigating the relationship of BMI with pulmonary function (15).

Compared with non-obese individuals, bronchoconstriction in obese individuals causes greater hyperinflation, possibly as a consequence of increased expiratory flow limitation and greater airway closure. Both expiratory flow limitation and airway closure contribute to changes in respiratory system reactance (16). Data suggesting a positive association between asthma and obesity remain controversial (1, 17).

It has been suggested that air flow obstruction, as measured by the FEV1/FVC ratio, is usually associated with obesity (13). Indeed, the FEV1/FVC ratio may be increased in obese individuals if airway closure and gas trapping reduce the FVC. As a consequence of breathing at lower FRC, airway caliber is decreased throughout the tidal breathing cycle, resulting in an increase in airway resistance. It has been suggested that the increase in air flow resistance may not be due entirely to the reduced lung volume but the cause of this additional resistance remains unknown. Another study suggested that the mechanical effects of obesity on the lungs could alter airway smooth muscle (ASM) contractility and increase airway responsiveness, also, it has been suggested that tidal volumes (16) like expiratory reserve volume (ERV), ERV/inspiratory capacity and DLco/VA(6) may be reduced and affected in the obese subjects (5, 7, 14, 16).

Some other studies have reported inverse associations between lung function and measures of central adiposity such as the waist circumference (WC) and the waist-to-hip ratio (WHR)(18, 19). It clears that physical fitness is required not only by athletes for better performance but also by non□athletes for maintenance of physical and mental health and pulmonary function is the long-term predictor of overall survival rates in both genders, and could be used as a tool in general health assessment (20). Fatemi and Ghanbarzadeh found a significant correlation among the three independent variables of FEV1, FVC, FEV1/FVC and projected VO_2max values or fitness. They concluded that these parameters have a close interaction with higher VO_2max levels, and therefore, having a lower airway resistance seems beneficial (20). In other studies it was indicated that one submaximal incremental aerobic exercise session causes a significant change in FEV1, FVC, FEV1/FVC (21, 22). Thus, various studies were carried out showing the effect of severe and morbid obesity on pulmonary functions (23). In addition, a recent study, found that higher body mass index (BMI) and obesity act as potential behavioral factors related to decreased asthma control and quality of life though not to asthma severity (17, 24). Obesity usually results in a reduction in compliance of respiratory system like asthma (7) leading to a decrease in lung volumes resulting mostly in a restrictive type of ventilatory defect (3).

For children and adolescents in the clinical setting, BMI percentiles are recommended by the Centers for Disease Control and Prevention, with a BMI equal to or above the

95th percentile suggesting obesity (1). Most of the studies evaluating the relationship between obesity and respiratory function tests have been carried out in adults (1, 2, 9). However, a few studies reported in the literature have evaluated the relationship of obesity (1), body fat percentage (25), the pattern of fat distribution (9) and WHR (18) with respiratory function in trained and untrained adolescents. On the other hand, obesity in children and adolescents has become a growing worldwide epidemic. It has been reported that dynamic variables of pulmonary function are associated with VO_2max levels, and can limit aerobic capacity. Thus, VO_2max level is among the main factors affecting pulmonary function (26). Further research is required to understand the mechanisms connecting asthma and obesity. However, targeted approaches such as weight management and early prevention of obesity are clearly prudent because of their considerable benefits in children and adolescents (10).

Hence, the aim of this study was to investigate the effect of obesity on pulmonary function tests, to evaluate the relationship of independent variables namely BMI, WHR, FAT% and weight with dependent variables namely pulmonary function and airway resistance values in pediatric primary care practices in normal trained and fat untrained subjects, and to find a possible correlation between these quantities. This study also assessed airway resistance indexes after a single session of submaximal incremental aerobic exercise in normal trained and fat untrained adolescents and compared their airway resistance.

MATERIALS AND METHODS

Subject

This study was conducted on age matched young males in the age group of 16 to 20 years. Subjects according to the International Classification of BMI – WHO (27) were divided into 2 groups: each group included 40 normal trained subjects (BMI: 18.14±0.81), and 40 Overweight untrained subjects (BMI: 27.65±1.24). The subjects had no history of cardiovascular disease (CVD), diabetes, cancer, respiratory disease, smoking, surgery or skeletal abnormality likely to affect lung functions.

Subjects were recruited and examined from the student population of Ahvaz high schools and they were screened for general physical health. The subjects' diet history, drug intake and personal habits such as cigarette smoking were obtained through a questionnaire. The BMI was categorized according to the WHO (World Health Organization) recommendations (27). All subjects gave written informed consent to participate in the study. The study was conducted in the laboratory of physical education and sport science faculty located at Shahid Chamran Ahvaz University, Iran. The study was approved by the Institutional Ethics Committee of the university.

Anthropometric measurements

Subjects attended the laboratory on two separate occasions. The initial visit aimed at familiarizing the subjects with the testing equipment and experimental protocol. The second visit assessed resting measures and the anthropometric data. The anthropometric measurements included height, weight, waist and hip circumference. Subjects were measured in light clothing without footwear, to the nearest centimeter. Height and weight were both measured standing. Height was measured with a horizontal wall mounted scale to the last complete 0.1 cm and weight with a digital weighing scale to the last complete 0.1 kg. BMI (in kg/m2) was calculated for each subject [BMI was calculated from measured values of height and weight by the equation BMI=weight (kg)/height^2 (m2)]. Waist and hip circumferences were measured with an insertion tape; hip circumference at the point of maximum circumference over the buttocks and waist circumference at the midpoint between the iliac crest and the lower ribs measured at the sides (28, 29, 30).

Body fat percentage was measured by the bioelectric impedance method, using a body composition analysis (Olympia 3.3 Jawon Co., Korea). The height, weight and age of subjects were entered the instrument, subjects were asked to hold the instrument in both hands and after that, the digital reading of the body fat percentage was recorded (29).

Lung functions and Assessment of airway resistance

All phases of this study were executed in laboratory at 25-28 ˚C between 9 and 11 am. The volunteers were asked to refrain from consuming beverages like tea and coffee and other stimulants with light breakfast to avoid interference with respiratory parameters. Subjects were briefed and familiarized with the procedure. Pulmonary function variables were measured by digital spirometry (Digital Spirometry, JAEGER, USA). After instruction and practice attempts, three satisfactory efforts were recorded for each subject according to the norms given by the American Thoracic Society (31). The essential parameters obtained were tidal volume (VT), inspiratory and expiratory reserve volume (IRV, ERV), forced vital capacity (FVC), forced expiratory volume in 1st second in Liters (FEV1), maximum ventilatory volume (MVV) and peak expiratory flow (PEF).

To measure FVC, each subject blew into the device with maximum force after full inspiration; three readings were taken and the best one was recorded. Based on this maneuver, VT, IRV and ERV were recorded. For accurate assessment of PEF and FEV1, each subject performed a minimum of 3 forced expiratory maneuvers to provide estimates of peak expiratory flow (PEF) and FEV1. PEF is the greatest flow velocity that can be obtained during a forced expiration starting from fully inflated lungs. FEV1 is the volume of air expired in the first second of forced expiration and is influenced by lung volume and airflow obstruction. Tests were carried out in sitting position and with nose clips (31).

The MVV12 maneuvers were recorded using a spirometer (Digital Spirometry, JAEGER, USA), which also provided a predicted MVV (40 × FEV1) for each subject. The MVVPRED was used to provide a target value for each subject to ensure that the maneuver was performed efficiently and correctly. Thus, the main focus was placed on ensuring that the participants especially overweight adolescents were aware of the correct way to complete a 12-s MVV maneuver (MVV12). Participants were encouraged to mimic the type of breathing encountered during heavy exercise (32).

After measuring the baseline pulmonary function, subjects performed exercise testing. Subjects performed Treadmill exercise test (Exer), while breathing ambient air (25 to 28 ˚C) with a nose clip to ensure mouth breathing, and cardio monitoring. In order to achieve approximately 80% of the maximum predicted heart rate (220- age in years) after a one minute warm-up at a lower work rate, the patients performed a near maximal constant load exercise for 6 minutes on a treadmill. All subjects in two groups performed exercise test completely, and no one was excluded from the study.

Pulmonary function of participants was assessed after performing exercise test. Before and after exercise test, airway resistance was assessed in subjects. To compare airway resistances in two groups, FVC, FEV1 and FEV1/FVC indices were measured by spirometry (20, 22). Descriptive statistics (means and standard deviations), anthropometric measurements and pulmonary function tests were carried out (Results were expressed as mean ± SD.). Pearson's correlation coefficient was used to quantify the relationship between anthropometric measurements (BMI, WHR, %FAT and weight) and pulmonary function values (VT, ERV, IRV, FVC, FEV1, PEF, MVV and FEV1/FVC ratio). Airway resistance in trained and untrained groups was compared with independent sample comparison method. Paired sample t-test was applied to compare airway resistance pre-test than post-test. The statistical software – SPSS version 19.0 was used for data analysis.

RESULTS

Participant characteristics

The characteristics of the understudy samples are presented in Table 1. Both trained and untrained groups were in the age range of 16 to 20 years. On average, the untrained subjects had a greater BMI, fat% and WHR than trained subjects. The untrained had mean BMI higher than 27 (kg/m^2) and trained males had BMI between 17 to 19 (kg/m^2). On average, all the measured parameters (except for age and height) were significantly different between the two groups. Thus, no significant differences in age or height were found between the two groups, indicating that the samples were homogeneous in this respect. However, as expected, weight, BMI, VO_2max, fat%, and WHR were significantly different between trained and untrained groups (Table 1).

Table 1. Comparison of mean±SD baseline physical and pulmonary function values between trained and untrained boys.

	TRAINED	UNTRAINED	P-VALUE
AGE	18.12±1.27	18.4±1.80	P>0.05
HEIGHT	174.00±3.01	172.15±2.66	P>0.05
WEIGHT	56.7±4.10	75.42±6.40	0.01
BMI	18.14±0.81	28.65±1.24	0.01
FAT%	10.09±1.50	26.15±1.93	0.01
WHR	0.65±0.04	0.89±0.06	0.01
V_T(L)	1.35±0.14	0.49±0.05	0.01
ERV(L)	0.87±0.11	0.64±0.05	0.01
IRV(L)	0.90±0.09	0.72±0.06	0.01
FVC(L)	4.22±0.64	3.62±0.41	0.01
FEV1(L)	3.95±0.51	2.59±0.48	0.01
FEV1/FVC	93.22±2.08	83.48±3.13	0.01
MVV(L/min)	131.62±8.83	118.22±6.37	0.01
PEF(L/min)	511.12±51.21	438.71±40.52	0.01
VO_2max	58.11±2.23	29.30±4.20	0.01

WHR =waist to hip ratio; BMI = body mass index (kg/m^2).

There were statistically significant differences between trained and untrained males, in terms of FVC, FEV1, FEV1/FVC, V_T, ERV, IRV, MVV and PEF values (Table 1). Overall, the trained group had higher (better) pulmonary function values than the other group (P<0.05), however, the untrained groups as expected, had higher values in weight, WHR, FAT% and BMI when compared to trained group (P<0.05).

Correlations in trained group

Table 2 shows the correlation between BMI, FAT% and WHR in trained and untrained groups. In trained group, there was a statistically significant negative correlation between BMI and FAT% (18.14±0.81 vs. 10.09±1.50; r=-0.455**, P<0.01) and WHR (10.09±1.50 vs. 0.65±0.04. r=-0.352*, P<0.05). In contrast, there was a negative correlation between BMI and WHR, which was not statistically significant.

Also, Table 2 shows the correlation between BMI and pulmonary function in trained and untrained groups. There were statistically significant positive correlations between BMI and VT (18.14±0.81 vs. 1.35±0.14; r=0.635**, P<0.01), BMI and ERV (18.14±0.81 vs. 0.87±0.11; r=0.459**; P<0.01), BMI and IRV (18.14±0.81 vs. 0.90±0.09; r=0.325*, P<0.05), BMI and FVC (18.14±0.81 vs. 4.22±0.64; r=0.466**, P<0.01) and BMI and FEV1 (18.14±0.81 vs. 3.95±0.51; r=0.432**, P<0.01). In contrast, there were no significant correlations between BMI and MVV, BMI and PEF, or BMI and FEV1/ FVC ratio.

Table 2. Correlation of BMI, WHR, and FAT% with pulmonary function in trained and untrained groups

	BMI	%FAT	WHR	V_T(L)	ERV(L)	IRV(L)	MVV (L/min)	PEF (L/min)	FVC(L)	FEV1(L)	FEV1/FVC
BMI		-0.455**	-0.060	0.635**	0.459**	0.325*	0.195	0.080	0.466**	0.432**	-0.196
FAT%	0.755**		-0.352*	-0.242	-0.006	-0.158	-0.159	-0.016	-0.116	-0.081	-0.134
WHR	0.354*	0.493**		-0.068	-0.041	-0.203	-0.161	0.030	-0.069	-0.218	-0.291
V_T(L)	-0.332*	-0.355*	-0.296		0.298	-0.031	-0.065	-0.046	0.240	0.257	-0.056
ERV(L)	-0.258	-0.369*	-0.382*	0.314*		0.279	-0.036	0.322*	0.126	0.063	-0.075
IRV(L)	-0.435**	-0.471**	-0.517**	0.247	0.458**		0.194	0.202	0.518**	0.416**	-0.226
MVV(L/min)	-0.255	-0.369*	-0.041	0.172	0.195	0.188		0.353*	0.525**	0.640**	0.193
PEF(L/min)	-0.369*	-0.566**	-0.383*	0.251	0.600**	0.415**	0.168		0.296	0.106	-0.341*
FVC(L)	-0.687**	-0.630**	-0.328*	0.483**	0.410**	0.468**	0.437**	0.371*		0.887**	-0.343*
FEV1(L)	-0.392*	-0.355*	-0.283	0.148	0.392*	0.355*	0.297	0.258	0.412**		0.114
FEV1/FVC	-0.260	-0.249	-0.019	-0.283	0.065	-0.002	-0.022	-0.047	-0.378*	0.678**	

Untrained + overweight

Trained+ normal weight

*.Correlation is significant at the 0.05 level (2-tailed)

**.Correlation is significant at the 0.01 level (2-tailed)

In addition, Table 2 shows the correlation between FAT% and pulmonary function in trained subjects. There was no significant correlation between FAT% and pulmonary function. However, FAT% had a negative correlation with VT, ERV, IRV, MVV, PEF, FVC, FEV1, and FEV1/FVC; but, among pulmonary function indexes, VT had the strongest negative correlation with FAT%.

No significant correlation was found between WHR and pulmonary function. Except for PEF, other parameters of pulmonary function had negative correlations with WHR, but none of them were statistically significant.

Correlations in untrained group

Table 2 shows the correlation between BMI, FAT% and WHR in trained and untrained groups. In untrained subjects, there were statistically significant positive correlations between body fat percentage and WHR (26.15±1.93 vs. 0.89±0.06; r=0.493**; P<0.01), body fat percentage and BMI (26.15±1.93 vs. 28.65±1.24; r=0.755**; P<0.01) and also, BMI and WHR (28.65±1.24 vs. 438.71±40.52; r=0.354*; P<0.05).

Regarding the correlation between BMI and pulmonary function in untrained subjects, inverse correlations were obtained between BMI and VT (28.65±1.24 vs. 0.49±0.05; r=-0.332*; P<0.05), BMI and IRV (28.65±1.24 vs. 0.72±0.06; r= -0.435**; P<0.01), BMI and PEF (28.65±1.24 vs. 0.49±0.05; r=-0.369*; P<0.05), BMI and FVC (28.65±1.24 vs. 3.62±0.41; r=--0.687**;P<0.01) and between BMI and FVC (28.65±1.24 vs. 2.59±0.48; r=-0.392*; P<0.05). However, BMI had a negative correlation with MVV and ERV, which was not statistically significant. In addition, negative correlations were found between BMI and FEV1/FVC (r=-0.260; P>0.05).

In the untrained group, negative correlations were found between body fat percentage (26.15±1.93) and VT (r=-0.332*; P<0.05), ERV(r=-0.369*; P<0.05), IRV(r=-0.471**; P<0.01), MVV(r=-0.369*; P>0.05), PEF(r=-0.566**; P<0.01), FVC(r=-0.630**; P<0.01) and FEV1(r=-355*; P<0.01). However, a negative correlation was found between body fat percentage and FEV1/FVC ratio, which was not statistically significant.

In untrained subjects, an inverse significant correlation was found between WHR and ERV(r=-0.382*; P<0.05), IRV(r=-0.517**; P<0.01), PEF(r=-0.383*; P<0.05) and FVC(r=-0.328*; P<0.05). Other indices did not have significant correlations in this regard.

Airway resistance

Table 3 indicates the comparison between pre-test and post-test values of FVC, FEV1 and FEV1/FVC in trained and untrained groups. Absolute values of FEV1, FVC and FEV1/FVC decreased after the test in trained and untrained groups. No significant differences were observed in percent reductions in FEV1, FVC and FEV1/FVC indices between trained and untrained groups. These results showed that the decrease in FEV1/FVC was -15.67 and -16.25 in trained and untrained subjects, respectively. Thus, similar to pervious studies both groups experienced airway resistance in the present study.

Table 4 shows the correlation of airway resistance with pre- and post-exercise test in two groups. Significant correlations were found between BMI and FAT%, and WHR and FEV1/FVC ratio (r=-0.393*; r=-0.390*; r= -0.352* respectively) in untrained subjects but no significant correlations were found in this respect in the trained group.

Table 3. Comparison of mean ±SD and % reduction in airway resistance indexes in trained and untrained boys.

	Untrained			Trained		
	% reduction	Post	Pre	% reduction	Post	Pre
FVC(L)	-1.93	3.55±0.71	3.62±0.41	-1.65	4.15±1.01	4.22±0.64
FEV1(L)	-14.91	2.51±0.35*	2.95±0.48	-17.72	3.25±0.93*	3.95±0.51
FEV1/FVC	-16.25	69.70±1.97*	83.48±3.13	-15.67	78.31±0.68*	93.22±2.08

*Significant decrease post than pretest.
**Significant difference between trained and untrained in %reduce.

Table 4. The correlation between BMI, WHR, and FAT% with airway resistance in trained and untrained subjects.

	Untrained	Trained	Untrained	Trained	Untrained	Trained
	WHR		%FAT		BMI	
FVC(L) before exercise	-0.328*	-0.069	-0.630**	-0.116	-0.687**	0.466**
FVC(L) after exercise	-0.403**	-0.150	0.800**	-0.290	-0.730**	0.552**
FEV1(L) before exercise	-0.283	-0.218	-0.255	-0.081	-0.392*	0.432*
FEV1(L) after exercise	-0.362*	-0.250	-0.400**	-0.200	-0.501**	0.500**
FEV1/FVC before exercise	-0.019	-0.291	-0.249	-0.134	- 0.249	-0.196
FEV1/FVC after exercise	-0.352*	-0.299	-0.390*	-0.270	-0.393*	-0.250

*.Correlation is significant at the 0.05 level (2-tailed)
**.Correlation is significant at the 0.01 level (2-tailed)

DISCUSSION

The aim of this study was to assess the relationship between body fat percentage, waist to hip ratio and body mass index with pulmonary function parameters such as tidal volume (VT), maximum voluntary ventilation (MVV), forced vital capacity (FVC), forced expiratory volume at the 1s second (FEV1), peak expiratory flow rate (PEF), expiratory reserve volume (ERV), inspiratory reserve volume (IRV) and FEV1/FVC ratio. The present investigation was based on the hypothesis that increased BMI in overweight subjects will lead to a decrement in pulmonary functions, and inactivity will lead to a decrease in pulmonary function and airway resistance compared to normal weight trained adolescents.

Results of the present study demonstrated a significant association between body mass index and pulmonary function in trained group. On the contrary, these results were inverse in untrained overweight group. In other words, there was a negative correlation between BMI and pulmonary function in this group. In addition, a negative correlation was found between body fat percentage and pulmonary function in both groups; however, the difference only in the overweight group was statistically significant.

Likewise, in both groups, a negative correlation was found between waist to hip ratio and pulmonary function; however, similar body fat percentage, these consequences was significant in overweight group. This finding supports the correlation of fat percentage, waist to hip ratio and body mass index with increased airway resistance in untrained group but not in trained group (Table 4).

In our study, the obese inactive group showed lower values of FVC, FEV1 when compared with the trained non-obese group and the difference between the two was statistically significant ($P<0.05$). Low FVC, FEV1 indicated a restrictive pulmonary defect. This may be due to the mechanical limitation of chest expansion as accumulation of excess fat interferes with the movement of the chest wall and the descent of the diaphragm. This may reflect intrinsic changes within the lungs in presence of obesity. Lipid deposition, cellular hyperplasia, alveolar enlargement, and reductions in alveolar surface area relative to lung volume may also occur (33). As reported in a pervious study, obese subjects have higher respiratory muscle strength compared to normal-weight women, either by adaptation to obesity over the years or by respiratory muscle overload imposed to the diaphragm, or even by changes in muscle fiber type. A study with a greater focus on obesity reported reduced respiratory muscle strength and endurance, suggested by static maximal inspiratory pressure values of 60-70% of normal subjects, among three severely obese subjects with obesity-hypoventilation syndrome (34, 35).

Concerning BMI and pulmonary function, we found a negative correlation between BMI and FEV1/ FVC in both groups; but, it was not statistically significant. This finding was in agreement with the results of El-Baz et al, who showed low FEV1/FVC % that was not significantly correlated with increased BMI (36). Also, FVC and FEV1 decreased after exercise performance test in both groups and this decline was statistically significant ($p<0.05$). These results were due to a drop in FEV1 but no fall in FVC. Thus, exercise test leads to a reduction in FEV1/FVC in both groups. Therefore, one anticipated finding was that obese participants (BMI ≈ 28 kg/m^2) had significantly lower values of FVC and FEV1 as compared to normal subjects (BMI ≈ 18 kg/m^2). These findings are consistent with those of some investigators who have shown that lung volumes are significantly lower among subjects with higher BMI (3, 14). These findings further support the idea of different pulmonary function values among BMI categories (3). This finding is consistent with the results of Costa et al, who reported no significant difference in FVC, FEV1 and FEV1/ FVC between obese and non-obese females (37).

It has been reported that in obese subjects, airway abnormalities include a predominant increase in proximal airway resistance but only minimal distal obstruction (36). Thus, the most interesting finding was the negative significant correlation between BMI and FEV, and FVC in obese and non-obese groups, after the exercise test; but, the correlation between BMI and FEV1/FVC was only significant in obese group. This finding was unexpected and suggests that BMI can be used as a predictor of airway resistance for the assessment of obese adolescents in epidemiological studies. In the literature, it has been shown that pulmonary function is under the influence of muscularity and fat distribution rather than body weight (38). Therefore, in overweight and obese teenagers, appropriate aerobic exercise training can partly improve lung function by strengthening the muscles of respiration (15). However, in order to achieve the predicted values of lung function, a further increase in activity duration and decrease in BMI are necessary (39). In addition, it has been mentioned that one submaximal incremental aerobic session of exercise causes a significant decrease in FEV1 and FEV1/FVC, and may be the cause of exercise induced asthma (22). Also, it is obvious that exercise training affects pulmonary function, as well as VO_2max. Therefore, it can be concluded that these indices have close interactions, and subjects with higher VO_2max have a lower airway resistance (20). In fact, increased BMI was associated with increased FEV1 and FVC. However, decrements in the FEV1/FVC ratio were noted with increased BMI. Thus, an increase in BMI of 5 units was associated with a decrease in FEV1/FVC of over 1%(40). Thus, based on the correlations between individual pulmonary function indices (FEV1, FVC and FEV1/FVC) and maximal oxygen uptake (VO_2max), it seems possible that exercise training leads to a decline in airway resistance in untrained obese subjects by increased VO_2max (20,22).

Additionally, obese subjects may demonstrate inefficiency of respiratory muscles, particularly the diaphragm. An overstretched diaphragm would place this respiratory muscle at a mechanical disadvantage, leading to decreased inspiratory muscle strength and efficiency. Azad et al. demonstrated that physical inactivity and obesity can impair FVC and FEV1, while appropriate aerobic exercise training can partly improve FVC and FEV1 due to the respiratory muscle performance enhancement (39). Thus, the results of this study indicate that participation in regular prolonged physical activity and reaching a normal BMI are two important factors that yield sufficient improvements in FVC and FEV1 in overweight and sedentary patients.

In our study, the obese inactive group showed lower values of V_T , ERV and IRV when compared with the trained non-obese group and the difference was statistically significant ($p<0.05$). Also, we found a positive significant correlation between V_T, ERV and IRV with BMI($r=0.635$, $r=0.459$, $r= 0.325$) in trained non-obese group;

but on the contrary, we showed negative significant correlation (except in ERV) in obese inactive group. It is an established fact that ERV contributes to the values of FRC, VC and TLC (6). On the other hand, the main physiological effects of simple obesity include reduced respiratory system compliance, increased work and oxygen cost of breathing, and increased peripheral airway closure. In a cohort study on individuals without airway obstruction, Jones and Nzekwu (12) confirmed an inverse correlation between increased BMI and static lung volume components. In that study, it was established that relatively small increases in BMI had profound effects on functional residual capacity (FRC) and expiratory reserve volume (ERV) (5, 14). Thus, the present study showed that increase in BMI resulted in a decrease in VT, IRV, FVC, FEV1 and PEF in overweight untrained subjects but VT, IRV, PEF, FEV1 and FVC indices showed a significant decrease with increased BMI. Our findings are consistent with those of Saxena and colleagues who indicated dynamic pulmonary function values in males showed a negative correlation but this correlation was not statistically significant. They also concluded that increased BMI did not impair pulmonary function in obese males or females (2). The differences between our study results and those of Saxena and colleagues may be due to the difference in age (16-20 years old vs. 20-40 years old, respectively), BMI (18 vs. 24 kg/m^2 in non-obese and 28 vs. 33 kg/m^2 in obese patients) and weight (68 vs. 56 kg in non-obese and 75 vs. 98 kg in obese patients). The results of this study indicate that obese individuals present greater morbidity and may be more susceptible to alterations in respiratory function due to lower expiratory reserve (2). We showed that aerobic exercise usually increases the pulmonary volumes and TLC. Also, it has been reported that eight weeks of interval exercise makes a significant difference in the Expiratory Reserve Volume. The reason is the reverse relationship between EVR levels and the total body fat. Thus, the interval training especially the endurance interval training is efficient in both decreasing the total body fat and increasing the resistance of expiratory respiratory muscles. Consequently, this study suggests that obese subjects may improve their pulmonary volumes and respiratory muscle function by exercise training (41).

The present study found a negative significant correlation between PEF and BMI in obese untrained adolescents; but no such correlation was found in normal trained subjects. Strong negative correlations between BMI and PEF value in children were reported by Gundogdu and Eryilmaz. They indicated that PEF values were lower in obese children than in non-obese children. Also, they reported that the association of higher BMI with lower PEF may indicate that obesity is an important risk factor for reduced airflow or lung function in children. These findings emphasize on the importance of the prevention of obesity in children and adolescents in order to avoid possible future respiratory problems (1).

Our results showed no significant correlation between MVV and BMI in both groups. However MVV value was significantly lower in obese untrained subjects compared to trained adolescents. Our results were similar to those of El-Baz et al, (36) who examined the impact of obesity and body fat distribution on pulmonary function of Egyptian children. They detected a statistically significant difference between obese and normal children as the obese cases showed a lower mean level of MVV. Thus, we could conclude that respiratory muscle function was markedly impaired in obese patients. Fat excess, particularly visceral obesity, probably interferes with respiratory muscle activity. In addition, our results were similar to those of Fabris et al, and Sahebjami and Gartside (42,43) who found that FVC, FEV1, forced expiratory flow at 50% vital capacity and maximum inspiratory flow rate were significantly lower in obese subjects with low MVV compared to those with a normal MVV. They concluded that the standard PFTs allow recognition of a subgroup of obese subjects without overt obstructive airway disease who have more severe lung dysfunction, the marker of which is a low MVV. Peripheral airway abnormalities may be responsible for these observations. It has been repotted that, after weight loss, MVV showed a highly significant improvement, which also is related to respiratory muscle function. Thus, these findings further support the idea that exercise training can improve MVV by improving the respiratory muscle function in obese adolescents (39).

Overweight and obesity lead to serious health consequences and increase in body fat alters the body's response to insulin, potentially leading to insulin resistance, and also creates a proinflammatory state, leading to the risk of thrombosis (44). The present study demonstrated the relationship of pulmonary function with body fat percentage in two groups. V_T, ERV, FVC, FEV1, MVV and PEF had significant negative correlations with body fat percentage in untrained subjects. There was also a negative correlation between pulmonary function and body fat percentage in untrained group but was not statistically significant. The difference in FEV1/FVC ratio was not significant between the two groups; however, this correlation was negative.

As stated earlier, In males body fat % showed negative correlation with expiratory reserve volume (ERV), forced vital capacity (FVC), maximum ventilatory volume (MVV), peak expiratory flow rate (PEFR) and forced expiratory volume at the end of first second (FEV1)(9). The reduced values of pulmonary function were due to increase in percentage of body fat and central pattern of fat distribution may affect the pulmonary function (9).Joshi and colleagues demonstrated a negative correlation between body fat % and expiratory reserve volume (ERV), forced vital capacity (FVC), maximum ventilatory volume (MVV), peak expiratory flow rate (PEFR) and forced expiratory volume at the end of first second (FEV1) in males. It has been observed that in females body fat % had a negative correlation with ERV, FVC, and MVV. These results indicate that increase in percentage of body fat and central pattern of fat distribution may affect the pulmonary function tests (9).The amount of body fat and a central pattern of fat distribution might be related to lung function via several mechanisms, such as through direct effects on the rib cage or thoracic compliance. It is also possible that compression of the abdominal viscera by local fat redistributes blood to the thoracic compartment, thus reducing vital capacity or through mechanical effects on the diaphragm and on the chest wall (25, 29, 36). Also, other authors have reported that FVC and FEV1 increased after 8 weeks of aerobic training in adults and attributed this finding to the improved contractility of the expiratory muscles as a result of endurance training. The exact mechanism of the FVC improvement in this study is unknown, but respiratory muscles function, fat mass reduction and weight loss possibly play roles in this improvement. Repeated exercise may result in respiratory muscle hypertrophy, and it is obvious that respiratory indices are related partly to respiratory muscles power (6, 45). Thus, the study suggests that increase in body fat % and central fat distribution is associated with a decrease in the static and dynamic pulmonary function in untrained overweight individuals. Our findings indicate that decrease in pulmonary function has been due to the increased body fat % and inactivity in untrained overweight individuals. Therefore, obese children have more respiratory symptoms than their normal weight peers. They have significant restrictive pulmonary defects, evident small airways obstruction and a defect in respiratory musculature, week effort and coordination, with increased airway resistance. BMI was inversely correlated with most pulmonary function abnormalities (46). Therefore, BMI is recommended to be used as a predictor of pulmonary function in assessment of obese and normal weight children in epidemiological studies.

Most previous studies about the relationship of obesity and lung function have used BMI as an indicator of overall obesity. Little is known about the effect of WHR on lung function (29). Our results showed a significant inverse association between WHR and pulmonary function in untrained adolescents, whereas no such significant relationship was observed in trained subjects. The main finding of this study is that WHR is a more important determinant of pulmonary function in obese untrained subjects than in trained normal weight adolescents. This finding supports the hypothesis that difference in the pattern of fat distribution is one mechanism explaining the difference in lung function impairment due to weight gain (29).

We assessed the correlation between each variable and the pulmonary function and found that, WHR was inversely correlated with most pulmonary function abnormalities. There was a significant negative correlation between WHR and IRV, ERV, FVC and PEF. However, negative correlations were found between WHR and FEV1, VT, MVV, and FEV1/FVC, but were not statistically significant in obese trained adolescents. In other words, by increased WHR, the restrictive pattern of the pulmonary function increased. Also, WHR was negatively correlated with pulmonary function in trained adolescents; however; the correlation was not strong. Low FEV1/FVC ratio was not significantly correlated with increased WHR. We concluded that WHR as a measure of overall obesity was significantly correlated with ventilatory function. Similar observations were reported by Chen et al, (19) in normal-weight, overweight, and obese subjects. They found that waist circumference was negatively associated with forced vital capacity and forced expiratory volume in 1 s, and the associations were consistent across sex, age, and BMI categories. On average, a 1-cm increase in waist circumference was associated with a 13-mL reduction in forced vital capacity and 11-mL reduction in forced expiratory volume in 1 s. The association between WC and pulmonary function was consistent in normal weight, overweight, and obese subjects (19). Also, it has been demonstrated that in men WC has a highly significant negative association with FVC and FEV1. Saxena et al. stated that the abdominal obesity marker is an important and better predictor of pulmonary function than BMI and the investigators suggest its inclusion as a potential confounding factor when investigating the determinants of pulmonary function (2).

Our study found a consistent association between WHR and pulmonary function in normal weight and obese subjects. The significant negative association between WHR and pulmonary function was observed only in obese cases. Thus, the present study suggests that decrease in pulmonary function is the consequence of increased waist to hip ratio and inactivity in untrained overweight individuals.

Obesity may be associated with a reduction in vital capacity (VC) and forced expiratory volume in one second (FEV1). Mechanical and inflammatory factors may be the possible causes of reduced VC in obese subjects (46). Mechanical causes include decreased respiratory compliance and increased gas trapping due to premature small airway closure. It has also been demonstrated that FEV1/VC ratio is usually normal or increased in obese cases. The latter is thought to occur because of peripheral airway closure and the resultant gas trapping disproportionately reducing the VC .The implication is that while obesity may affect small airway function, it may not affect large airways. Thus, obesity may be associated with obstructive ventilatory abnormality, in addition to its well-known association with restrictive abnormality (35). Also, we found that body fat percentage, body mass index and waist to hip ratio have negative correlation with FEV1/FVC %, but this correlation was not significant. Our results after exercise test indicated this correlation to be significant only in untrained obese subjects (between BMI, body fat% and WHR with FEV1, FVC and FEV1/FVC). It seems that pulmonary function after exercise is influenced only in untrained obese subjects and not in normal weight trained adolescents. This may be attributable to breathing at low FRC which in turn results in a relatively decreased airway caliber throughout the tidal breathing cycle (6, 35). Also, obese subjects have high levels of ventilation-perfusion mismatch from atelectasis of under-ventilated dependent lung units, which continue to be well-perfused.

This results in an increased alveolar-arterial oxygen tension gradient [P(A-a)O2)] and reduced partial pressure of oxygen in arterial blood (PaO2). Thus, the association between BMI and functional residual capacity is more clearly understood. These findings further support the improvement in functional residual capacity that was observed to be correlated with the decrease in BMI. This finding is in agreement with the results of Guimaraes and colleagues who showed that after weight loss, the only correlation found was between reduced BMI and increased functional residual capacity. These results suggest a relationship between obesity and pulmonary restriction and the positive impact of bariatric surgery on PFT. Thus, there was a significant weight loss which led to a significant improvement in lung function and gas exchange (47).

BMI hampers lung function in normal individuals, and seems not to be related to airway hyperresponsiveness (AHR). Regular exercise should be encouraged in overweight and obese individuals, since it increases their bronchial permeability as shown in lower frequency of positive exercise tests. The same is advisable for lean individuals for different reasons. Their increased basal RV and Raw improve upon exercise. Despite overweight and obesity being related to a low-grade basal systemic inflammation, there was no association with a higher basal bronchial hyperresponsiveness in these individuals (30).

Hence, obese adolescents must be advised for regular exercise, because it increases their bronchial permeability besides lower positivity to exercise test. For instance, it has been reported that the intensity and duration of different exercises (e.g., baseball and jogging) may play a critical role in the association between BMI and asthma risk (10). Lean individuals should also be advised for regular exercise, because it decreases the values of basal RV and Raw and increases pulmonary function (21, 30). It has been reported that the asthma-oxidant stress association is confounded by gender and obesity especially F2-isoprostanes (One such indirect measure, and reportedly the most accurate in vivo, is the plasma concentration of F2-isoprostanes, which are products of lipid peroxidation (48).

CONCLUSION

The results showed that in untrained obese adolescents, fat% and BMI were significant negative predictors of pulmonary function whereas WHR was not. In contrast, only BMI was significantly associated with pulmonary function in trained adolescents. Also, the present study showed that the relationships among BMI, body fat percentage (BF %), and body fat distribution differ in trained and untrained populations, especially in adolescents with same age and height.

However, it has been indicated that BMI and BF% are poor indicators of health status among young adults (44). But, based on the results of the present study, in obese subjects BMI was closely correlated with BF% and WHR and its changes could reflect the variations of pulmonary function. Combination of BF% with BMI in this group might be necessary for assessment of pulmonary function. In normal weight trained subjects only BMI was a good predictor of pulmonary function and WHR and body fat % were not. In addition, obese subjects may have impaired lung function, but its mechanism is unclear. Obesity can affect the thorax, diaphragm, and abdominal muscles and due to increased respiratory effort and impairment of the gas transport system can result in altered respiratory function even if the lungs are normal. As well as having a direct effect on the mechanical behavior of the respiratory system by altering lung volume, airway caliber or respiratory muscle strength, obesity may also cause impairment of diaphragmatic activity-dependent respiratory function (1, 46). The same can be reflected by an increased oxygen consumption and increased production of carbon dioxide in obese persons both at rest and during exercise, compromising the cardiorespiratory system (2). Obesity has various effects on respiratory function in the form of alteration in the respiratory mechanics, decreased respiratory muscle strength, decrease in the pulmonary gas exchange, a lower control of breathing and a limitation in the pulmonary function tests (8). Consequently, not only main symptom of obesity such as BMI, body fat% and WHR have negative impacts on pulmonary function, but also inactivity in obese subjects could have negative effects on pulmonary function.

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