ORIGINAL ARTICLE

The effect of body mass index on pulmonary function

O efeito do índice de massa corpórea na função pulmonar

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ABSTRACT

Objective: to characterize lung volumes, airway resistance (AWR), and carbon monoxide diffusion capacity (CMD) in individuals with normal, pre-obese, class I obesity, class II obesity, and class III obesity body mass index (BMI). **Methodology:** this was a retrospective, quantitative, and cross-sectional study. The sample consisted of 304 individuals of both genders with suspicion or clinical diagnosis of asthma, with BMI ≥ 25 kg/m^2, and without alterations in respiratory functional tests and 95 healthy and with normal BMI individuals of both genders.

Key words: Body Mass Index; Plethysmography, Whole Body; Physical Endurance; Pulmonary Diffusing Capacity.

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RESUMO

***Objetivo**: caracterizar os volumes pulmonares, a resistência das vias aéreas (Rva) e a capacidade de difusão do monóxido do carbono (DCO) em indivíduos com índice de massa corpórea (IMC) normal, pré-obesos, obesidade classe I, obesidade classe II e obesidade classe III. **Metodologia**: estudo retrospectivo, quantitativo e transversal. A amostra foi constituída por 304 indivíduos de ambos os gêneros com suspeita ou diagnóstico clínico de asma, com IMC≥25 kg/m^2 e sem alterações nas provas funcionais respiratórias e por 95 indivíduos de ambos os gêneros, saudáveis e com IMC.*

***Palavras-chave**: Índice de Massa Corpórea; Pletismografia Total; Resistência Física; Capacidade de Difusão Pulmonar.*

INTRODUCTION

The World Health Organization (WHO) defines obesity as a condition in which excess body fat may reach levels that could affect health. Obesity is currently considered a public health problem, affecting approximately half a billion people around the world.[1]

Obesity is often related to alterations in lung function, secondary to high ventilatory needs, elevated ventilatory effort, inefficiency of respiratory muscles, and reduced pulmonary complacency.[2-6] The effects of obesity on pulmonary function are caused by the presence of excess fat tissue in the thorax and abdomen exerting pressure on the thorax, diaphragm, and lungs, which can condition the reduction in lung volume and compromise gaseous exchanges.[3]

The functional respiratory parameters most commonly affected by obesity are lung volumes. The impact of obesity on total lung capacity (CRF) and vital capac-

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ity (CV) are modest. However, the residual functional capacity (CRF) and expiratory reserve volume (VRE) can be decreased.[3,7-9]

The mechanical properties of the airways, such as airway resistance (Rva) and reactance are highly dependent on lung volumes and can be affected by any CRF reduction.[5]

Obesity promotes abnormalities in the ventilation-perfusion ratio. The carbon monoxide diffusing capacity (Dco) is generally preserved in the obese. However, it may be reduced or increased.[10-13]

It is known that obesity has a negative impact on quality of life, which leads many of these individuals to seek health services, particularly in the specialty of Pulmonology and Allergology. This is because this condition is strongly associated with clinical phenotypes of asthma[6]; lung function tests are often requested for the clarification of respiratory complaints.

There are very limited data on the relationship between obesity and lung function in Portugal. According to the literature, this relationship is still controversial. Therefore, this study analyzed lung volumes, Rva, and D_{CO} in individuals diagnosed with asthma or suspected of having asthma and that, however, do not present altered respiratory functions in order to understand if even without major alterations in lung function tests, the body mass index (BMI) promotes changes in these parameters.

The objective of this study was the characterization of lung volumes, Rva, and D_{CO} in subjects with normal BMI (18.5-24.9 kg/m^2), and in the pre-obese (25-29.9 kg/m^2), obesity class I (30 to 34.9 kg/m^2), obesity class II (35 to 39.9 kg/m^2), and obesity class III (≥40 kg/m^2) groups.

MATERIAL AND METHODS

This was a retrospective, quantitative, and cross-sectional study. The data were compiled from two databases belonging to the Respiratory Pathophysiology Laboratory of the Central Hospital where the research was conducted. One of them included individuals from an outpatient clinic in that institution and the other included data from individuals who are on the hospital staff and agreed to participate in the study in the area of lung function. Pre-obese and obese patients (cases) were selected from the first database, and individuals with normal BMI (control) were selected from the second database.

The inclusion criteria for the pre-obese and obese sample were defined as: Caucasian race, 18 years old and older, suspected or diagnosed with asthma, BMI≥25 kg/m^2, and performance of lung function testing including spirometry, total body plethysmography (lung volumes and Rva), and D_{CO}. The exclusion criteria were: altered respiratory functions (airway obstruction, pulmonary restriction, mixed ventilatory alteration, or decreased D_{CO}), performance of bronchodilator therapy on the day of respiratory function tests, presence or suspicion of other concomitant respiratory disease, and presence of deformity in the ribcage.

Although asthma can occur together with airway obstruction, only individuals without this respiratory pattern were included in this research in order to facilitate uniformity among the BMI groups. The rationale was that bronchial obstruction in asthmatic patients may vary with respect to the degree of severity and can even be totally reversed, spontaneously or with the use of medication.

The non-exclusion of individuals with restrictive lung function, mixed ventilatory alteration, or reduced D_{CO} was established in order to prevent respiratory functional alterations caused by other disease processes that could be confused with those caused by the detection of elevated BMI.

Individuals with normal BMI (18.5-24.9 kg/m^2) did not manifest respiratory complaints, had no known respiratory disease, had no deformity in the ribcage, and did not reveal changes in lung function.

The pre-obese and obesity sample consisted of 304 individuals (cases), and the sample of individuals with normal BMI of 95 individuals (control).

The entire sample was sub-distributed according to the BMI categories proposed by the WHO. Five subgroups were formed; normal BMI group (18.5-24.9 kg/m^2) with 95 individuals, pre-obese group (25-29.9 kg/m^2) with 132 individuals, obesity class I group (30 to 34.9 kg/m^2) with 105 individuals, obesity class II group (35 to 39.9 kg/m^2) with 48 individuals, and obesity group class III (≥ 40 kg m^2) with 19 individuals.

The percentage values of parameters obtained by spirometry (CVF, VEF_1, and VEF_1/CVF), total body plethysmography (VR, CPT, VR/CPT, CRF, VRE, CI, CV, and Rva), and D_{CO} were analyzed in this study. However, some parameters obtained by these techniques are not expressed in percentages (European Community for Coal and Steel equations – ECCS – do not provide reference values for VRE and CI), therefore, the absolute values were analyzed in their specific unit.

A properly calibrated scale was used to determine heights and weights; the ATS/ERS Task Force standards were followed: Standardization of Lung Function Testing – General considerations for lung function testing.[14] BMI was calculated based on the formula weight/(height).[2]

The equipment used in this study was a plethysmograph Vmax Series Autobox 6200 SensorMedics® (Yorbalinda, California, USA, 1998). Spirometry, total body plethysmography, D_{CO} (single-breath method), and compliance with the quality standards followed the guidelines proposed by the ATS/ERS Task Force: Standardization of Lung Function Testing – Standardization of Spirometry,[15] ATS/ERS Task Force: Standardization of Lung Function Testing – Standardization of Measurement of Lung Volumes[16], and ATS/ERS Task Force: Standardization of Lung Function Testing – Standardization of single-breath determination of carbon monoxide uptake in the lung.[17]

The interpretation of the results of the lung function tests was developed according to the criteria proposed by the ATS/ERS Task Force: Standardization of Lung Function Testing – Interpretive Strategies for Lung Function Tests.[18] The reference equations considered were those from ECCS.[19]

The developed study was approved by the Hospital Ethics Committee where the investigation was conducted.

Regarding the statistical analysis to characterize the sample, descriptive statistics (mean and standard deviation) was used for quantitative variables and frequency distribution for qualitative variables. The Kolmogorov-Smirnov test was used to verify the normal distribution of the studies variables; since the variables considered did not meet this assumption, nonparametric statistics methodologies were applied. The Kruskal-Wallis test was used to determine differences in lung volumes, Rva, and D_{CO} between individuals with normal BMI and in the pre-obese, obesity class I, obesity class II, and obesity class III groups. The multiple comparisons of means of orders from independent samples were performed to identify which one, or ones, in the respiratory function groups presented these differences. The significance level was considered 0.05 in all statistical tests.

RESULTS

The database considered for obtaining cases included data on 5,673 individuals of both genders who underwent lung functional testing between 2005 and 2012. Out of these individuals, 1,948 presented suspected or clinical diagnosis of asthma, however, of these, 1,022 individuals exhibited altered respiratory function, 13 had kyphoscoliosis, 37 had BMI<25 kg/m^2, and 572 did not undergo total body plethysmography and/or determination of D_{CO}. Thus, the sample of cases (pre-obese and obese patients) consisted of 304 individuals.

Controls were taken from a database that included data on 100 individuals; five were excluded from this investigation for having BMI>24.9 kg/m^2, therefore, the control group consisted of 95 subjects.

Table 1 featured the five groups established according to BMI categories. The sample consisted of 399 individuals, 308 females (77.2%) and 91 males (22.8%). All groups were formed mainly of female subjects.

The determination of whether the functional respiratory variables varied according to the BMI categories through the Kruskal-Wallis test revealed that for some of the significant differences ($p < 0.05$) in the studied variables were observed in at least one of the groups. Multiple comparisons of means of orders from independent samples were necessary to identify which of the BMI groups presented these differences.

Table 1 - Characterization of the sample according to BMI categories

	Normal BMI (n=95)	Pre-obese (n=132)	Obesity Class I (n=105)	Obesity Class II (n=48)	Obesity Class III (n=19)
Gender n (%)	M 21 (22.1) F 74 (77.9)	M 34 (25.7) F 98 (74.3)	M 28 (26.7) F 77 (73.3)	M 5 (10.4) F 43 (89.6)	M 3 (15.8) F 16 (84.2)
Age (anos)	47.8 ± 17.2	57.5 ± 14.7	59.0 ± 12.9	59.6 ± 12.6	61.2 ± 11.5
Height (cm)	160.8 ± 8.40	158.7 ± 7.68	158.4 ± 9.10	156.8 ± 7.22	157.0 ± 7.45
Weight (kg)	59.2 ± 7.46	69.9 ± 7.36	81.4 ± 10.2	90.9 ± 9.00	108.2 ± 11.4
BMI (kg/m^2)	22.4 ± 1.82	27.2 ± 1.47	31.9 ± 1.35	36.5 ± 1.27	43.4 ± 3.15

Results presented in averages ± standard deviation; cm: centimeters; BMI: body mass index; Kg: kilograms; and male; kg/m^2: kilograms per square meter.

Table 2 presents the functional respiratory characterization of all groups.

The normal BMI group showed CPT statistically superior (p <0.05) to that presented by the pre-obese, obesity class I, and obesity class II groups (Table 2).

Individuals with normal BMI obtained VRE statistically superior (p <0.05) to that observed in the pre-obese, obesity class I, obesity class II, and obesity class III groups. In addition, the pre-obese group showed statistically superior VRE (p <0.05) to that in the class I obesity, class II obesity, and class III obesity groups (Table 2).

Regarding the CRF, the normal BMI group showed values in this variable that were statistically superior (p <0.05) to those found in the pre-obese, obesity class I, obesity class II, and obesity class III groups. The pre-obese group showed a CRF value statistically higher (p <0.05) than that observed in the obesity class I group (Table 2).

The group with normal BMI showed VR statistically superior (p <0.05) to that in the pre-obese and obesity class I groups (Table 2).

The pre-obese group showed statistically higher levels (p <0.05) of the CV parameter than that found in the obesity class II and class III groups (Table 2).

The normal BMI group showed Rva values statistically lower (p <0.05) than those observed in the obesity class I, obesity class II, and obesity class III groups. In the pre-obese group, Rva was statistically lower (p <0.05) than that in the obesity class I and obesity class II groups. This parameter was statistically lower (p <0.05) in the obesity class I group compared with obesity class II and class III groups (Table 2).

The group with normal BMI presented D_{CO} statistically lower (p <0.05) than that obtained in the pre-obese groups, obesity class I, obesity class II, and obesity class III groups. Moreover, statistically lower D_{CO} values (p <0.05) were found in the pre-obese group compared to the obesity class III group (Table 2).

DISCUSSION

There is a predominance of pre-obese and obesity in the male gender[20] in Portugal, however, the sample of this research (all groups) consisted mainly of women, which can be explained by the fact that it has been taken from the hospital database. According to Ophir et al.,[21] dyspnea complaints related to physical activity are more common in women than men. Thus, women also often seek health care more than men, which is the possible reason for the predominance of females in this sample.

Table 2 - Functional respiratory characterization according to BMI categories

	Normal BMI (n=95)	Pre-obese (n=132)	Obesity Class I (n=105)	Obesity Class II (n=48)	Obesity Class III (n=19)
CVF (%)	112.4 ± 13.3	111.2 ± 14.6	111.0± 15.2	110.8 ± 14.7	110.6 ± 25.4
VEF_1 (%)	105.4 ± 13.4	104.9 ± 15.1	104.1 ± 15.2	103.9 ± 13.9	103.8 ± 24.2
VEF_1 /CVF (%)	78.9 ± 5.49	78.1 ± 4.86	78.5 ± 4.64	79.2 ± 4.08	77.8 ± 5.59
VR (%)	100.4 ± 23.4 [a,b]	91.2 ± 19.4	93.5 ± 20.1	97.6 ± 24.7	100.0 ± 20.3
CPT (%)	102.8 ± 11.4 [a,b,c]	98.6 ± 13.0	98.5 ± 11.0	98.0 ± 12.0	98.6 ± 14.0
VR/CPT (%)	33.5 ± 8.86	35.2 ± 8.86	36.8 ± 8.31	39.1 ± 9.30	40.6 ± 9.44
CRF (%)	98.6 ± 19.2 [a,b,c,d]	87.6 ± 15.0 [b]	83.5 ± 15.2	84.1 ± 18.2	85.9 ± 15.2
VRE (L)	1.00 ± 0.53 [a,b,c,d]	0.72 ± 0.41 [b,c,d]	0.52 ± 0.27	0.43 ± 0.24	0.52 ± 0.27
CI (L)	2.26 ± 0.59	2.33 ± 0.56	2.41 ± 0.64	2.24 ± 0.64	2.23 ± 0.59
CV (%)	107.2 ± 13.2	110.0 ± 14.9 [c,d]	108.0 ± 14.3	104.8 ± 14.1	104.9 ± 24.0
Rva (kPa/L/s)	0.214 ± 0.073 [b,c,d]	0.231 ± 0.081 [b,c]	0.242 ± 0.088 [c,d]	0.268 ± 0.090	0.298 ± 0.071
D_{CO} (%)	85.7 ± 15.7 [a,b,c,d]	95.2 ± 19.7 [d]	94.7 ± 21.6	100.3 ± 22.8	111.5 ± 22.1

Results presented in averages ± standard deviation. Kruskal-Wallis test for multiple comparisons of means of orders from independent samples.
a – Significant differences (p<0.05) with the pre-obese group. b – Significant differences (p<0.05) with obesity class I. c – Significant differences (p<0.05) with obesity class II. d – Significant differences (p<0.05) with obesity class III. BMI: body mass index; CI: inspiratory capacity; CPT: total pulmonary capacity; CRF: functional residual capacity; CV: vital capacity; CVF: forced vital capacity; Dco: carbon monoxide diffusing capacity kPa/L/s: kilopascals per liter per second; L: liters; Rva: airway resistance; VEF1: forced expiratory volume in the first second; VEF1/CVF: ratio between the forced expiratory volume in the first second and forced vital capacity; VR: residual volume; VR/CPT: ratio between residual volume and total pulmonary capacity; VRE: expiratory reserve volume.

In the present study, VEF_1 and CVF tend to decrease with increasing BMI (there were no statistical differences), however, the VEF_1/CVF ratio remained normal. Zerah et al.[22], also found that the VEF_1/CVF ratio remained within the normal range (absence of obstructive component) in a study to characterize the properties of the respiratory system in individuals within various classes of obesity, justifying this fact by the decrease in VEF_1 followed by the proportional reduction in CVF. Lazarus et al.[23] verified that in individuals within obesity class I and II, the spirometry test revealed progressively restrictive ventilatory alterations, and that individuals in obesity class III showed airway obstruction. The authors explained that the final result might be related to the collapsing of small airways resulting from decreased lung volumes with increased obesity. In the present study, obstructive or restrictive ventilatory alterations were not detected in the spirometry test because one of the defined exclusion criteria was the presence of ventilatory alterations, i.e., the study included only patients with CVF, VEF_1, and normal VEF_1/CVF ratio.

The average CPT was statistically higher in the group of individuals with normal BMI compared to those in the other BMI categories (except obesity class III), i.e., it significantly decreased with increasing weight. Jones and Nzekwu[13] obtained similar results because their sample in individuals with normal BMI showed higher CPT values in relation to the other groups. These authors concluded that there was a decrease of 0.5% in CPT for each unit increase in BMI; the average CPT in the obesity class III group was only 12% lower than expected. Different results were obtained for this variable by Watson et al.[24] because these authors compared two BMI groups (non-obese – mean: 25.5 kg/m^2 and obesity – mean: 38.8 kg/m^2) and did not find significant differences in CPT. This last study included only male subjects and evaluated only two groups of individuals, i.e., its sample was not subdivided into various obesity classes. These methodological differences may eventually be responsible for the discrepancy between results.

The study of Zerah et al.[22] included 46 healthy individuals of both genders who were divided into three groups according to their BMI: 13 pre-obese (group 1), 24 with BMI between 30 and 40 kg/m^2 (group 2), and nine at obesity class III (group 3). This study found a restrictive pattern defined as 20% reduction in CPT in 8% of individuals in group 1, 25% in group 2, and 56% in group 3. In the present investigation, this type of evaluation was not conducted, nor was such criterion used. However, from the analysis of averages and verification of absence of CPT differences of statistical significance between the various obesity groups (pre-obese, obesity class I, II, and III), it was found that increased BMI in such groups was not responsible for restrictive ventilatory alterations and did not promote a significant decrease in the percentage of CPT.

It was observed that VRE decreased over the BMI categories (except in obesity class III). Costa et al.[25] suggest that the VRE reduction can possibly be attributed to decreased diaphragmatic mobility towards the abdomen during inspiration, a phenomenon that is caused by the increase in abdominal volume in obese individuals. Pre-obese and individuals with normal BMI exhibit levels of VRE statistically higher than those in the obesity classes I, II, and III groups. Significant differences between normal BMI and pre-obese individuals were also observed, i.e., VRE decreases in the early stages of weight gain, however, between classes with higher BMI (obesity classes I, II, and III), the corresponding increased BMI is not followed by the decrease in VRE. A possible explanation for this result may be that VRE in obesity groups is low (0.52 L, 0.43 L, and 0.52 L), therefore, a progressive and proportional reduction of this parameter would lead to reaching physiological limits.

For Jones and Nzekwu[13], VRE decreases exponentially with increasing BMI, however, unlike the results presented here, these authors reported differences between the various obesity classes because obesity class I subjects had VRE of 42.4+29.3% of the predicted value, whereas those in the obesity class III group showed VRE of 24.6 + 18.8%.

According Bedell et al.[26] and Zerah et al.[22], obesity can lead to decreased CRF, secondary to a decreased VRE. The results of the present study revealed that CRF decreases over the BMI groups (except in obesity class III). Jenkins and Moxham[27] and Jones and Nzekwu[13] found in their studies that CRF decreased with increasing BMI; these latter authors observed that this parameter decreased approximately 0.5% per unit of increase in BMI. In the present study, the group with normal BMI had statistically higher values of CRF compared to the other groups, and the pre-obese group showed levels of this variable statistically higher than those seen in the obesity class I group. These results show that the effect of increasing BMI is not accompanied by an equal reduction in CRF along the obesity groups because only BMI increases, responsible for the inclusion of individuals within the pre-obese and obesity class I groups, show statistically significant reductions in CRF. In the other classes of obesity, despite the increase in BMI between groups, there was no reduction with statistical significance between them.

The obesity class III group showed an average VR (100.0 + 20.3%) very similar to that found in the group of subjects with normal BMI (100.4 + 23.4%). Sharp et al.[28] reported that the VR results in the obesity class III were higher in the group with normal BMI. These authors reported that there was a significant reduction in VR values with increasing obesity. In the present study, a statistical reduction of this parameter with increasing BMI was noticed because the group with normal BMI had levels of this functional respiratory variable statistically higher than those in the pre-obese and obesity class I groups.

Jones and Nzekwu[13] demonstrated that although the decrease in VR values depends on the BMI, there were no significant differences between the various parameters among the BMI groups. In the present investigation, VR remained within the normal range in all groups, and no increase in this variable was observed in relation to predicted values. In the study of Sharp et al.[28], increased VR in subjects with BMI<40 kg/m^2 is suggestive of a concomitant disease.

Jenkins and Moxham[27] showed that VRE and CRF decreases proportionally to the degree of obesity while CV is often normal. In the current study, VRE, CRF, and VC are within the normal range; VC in the pre-obese group was statistically above those recorded in the obesity class II and obesity class III groups. Lazarus et al.[23] have shown that obesity can be associated with the CV reduction depending on age, type of fat distribution, and severity of obesity. Jones and Nzekwu (2006)[13] verified that the effect of increasing BMI in lung volumes leads to a decrease of approximately 0.5% in CV per unit increase in the BMI.

The Rva analysis revealed that this parameter increases along the BMI classes, with the obesity class III group presenting the highest value (0.298 kPa/l/s); however, Rva was not above the normal limits in any group. King et al.[29] and Watson and Pride[10] report that Rva in obese individuals may be increased, and may not be entirely due to lung volume reduction, since the differences between obese and non-obese individuals may persist after adjusting for this variable. Out of all studied respiratory function parameters, Rva was one in which there have been significant differences in a high number of groups. Zerah et al.[22] observed a significant increase in this parameter in obesity class III individuals compared to those in the obesity class I. In our study, this difference was also noted. However, important differences were also determined in other groups.

D_{CO} values increased over the BMI groups. It was found that individuals within the obesity class III showed the highest average in this parameter (111.5 + 22.1%); DCO remained within normal limits in all groups. Oppenheimer et al.[30] developed a study that analyzed D_{CO} in obesity class III, asymptomatic, and without evidence of heart or lung disease individuals. They found that the average of this variable was within the normal range suggesting that the function of the alveolar-capillary membrane was normal in these individuals.

There are authors who obtained increased D_{CO} values in obese individuals, such as Saydain et al.[31] who studied two groups of individuals, group 1 with normal D_{CO} (85-115%) and group 2 with increased D_{CO} (>140%), and identified that individuals with elevated D_{CO} had BMI (32.9 + 7.4 kg/m^2) higher than that observed in the group with normal D_{CO} (29.4 + 4.4 kg/m^2).

The normal BMI group showed statistically lower D_{CO} than that found in the pre-obese, obesity class I, obesity class II, and obesity class III groups; the pre-obese group had lower values than those in the obesity class III group. Jones and Nzekwu[13] determined the existence of a small but significant increase in D_{CO} with increased BMI, since individuals with BMI between 20 and 35 kg/m^{2}exhibited D_{CO} values that were significantly lower than those found in the group with BMI>40 kg/m^2. Contrary results were obtained by Enache et al.[32] because the average D_{CO} in the group of obese individuals was slightly but statistically lower (-6%) than that in the control group (non-obese).

Obesity promotes abnormalities in the ventilation-perfusion ratio, with D_{co} usually preserved in obese subjects. There are published reports of situations in which this can be reduced or increased.[11,12] In the present investigation, although the observed D_{co} values are not abnormally high, they are statistically superior to those obtained in the group with normal BMI. Li et al.[12] suggested increased blood lung volume in obese individuals as the reason for increased D_{co} values.

CONCLUSION

This investigation provides a global and integrated view of the BMI effects on respiratory function with the analysis of multiple respiratory function parameters. Most studies in the literature only report reduction in lung volumes, particularly of CRF and VRE. In this study, obesity promoted significant changes in CPT, VR, CV, Rva, and D_{CO}.

The majority of changes in the respiratory function parameters occurred in minor degrees of obesity, i.e., there were differences between normal BMI and pre-obese and obesity groups (CPT, VRE, CRF, VR, and D_{CO}). Rva differences were only observed among the obesity class I, class II, and class III groups. These results reveal that the initial increase in BMI is accompanied by a more significant effect on pulmonary function than those that are promoted by the subsequent increase in BMI, i.e., the progression of obesity does not appear to cause changes in lung function variables in the same magnitude as those that are caused by the initial increase in BMI.

This study alerts to the need for valuing the effects of increased BMI in respiratory function because even in individuals without ventilatory alterations, significant changes in lung function variables are registered.

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