# Increased Abdominal Perimeter Differently Affects Respiratory Function in Men and Women

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## Abstract

Obesity is a worldwide epidemic being the main cause of cardiovascular, metabolic disturbances and chronic pulmonary diseases. The increase in body weight may affect the respiratory system due to fat deposition and systemic inflammation. Herein, we evaluated the sex differences in the impact of obesity and high abdominal circumference on basal ventilation. Thirty-five subjects, 23 women and 12 men with a median age of 61 and 67, respectively, were studied and classified as overweight and obese according to body mass index (BMI) and were also divided by the abdominal circumference. Basal ventilation, namely, respiratory frequency, tidal volume, and minute ventilation, was evaluated. In normal and overweight women, basal ventilation did not change, but obese women exhibited a decrease in tidal volume. In men, overweight and obese subjects did not exhibit altered basal ventilation. In contrast, when subjects were subdivided based on the abdominal perimeter, a higher circumference did not change the respiratory frequency but induced a decrease in tidal volume and minute ventilation in women, while in men these two parameters increased. In conclusion, higher abdominal circumference rather than BMI is associated with alterations in basal ventilation in women and men.

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## Keywords

Abdominal circumference · Basal ventilation · Obesity · Overweight

## 15.1 Introduction

Obesity has reached epidemic proportions and it is considered one of the major diseases of the last decades, contributing to significant morbidity and mortality worldwide (WHO Consultation on Obesity 1998). Overweight and obesity have

been associated with risks of developing type 2 diabetes, cardiovascular diseases, chronic kidney diseases, non-alcoholic fatty liver disease, and cancer (Malnick and Knobler 2006). The excess of adiposity is also associated with chronic pulmonary diseases such as obstructive sleep apnea, obesity hypoventilation syndrome, and asthma (Zammit et al. 2010).

The respiratory system may be affected by obesity due to a direct effect of fat deposition in the chest wall, abdomen, and upper airway promoting a decrease in lung volumes with a reduction in the functional residual capacity and expiratory reserve volume, being this observed even at a moderate augment in weight (Jones and Nzekwu 2006; Peralta et al. 2020). Moreover, in obese subjects it was also described an increase in the airway resistance, due to a decrease in lung volume (Zerah et al. 1993). Additionally, obesity may also change muscle respiratory strength (Sanchez et al. 2016). In obese patients with morbid obesity, which exhibited a body mass index (BMI) higher than 40 kg/m$^2$, the respiratory rates were increased due to a reduction in the expiratory time per breath (Sampson and Grassino 1983; Pankow et al. 1998; Chlif et al. 2009). Morbidly obese patients have been also shown to exhibit a decrease in tidal volume (Sampson and Grassino 1983; Pankow et al. 1998; Chlif et al. 2009). All these alterations promoted by obesity are fundamental to maintain an appropriate ventilation in obese states, and in fact, it has been observed that weight loss is associated with an improvement in pulmonary function (Alsumali et al. 2018; Nguyen et al. 2009).

Adipose tissue is an endocrine organ that secretes adipokines (e.g., adiponectin, leptin) and inflammatory cytokines (e.g., interleukin 6, tumor necrosis factor alpha, monocyte chemoattractant protein-1), having a key role in the metabolic dysfunction and inflammation observed in obesity (Chait and den Hartigh 2020). Adipokines have been also associated with respiratory disorders (Palma et al. 2022). In obese patients with obstructive sleep apnea and obesity hypoventilation syndrome, it was observed that an increase in interleukin 6 (Roytblat et al. 2000) and continuous positive airway pressure therapy diminished

inflammatory cytokines in patients with obstructive sleep apnea (Jin et al. 2017). Additionally, there are two main areas of fat accumulation in the body: a peripheral region that is characterized by fat deposition in the subcutaneous tissue and a central region that is characterized by fat deposition in the thorax, abdomen, and visceral organs (Sari et al. 2019). Abdominal adiposity appears to have a higher effect on pulmonary mechanics (Collins et al. 1995). A large-scale study showed that abdominal obesity, rather than weight and body mass index (BMI), was associated with lung function impairment, being this association consistent in men and women (Leone et al. 2009).

In the present study, we evaluated the sex differences in the effects of obesity and high abdominal perimeter on basal ventilation. We found that higher abdominal circumference, rather than BMI, impacts basal ventilation in old men and women, with the increased abdominal perimeter correlating negatively with tidal volume in women and positively in men.

## 15.2    Methods

### 15.2.1 Ethical Approval

The study was approved by Hospital Santa Marta, Centro Hospitalar Lisboa Central EPE (CHLC-EPE, n°63/2010), and NOVA Medical School Ethics Committee and performed in accordance with the Helsinki Declaration. Written informed consent was obtained from all individuals.

### 15.2.2 Subjects and Study Design

Subjects were recruited at the Cardiology Service, Hospital Santa Marta, CHLC-EPE. Individuals eligible for the study were adults over 18 years of age. Exclusion criteria were cardiovascular disorders, except hypertension, renal diseases, obesity hypoventilation syndrome, chronic respiratory failure, and psychiatric diseases.

The study was conducted in two visits. The first visit occurred in the CHLC-EPE. Sociodemographic and anthropometric

data, comorbidities, and ongoing medication profile were documented. Weight, height, and abdominal circumference were assessed. The BMI (kg/m$^2$) was calculated as weight (kilograms) divided by square of the height (meters). Subjects were categorized into normal weight, overweight, and obese according to their BMI and following the recommendations of the World Health Organization (WHO) (WHO Consultation on Obesity 1998): normal weight, 18.5–24.9 kg/m$^2$; overweight, 25–29.9 kg/m$^2$; and obese, ≥30 kg/m$^2$. Subjects were also divided based on the abdominal circumference, according to WHO (WHO Consultation on Obesity 1998): ≥80 cm in women and ≥94 cm in men, which indicate an increased risk of metabolic complications. The second visit was at NOVA Medical School, Faculdade de Ciências Médicas. Basal ventilation, namely, respiratory frequency, tidal volume, and minute ventilation, was measured via a mouthpiece connected to a three-way valve in a whole-body plethysmography system (MasterScreen Body, Jaeger, Germany). The measure of the basal ventilation was repeated three times.

### 15.2.3  Statistical Analysis

Data was evaluated using Prism version 9 (GraphPad Software Inc., La Jolla, CA, USA) and was presented as mean ± SEM. The normal distribution of the variables was confirmed with the Shapiro-Wilk test. The significance of the differences between the mean values was calculated by Student's $t$ test and one-way ANOVA with Dunnett's multiple comparison test. Differences were considered significant at $p < 0.05$.

## 15.3  Results

### 15.3.1  Demographic and Clinical Information of the Participants

Table 15.1 illustrates the demographic and clinical characteristics of the study participants. A total of 35 subjects were included in the study, 23 women and 12 men, with a median age of 61 and 67 years, respectively. When patients were divided based on the BMI, in women, five exhibit normal weight, eight were overweight, and ten were obese. Men subjects included four with normal weight, four overweight, and four obese. In both groups, a high percentage of the participants had hypertension and dyslipidemia.

### 15.3.2  Effect of Overweight and Obesity on Basal Ventilation

Figure 15.1 shows the impact of overweight and obesity on basal ventilation in women and men. In women, the increase in body weight did not

**Table 15.1**  Demographic and clinical characteristics

| Characteristics | | Women $n = 23$ | Men $n = 12$ |
|---|---|---|---|
| Age (years) | | 61.36 ± 2.68 | 67.31 ± 2.40 |
| Abdominal circumference (cm) | *Normal* | 72.80 ± 2.06 | 85.00 ± 3.26 |
| | *High* | 98.25 ± 2.88### | 106.70 ± 4.75## |
| Body mass index (kg/cm$^2$) | *Normal weight: 18.5–24.9* | 22.28 ± 1.15 | 21.76 ± 1.31 |
| | *Overweight: 25–29.9* | 27.26 ± 0.52# | 28.19 ± 1.14# |
| | *Obese: ≥ 30* | 35.97 ± 3.73### | 33.94 ± 2.13### |
| Type 2 diabetes (%) | | 17.39 | 41.67 |
| Hypertension (%) | | 69.57 | 83.33 |
| Dyslipidemia (%) | | 73.91 | 83.33 |

Normal abdominal circumference: women <80 cm and men <94 cm. High abdominal circumference: women ≥80 cm and men ≥94 cm. Values are presented as mean ± SEM. One-way ANOVA with Dunnett's multicomparison test or Student's t-test: #$p < 0.05$, ##$p < 0.01$ and ###$p < 0.001$, comparing with normal abdominal circumference or normal weight
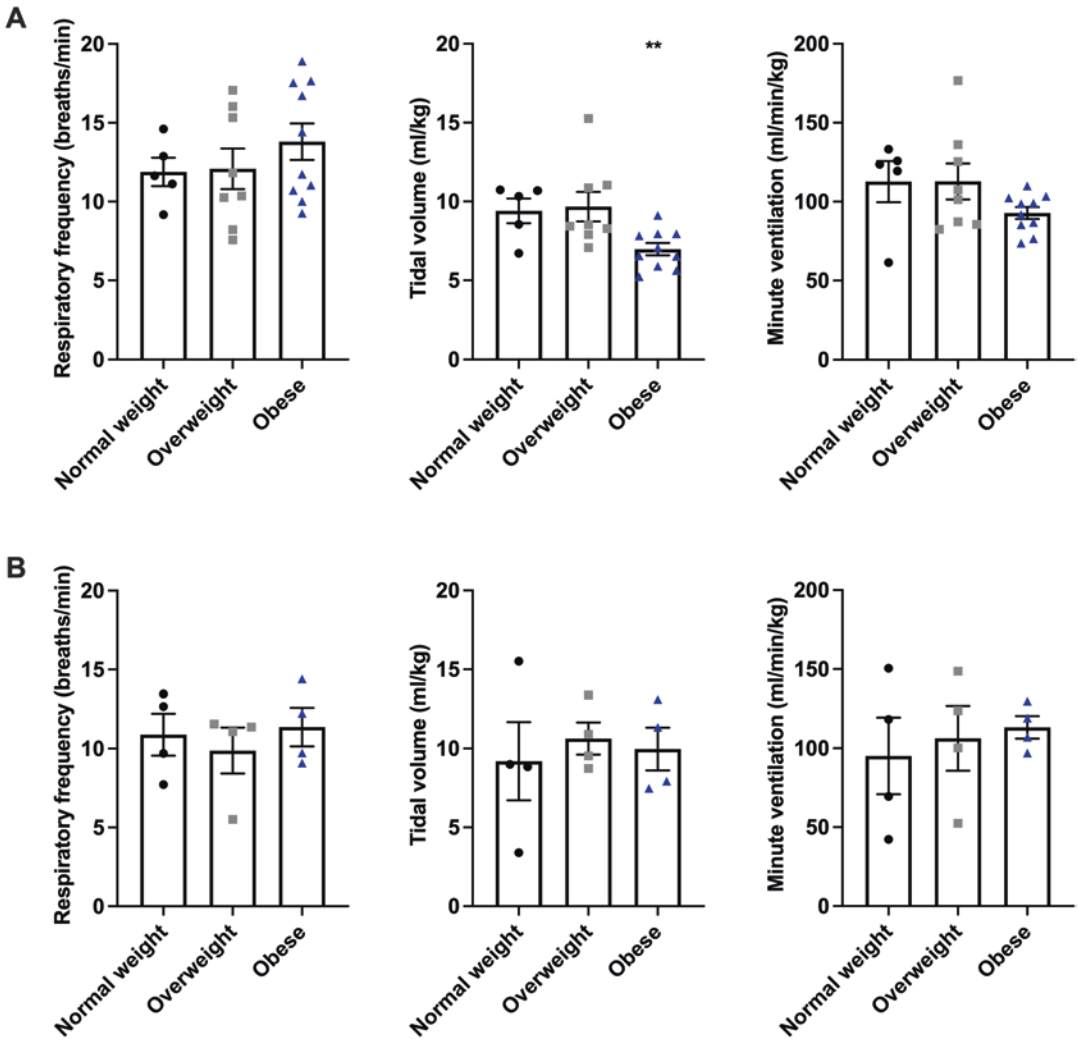
**Fig. 15.1** Effect of overweight and obesity on basal ventilation in women and men subjects. Basal ventilatory parameters, respiratory frequency, tidal volume, and minute ventilation in women (**a**) and men (**b**) with normal weight (BMI = 18.5–24.9 kg/m²), overweight (BMI = 25–29.9 kg/m²), and obesity (BMI ≥ 30 kg/m²). Data represent the mean ± SEM of 25 women and 13 men subjects. One-way ANOVA with Dunnett's multicomparison test: $p < 0.01$ comparing with normal weight subjects

modify the respiratory frequency but decreased tidal volume in the obese stage by 26% (Fig. 15.1a). The decrease in tidal volume in obese women was not sufficient to promote alterations in minute volume. In contrast, increased BMI in men did not impact the respiratory frequency, tidal volume, and minute ventilation (Fig. 15.1b).

### 15.3.3 Effect of Increased Abdominal Circumference on Basal Ventilation

Despite BMI is currently used to diagnose and classify obesity, recent studies proposed that BMI underestimates the prevalence of overweight and obesity, since it only contemplates

subjects' weight and height and not total body fat (Gómez-Ambrosi et al. 2011). Therefore, herein we also classified study subjects considering the abdominal circumference, as an indicator of increased visceral fat. Figure 15.2 depicts the impact of increased abdominal perimeter on basal ventilation in women and men. In women, the increase in abdominal circumference ($\geq$80 cm) did not modify respiratory frequency and the minute ventilation; however, tidal volume decreased significantly by 22% (Fig. 15.2a). In men, the respiratory frequency did not change with the increase in the abdominal circumference ($\geq$94 cm) (Fig. 15.2b). However, tidal volume and minute ventilation increased significantly by 51% and 59%, respectively, when men exhibited a higher abdominal circumference (Fig. 15.2b).

## 15.4  Discussion

The present study demonstrates that an increase in abdominal circumference, rather than BMI, has a higher impact on basal ventilation both in women and men. Moreover, the increase in abdominal circumference correlates differently in both sexes: in women it correlates negatively with tidal volume where in men it correlates positively.

It was previously described that morbid obesity, classified according with BMI, is associated with an increase in the respiratory rate and a decrease in the tidal volume (Sampson and Grassino 1983; Pankow et al. 1998; Chlif et al. 2009). Herein, this effect was only observed in women, since in men, basal ventilation did not change with the increased body weight. The absence of effects of obesity on basal ventilation in men herein observed could be related with the degree of obesity of the subjects. In the present study, obese men had a BMI of 33.94 kg/m$^2$, corresponding to a class I obesity and therefore to moderate obesity. This agrees with previous findings showing that patients with moderate obesity (BMI $\geq$ 30 kg/m$^2$) did not exhibit alterations in tidal volume (Boulet et al. 2005; Torchio et al.

2009). In contrast, in morbidly obese patients (BMI $\geq$ 40 kg/m$^2$), it was described as an increase in the respiratory rate and a decrease in the tidal volume (Sampson and Grassino 1983; Pankow et al. 1998; Chlif et al. 2009). Altogether, these findings suggested that in men, when obesity is defined by the BMI, the tidal volume is only affected in higher degrees of obesity, as morbid obesity (BMI $\geq$ 40 kg/m$^2$).

The BMI is often used to define obesity and to classify its severity; however, it did not consider the total body fat, since it only takes into consideration the weight and the height of the individuals (Gómez-Ambrosi et al. 2011). Besides, fat distribution and accumulation in the central/abdominal area appear to have a higher effect on pulmonary mechanics (Collins et al. 1995). In fact, when we divided the subjects by the abdominal circumference, we observed significant effects on tidal volume and minute ventilation, rather than with BMI, being the effects opposite in women and men. This difference may be related with a higher abdominal circumference that is observed in women, 98.25 cm, a perimeter that characterized women with substantial increased risk of developing metabolic disturbances (WHO reference value is $\geq$88 cm). This high abdominal perimeter also showed that the women included in the present study have a higher accumulation of fat in the abdominal area. Women and men exhibit different patterns of body fat distribution, since women have more subcutaneous fat and men are characterized by an accumulation of fat in the abdominal area (Karastergiou et al. 2012). However, menopause transition is associated with augmented of total and abdominal adiposity (Svendsen et al. 1995; Panotopoulos et al. 1996), an effect that could be due to the decrease in estrogen levels (Lovejoy et al. 2008). In the present study, the mean age of women was 61 years old, which indicates that most of the women are in menopause or in the post-menopause. Moreover, menopause in non-obese women promoted a decline in tidal volume (Preston et al. 2009) and lung function (Triebner et al. 2017). Therefore, we can suggest that in the
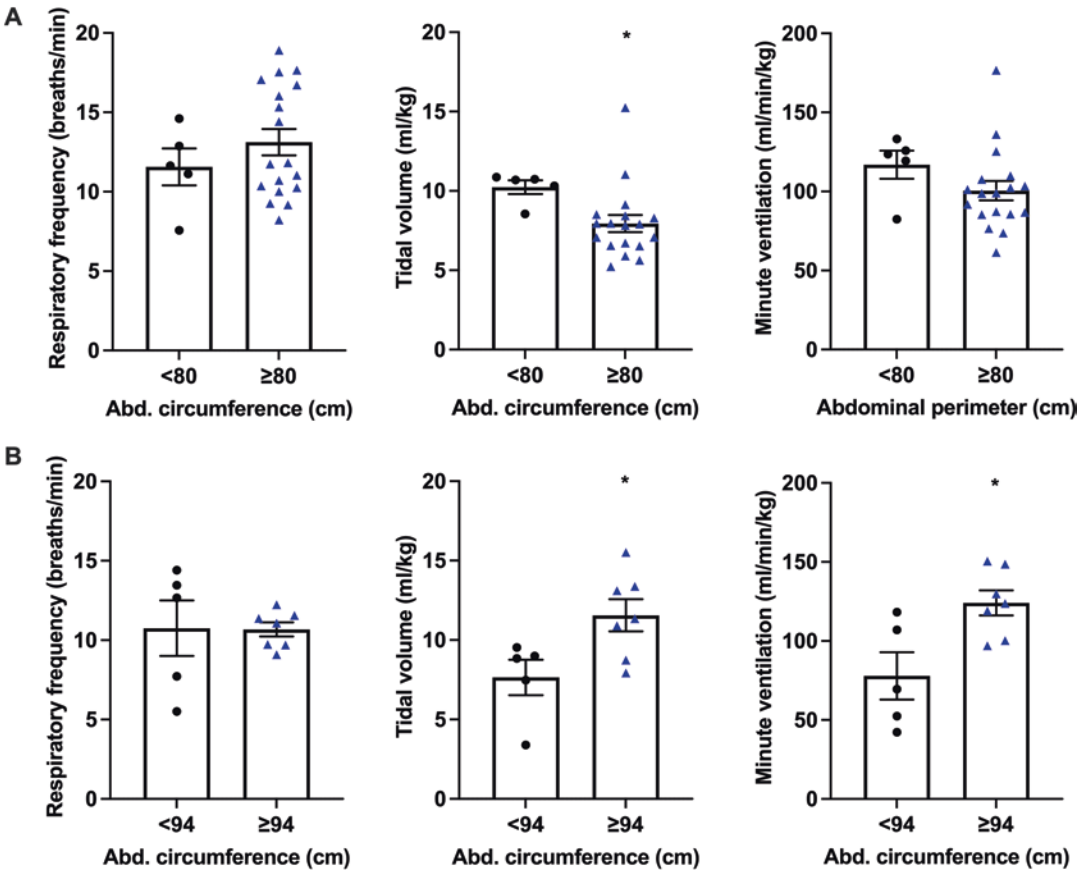
**Fig. 15.2** Effect of abdominal circumference on basal ventilation in women and men subjects. Basal ventilatory parameters, respiratory frequency, tidal volume, and minute ventilation in women (**a**) and men (**b**) with normal (women <80 cm and men <94 cm) and high abdominal circumference (women ≥80 cm and men ≥94 cm). Data represent the mean ± SEM of 25 women and 12 men subjects. Student's $t$ test: $p < 0.01$ comparing with normal abdominal circumference

present study, the decrease in the tidal volume and the increase in minute ventilation observed in women are due to the elevated abdominal circumference and to the decrease in estrogens due to menopause.

We can conclude that the degree of obesity impacts differently basal ventilation in men and women, particularly in tidal volume. Moreover, our results also highlight the importance of classify obesity taking into consideration not only the BMI but also the abdominal perimeter.

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