



Impact of Abdominal Obesity and Smoking on Respiratory Muscle Strength and Lung Function

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Background: Smoking and abdominal obesity are independent risk factors contributing to the global burden of diseases, which are major causes of morbidity and mortality. To date, it is unclear about the combined effects of obesity and smoking on respiratory muscle strength and lung function. The aim of this study was to examine the combined effects of abdominal obesity and smoking on respiratory muscle strength and lung function. **Methods:** Seventy-two men aged 20–40 years were classified into four groups: control, obesity, smoking, and obesity plus smoking groups. Respiratory muscle strength and lung function were assessed and compared between groups. **Results:** Obesity plus smoking group evidenced the lowest levels of both respiratory muscle strength and lung function, followed by the smoking group and obesity group, relative to the control group ($P < 0.01$). Moreover, obesity status was significantly negatively correlated with lung function ($r = -0.584$, $P = 0.001$ for obesity group and $r = -0.631$, $P = 0.001$ for obesity plus smoking group). Smoking status showed a negative correlation with lung function ($r = -0.397$, $P = 0.037$ for smoking group and $r = -0.706$, $P < 0.001$ for obesity plus smoking group). **Conclusions:** The combination of obesity and smoking showed greater deterioration in respiratory muscle strength and lung function relative to obesity or smoking alone, and this is, therefore, likely to increase the risk of respiratory-related chronic diseases. Thus, close monitoring of respiratory symptoms, primary prevention, and early management in individuals who are obese and smoking should be given priority concern.

Key words: Obesity, tobacco, lung function, respiratory muscle

INTRODUCTION

Smoking is known to contribute to the greater risk for a large variety of negative health outcomes, such as chronic obstructive pulmonary disease, lung cancer, and risk of mortality.¹⁻³ Substantial amounts of carcinogens that are in cigarette smoking have direct deleterious effects on lung function, exacerbating chronic respiratory diseases, causing malignant diseases, and increasing risk of respiratory symptoms.¹⁻⁴ National Statistical Office (2017) reported the prevalence rate of smoking to be 20% in the Thai population, with the highest prevalence in adults aged 20–44 years (22%).⁵ Moreover, men have a greater rate of smoking than women (41% and 25%, respectively), >1.8

million adults die a year from respiratory diseases caused by smoking.^{5,6}

Obesity – in particular, abdominal obesity – is a condition that contributes to reduced lung function and an increased risk of developing health conditions, such as respiratory diseases, heart disease, and metabolic syndrome.^{7,8} National Statistical Office (2018) reported that over 38% of Thai adults were obese, with the highest prevalence being among men aged between 20 and 59 years.⁹ Teerawattananon *et al.* reported that obesity-related illnesses, especially respiratory diseases, resulted in costs to Thailand's healthcare system of >300 million

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US Dollars annually.¹⁰ Abdominal obesity directly interferes with lung function by restricting diaphragmatic mobility, resulting in the less efficient ability of the inspiratory muscles to expand rib cage, which increased risk for airflow limitations, respiratory diseases, and other medical complications, as well as longer lengths of hospital stay following surgery.^{7,8,11,12}

Smoking and obesity range in the top 6 of risk factors contributing to the global burden of diseases, which are major causes of morbidity and mortality.^{13,14} Although smoking and obesity are independent health risk factors, they are also interconnected. Previous research has shown significant associations between smoking and abdominal obesity.^{13,15–17} As a result, male smokers evidenced greater waist circumference (WC) (>6.07 cm, $P = 0.041$), and are more likely to be centrally obesity (odds ratio, 1.30; 95% confidence interval [CI] 1.02–1.67) than nonsmokers.^{15,16} Carreras-Torres *et al.* (2018) found that an increase in the body mass index (BMI) every 4.6 kg/m² was more likely to increase the risk of being a smoker (odds ratio 1.24, 95% CI 1.15–1.33) and cigarettes smoked per day (odds ratio 1.14 cigarettes, 95% CI 0.48–1.80).¹³ Furthermore, previous studies have shown that combined effect of obesity and smoking significantly increase the risk of mortality (relative risk 1.5, 95% CI 0.7–3.7) and poorer cardio-metabolic profiles than lean nonsmokers.^{15,17}

Given all these considerations, it is unclear about the combined effects of obesity and smoking on respiratory muscle strength and lung function. Thus, the primary objective is to address this knowledge gap by examining the combined effects of abdominal obesity and smoking on respiratory muscle strength and lung function. We hypothesized that obesity plus smoking would have negative additive effects, such that the presence of one would make the effects between the other and health outcomes stronger.

METHODS

Study design

This study was a cross-sectional design. The study was approved by the Ethics Review Committee for Research Involving Human Research Participants, Health Science Group (ERCCU) (Approval No. 171/2017).

Study participants

Potential participants were recruited from a general population via announcements on boards in the university and social media. All participants provided written informed consent before data were collected. The study sample was comprised 72 participants, consisting of 18 participants in each group. Based on power analysis, this study had sufficient

statistical power (80%) to detect a moderate effect (Cohen's d effect size = 0.40–0.49) between-group differences in the criterion variables.

The inclusion criteria for the study participants included being a Thai male aged between 20 and 40 years. Their physical activity was at the sedentary level assessed using the Baecke habitual physical activity score.¹⁸ The participants were classified into one of four groups based on BMI and smoking status: (1) control group, (2) obesity group, (3) smoking group, and (4) obesity plus smoking group.

To be classified as being in the obesity group, participants needed to have a BMI ranging between 25 and 34.99 kg/m².¹⁹ Participant's waist-hip ratio (WHR) had to be >0.9 ,¹⁹ and their truncal skinfold thickness higher than 90 mm.²⁰ This group represented abdominal obesity.

To be meet the criteria for the smoking group, the participant needed to have continuously smoked for at least 1 year. The level of nicotine dependence was at the mild to moderate level as assessed using the Fagerstrom Test for Nicotine Dependence questionnaires (Thai version), with a score <5 .²¹

To be included in the obesity plus smoking group, the participants need to meet the criteria of being both obese and a smoker.

Research procedure

Baseline assessments

The subject's baseline assessments were composed of anthropometric measurements, body compositions, and truncal skinfold thickness.

Anthropometric measures

Height, weight, and WC and hip circumference (HC) measures were made using the World Health Organization guidelines, 2011.¹⁹ The WHR was calculated from WC and HC to classify the abdominal obesity.¹⁹

Body composition

Percentage of body fat, subcutaneous fat, and visceral fat rating was assessed using bioelectrical impedance (Karada scan: OMRON, Model HBF-375).

Truncal skinfold thickness

Truncal skinfold thickness was assessed at five sites in the standing position using a skinfold caliper (Moore and Wright, UK).²⁰ The sites were pectoral, mid-axillary, subscapular, supra-iliac, and abdomen. We used Surendar *et al.*'s method to create a composite score of skinfold thickness;²⁰ that is, the results of three trials of skinfold thickness measurements at each site were averaged, and then totaled to create a composite score.²⁰

Health outcomes

The health outcomes in this study were classified into respiratory muscle strength and lung function. The details of the outcomes were as follows.

Respiratory muscle strength

Respiratory muscle strength was measured by respiratory pressure meter (Micro RPM®, CareFusion, United Kingdom). Participants were asked to make a maximum inhalation through a mouthpiece from residual volume and then a maximum expiration from total lung capacity.²² Each participant performed three maneuvers with variations of <10% between them. Maximum inspiratory pressure was measured from residual volume to total lung capacity, and maximum expiratory pressure started from total lung capacity to residual volume.²² The best of the three maneuvers were documented.

Lung function

Participants were asked to avoid exercise and the ingestion of food, alcohol, or caffeine for at least 6 h before lung function testing. The spirometry system was calibrated before each test run, based on the manufacturer's specifications. Lung function tests were done in a laboratory using a spirometer (PonyFx, COSMED, Italy). The overall protocol was described and then demonstrated to participants based on ATS/ERS recommendations (2005).²³ The lung function outcomes included forced expiratory volume in the first second (FEV1), forced vital capacity (FVC), the ratio of FEV1/FVC, and peak expiratory flow rate (PEF). The highest of the three acceptable trials was selected for data analysis.²³ All lung function parameters were considered as the percentage of predicted of the Thai population.²⁴

Data analysis

Data were analyzed with statistics software (SPSS 22.0, Chicago, Illinois). Means and standard deviations were computed for all descriptive and study variables. Kolmogorov–Smirnov tests were used to evaluate the distribution of all variables.

One-way ANOVA with Bonferroni *post hoc* analysis was used to evaluate the differences for all outcomes among groups (control, obesity, smoking, and obesity plus smoking groups). The level of statistical significance was set at $P < 0.05$.

RESULTS

Baseline characteristics of participants

The results of the Kolmogorov–Smirnov tests indicated that all variables had normal distribution ($P > 0.05$). The

characteristics of the participants are described in Table 1. Weight, BMI, WC, HC, WHR, percentage of body fat and visceral fat, and truncal skinfold thickness in the obesity and obesity plus smoking groups were shown to be significantly higher than smoking and control groups ($P < 0.001$). There were no significant differences in baseline characteristics between obesity and obesity plus smoking groups. No significant difference in age, height, blood pressure, heart rate, respiratory rate, and oxygen saturation between groups was found ($P > 0.05$).

Effects of abdominal obesity and smoking on health outcomes

Respiratory muscle strength

Regarding respiratory muscle strength, a significant difference was found in the respiratory muscle strength between four groups ($F_{3,68}$, $P < 0.01$). The Bonferroni *post hoc* analysis shows that obesity plus smoking group had the lowest respiratory muscle strength by 18–21% reduction, followed by 10–12% reduction in smoking group, and <5% reduction in obesity group – compared with the control group [Table 2].

Lung function

One-way ANOVA indicated significant differences in lung function between four groups ($F_{3,68}$, $P < 0.01$). The Bonferroni *post hoc* analysis shows that obesity plus smoking group had the lowest lung function, including FVC, FEV1, and PEF followed by the smoking group, obesity group – relative to control group ($P < 0.01$) [Table 2]. Furthermore, both smoking and obesity plus smoking groups had significantly lower FVC, FEV1, and PEF compared with the obesity group ($P < 0.01$). No significant difference between the four groups was found in FEV1/FVC.

Associations between obesity/smoking status and lung function

Regarding the relationship between obesity status and lung function, there was moderate level in both the obesity group ($r = -0.584$, $P < 0.001$) and the obesity plus smoking group ($r = -0.631$, $P < 0.001$). Figure 1 shows that obese individuals with a BMI of more than 30 kg/m² combined with smoking tended to have lost a quarter of lung function, indicating a mild level of lung impairment. In the case of obesity, individuals who did not smoke, impairment of lung function occurred in individuals with BMI raising to >40 kg/m².

Considering smoking status and lung function, there was a negative correlation between smoking status and lung function at a fair level for the smoking group ($r = -0.397$, $P = 0.037$) and nearly a good level for the obesity plus

Table 1: Characteristics of participants ($n=72$)

Parameters	Mean $\pm$ SD				P (F3,68)
	Control group ($n=18$)	Obesity group ($n=18$)	Smoking group ($n=18$)	Obesity plus smoking group ($n=18$)	
Age (years)	27.39 $\pm$ 4.23	28.78 $\pm$ 5.73	27.78 $\pm$ 4.09	28.22 $\pm$ 5.15	0.858
Weight (kg)	64.47 $\pm$ 4.86	87.58 $\pm$ 10.09 ^{†‡}	65.89 $\pm$ 4.04	83.20 $\pm$ 7.84 ^{†‡}	<0.001*
Height (cm)	171.94 $\pm$ 5.16	173.00 $\pm$ 4.57	174.89 $\pm$ 3.86	171.61 $\pm$ 5.24	0.166
BMI (kg/m ²)	22.04 $\pm$ 5.32	28.99 $\pm$ 2.49	21.39 $\pm$ 1.17	28.16 $\pm$ 2.35	<0.0001*
Physical activity (score)	5.12 $\pm$ 0.37	4.93 $\pm$ 0.68	5.18 $\pm$ 0.42	5.10 $\pm$ 0.67	0.333
History of smoking (years)	-	-	7.22 $\pm$ 4.15	7.22 $\pm$ 2.55	0.637
Cigarette per day	-	-	11.27 $\pm$ 5.00	7.00 $\pm$ 3.97	0.198
Pack-year smoking	-	-	3.79 $\pm$ 2.27	2.77 $\pm$ 2.39	0.083
FTND score	-	-	2.72 $\pm$ 0.83	2.89 $\pm$ 1.23	0.940
Waist circumference (cm)	75.86 $\pm$ 5.45	96.03 $\pm$ 6.71 ^{†‡}	76.83 $\pm$ 4.71	94.42 $\pm$ 4.19 ^{†‡}	<0.001*
Hip circumference (cm)	90.75 $\pm$ 3.34	102.19 $\pm$ 4.84 ^{†‡}	92.78 $\pm$ 5.16	99.61 $\pm$ 4.73 ^{†‡}	<0.001*
WHR	0.83 $\pm$ 0.04	0.95 $\pm$ 0.06 ^{†‡}	0.83 $\pm$ 0.02	0.95 $\pm$ 0.03 ^{†‡}	<0.001*
Total body fat (%)	14.97 $\pm$ 3.58	27.33 $\pm$ 4.01 ^{†‡}	14.41 $\pm$ 3.11	26.56 $\pm$ 2.50 ^{†‡}	<0.001*
Visceral fat rating	5.23 $\pm$ 1.26	13.37 $\pm$ 2.97 ^{†‡}	5.33 $\pm$ 2.71	15.09 $\pm$ 3.64 ^{†‡}	<0.001*
Subcutaneous fat (%)	10.99 $\pm$ 2.02	20.32 $\pm$ 4.78 ^{†‡}	11.14 $\pm$ 2.82	19.28 $\pm$ 1.64 ^{†‡}	<0.001*
Truncal skinfold (mm)	54.29 $\pm$ 20.47	115.56 $\pm$ 15.93 ^{†‡}	45.01 $\pm$ 13.83	117.24 $\pm$ 10.84 ^{†‡}	<0.001*
SpO ₂	98.55 $\pm$ 0.51	98.61 $\pm$ 0.50	98.72 $\pm$ 0.46	98.28 $\pm$ 0.46	0.051
Systolic blood pressure (mmHg)	111.78 $\pm$ 5.97	114.47 $\pm$ 4.33	113.33 $\pm$ 3.63	115.89 $\pm$ 5.46	0.840
Diastolic blood pressure (mmHg)	79.44 $\pm$ 2.89	77.53 $\pm$ 4.09	80.78 $\pm$ 3.15	76.78 $\pm$ 7.33	0.053
Heart rate (bpm)	80.17 $\pm$ 8.59	81.47 $\pm$ 6.18	76.22 $\pm$ 8.34	79.00 $\pm$ 5.75	0.214
Respiratory rate (bpm)	14.44 $\pm$ 1.25	16.00 $\pm$ 1.05	14.28 $\pm$ 1.49	15.94 $\pm$ 1.76	0.402

*Significant difference between group; ANOVA test; [†]Significant difference compared with control group; Bonferroni *post hoc* test; [‡]Significant difference compared with smoking group; Bonferroni *post hoc* test. SD=Standard deviation; BMI=Body mass index; FTND=Fagerstrom Test for Nicotine Dependence; WHR=Waist hip ratio

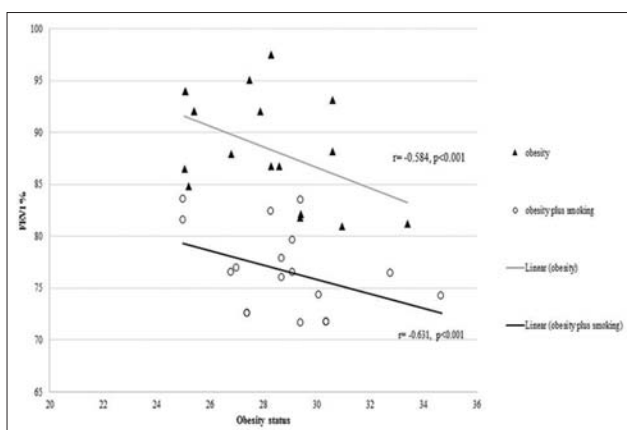


Figure 1: The association between obesity status and lung function

smoking group ($r = -0.706$, $P < 0.001$). Figure 2 demonstrates that obesity plus smoking further accelerates the loss of lung function (30% reduction of FEV1%) more than the smoking

group (25% reduction of FEV1%) - compared at the same pack-year of smoking (i.e. 6 pack-years).

DISCUSSION

This is the first study to investigate the combined effects of abdominal obesity and smoking on respiratory muscle strength and lung function in Thai males aged 20–40 years. The findings support the assertion that the combination of obesity and smoking extremely impact on respiratory muscle strength and lung function -relative to obesity and smoking alone. One notable finding of this study was that the obesity plus smoking group had twice the percentage reduction of respiratory muscle strength than the smoking group (18%–20% vs. 10%–12% reduction) and four times than the obesity group (18%–20% vs. 5% reduction). Deteriorating of the respiratory muscle strength could also influence on the alteration of lung function. The current findings indicate that combined effects of obesity

Table 2: Effects of abdominal obesity and smoking on respiratory muscle strength and lung function

Parameters	Mean±SD				P (F3,68)
	Control group (n=18)	Obesity group (n=18)	Smoking group (n=18)	Obesity plus smoking group (n=18)	
MIP (cm H ₂ O)	80.22±16.05	79.72±10.39	70.94±9.04 ^{†‡}	65.88±7.38 ^{†‡}	0.019*
Percentage	100	98.75	88.43	82.12	
MEP (cm H ₂ O)	75.72±9.35	73.33±9.68	67.44±7.27 ^{†‡}	60.11±8.67 ^{†‡}	0.012*
Percentage	100	96.84	89.06	79.38	
FVC (L)	4.24±0.72	3.87±0.39 [†]	3.78±0.36 ^{†‡}	3.38±0.40 ^{†‡}	0.011*
Percentage	100	91.27	89.15	79.72	
FEV ₁ (L)	3.74±0.66	3.39±0.27 [†]	3.09±0.48 ^{†‡}	2.64±0.27 ^{†‡}	0.012*
Percentage	100	90.64	82.62	70.59	
FEV ₁ /FVC (%)	88.43±6.16	84.62±6.81	81.75±9.88	80.10±9.97	0.059
PEF (L/s)	6.55±1.69	5.91±0.86 [†]	5.84±1.35 ^{†‡}	5.15±0.74 ^{†‡}	0.018*
Percentage	100	90.23	89.16	78.62	

*Significant difference between group; ANOVA test; [†]Significant difference compared with control group; Bonferroni *post hoc* test; [‡]Significant difference compared with obesity group; Bonferroni *post hoc* test. SD=Standard deviation; MIP=Maximum inspiratory pressure; MEP=Maximum expiratory pressure; FEV₁=Forced expiratory volume in the 1 s; FVC=Forced vital capacity; PEF=Peak expiratory flow rate

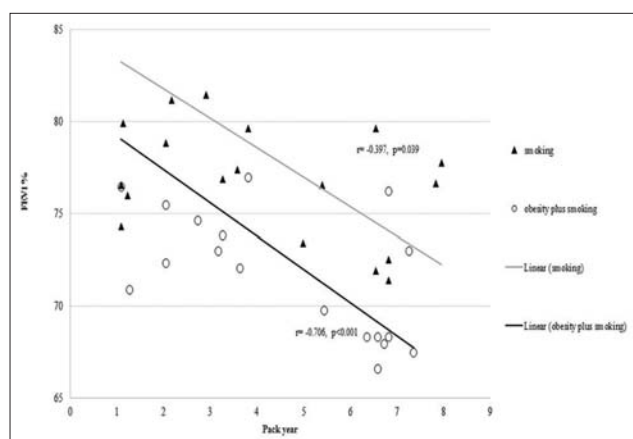


Figure 2: The association between smoking status and lung function

and smoking induce the loss of lung function above and beyond either obesity or smoking alone, thereby increasing risk of respiratory symptoms, chronic diseases, and rate of mortality.^{23,25} Thus, this critical point requires action be taken in health promotion and disease prevention for obesity control and smoking cessation before becoming obese and developing many smoking-related chronic diseases.

Considering the respiratory muscle strength outcomes, obesity plus smoking group showed the greatest deterioration in respiratory muscle strength- relative to the other groups. It seems that the toxicity from smoking with excessive abdominal fat accumulation may induce more negative effects on respiratory muscle performance than the presence of obesity and smoking alone. Smoking releases carcinogens and free radicals into the vascular system leading to decreased blood supply and gas exchange into the respiratory muscle,

which adversely alters respiratory muscle performance.^{13,26-28} Furthermore, fat mass loading from abdominal obesity has mechanical effects that directly restrict lung expansion and also diaphragmatic excursion and subsequently disturb respiratory muscle contraction.¹¹⁻¹³ These possible mechanisms are caused by reducing in respiratory muscle strength in obesity plus smoking group.

Regarding lung function parameters, obesity plus smoking group indicated the highest reduction of lung function- compared with the other groups. The results were in line with the previous study that revealed a significantly negative effect on abdominal obesity plus smoking on bronchial hyper-responsiveness.²⁹ It might be that decreasing of the respiratory muscle performance resulted in the disturbances of lung function.¹¹⁻¹³ Moreover, obesity and smoking are both inducing systemic inflammation that causes reduction of lung function.²⁹ Accumulation of adipose tissue also produces a large number of the pro-inflammatory mediators that is contribute to the increase in airway inflammation and loss of lung viscoelasticity resulting in the reduction of lung function.^{7,8,11,29} Similar to the effect of smoking, the release of free radicals and carcinogens from smoking stimulates systemic inflammation and produces oxidative stress resulting in airway and lung parenchyma inflammation, bronchial hyper-responsiveness and irritation, and airway narrowing which, in turn, influences lung function.^{1,2,4,30,31} With these possible mechanisms, the systemic inflammation caused by obesity plus smoking may more greatly increase the deteriorative effects on respiratory muscle strength and lung function than those who are obesity or smoke alone.

Regarding the effects of obesity or smoking alone, current findings showed that obesity causes negative effects on

respiratory muscle strength and lung function. The results in this study were in line with Collins *et al.* and Ceylan *et al.* which showed that obese individuals had significantly lower lung volume and airflow than the control group.^{32,33} It might be that the mechanical effect of fat distribution around the chest wall may directly limit chest wall expansion, restrict the downward movement of diaphragm and performance of the abdominal muscles, resulting in reducing their lung volume and airflow.^{7,11} Similar to the effect of smoking on respiratory muscle strength and lung function, these results agreed with those of Tantisuwat *et al.* and Tammola *et al.* that smokers had significantly decreased respiratory muscle strength and lung function compared with non-smokers.^{26,27} Toxicity from smoking destroyed lung parenchyma and lost the lung tissue viscoelasticity, which affected respiratory muscle strength and lung function.³⁰ Moreover, free radicals and carcinogens from cigarette smoking-induced oxidative stress, resulting in inflammation, hyper-responsiveness, and irritation of the airways.^{1,2}

Considering to the relationship between obesity status and lung function, the results indicate that there is a negative correlation between obesity status and FEV1%. The FEV1 parameter is well known as a strong predictor of lung impairments and airway function.^{23,34} The result was in agreement with Gabrielsen *et al.* (2011)³⁵ that a BMI exceeding a 25 kg/m² tended to result in a loss of lung function ($r = -0.25$). However, the current study showed a moderate level of the correlation ($r = -0.584$ – 0.631). It might be that this study included the specific type of obesity (abdominal obesity), which strongly related lung function compared with overall and peripheral obesity.³⁵ Furthermore, the current results showed that participants with a BMI of more than 30 kg/m² tended to see more than a 25% reduction in lung function (referring to a mild level of lung impairment). Beeckman *et al.* reported that 25% reduction of FEV1 induced twice the risk of dying of cardiovascular and nonmalignant respiratory diseases³¹ In addition, monitoring and control of obesity should be needed.

Considering the relationship between smoking status and lung function in smoking group, the results showed that pack-year had a fairly negative correlation with lung function. This result was in concurrence with Rawashdeh *et al.*²⁸ Increasing the number of cigarettes smoked per day and smoking duration tended to decrease lung function and risk lung impairment. Furthermore, the results in this study additionally highlighted that a smoking history of >6 pack-years is associated with the loss of a quarter of lung function, which indicates a mild level of lung impairment.

Regarding the obesity plus smoking group, this research revealed that increasing smoking consumption among those with abdominal obesity had a moderately converse correlation

on lung function. Moreover, the results pointed out that the obesity plus smoking group had an accelerated loss of lung function than the smoking group (30% reduction vs. 25% reduction). The combination of obesity and smoking of more than 3 pack-years results in a quarter loss of lung function. This finding supports the assertion that the combined effects of obesity and smoking show greater rapid loss of lung function compared with smoking or obesity alone.

Clinical implications

The findings provide important information regarding the combined effects between obesity and smoking on respiratory muscle strength and lung function to the clinical practitioners for early monitoring, prevention, and control of abdominal obesity and smoking before the development of comorbidity and mortality. Further studies are needed to identify the appropriate interventions and strategies to manage abdominal obesity and smoking.

Limitations

This study has some limitations. First, the study investigated only male abdominal obesity. Gender differences and types of obesity are factors that influence lung function and respiratory muscle strength. Second, the level of nicotine dependence is limited to a mild to moderate level. A high level of nicotine dependence may reveal more adverse effects on health outcomes. Research is needed to investigate the differences in nicotine dependence level on lung function measures. Third, the results from the correlation should be interpreted with caution due to the small sample size. Future research is needed to clarify the results as well.

CONCLUSIONS

Combined effects of abdominal obesity and smoking adverse impacts on respiratory muscle strength and lung function. The finding suggested that BMI raising more than 30 kg/m² combined with smoking tended to lose a quarter of lung function. Regarding smoking, more than a 3-pack year of smoking in individuals with obesity and more than a 6-pack year of smoking in individuals without obesity tended to result in the loss of a quarter of respiratory muscle strength and lung function- would, therefore, increase the risk respiratory-related chronic diseases.

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Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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