Waist to Height Ratio and Metabolic Syndrome as lung dysfunction predictors

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Metabolic Syndrome (MetS) has been related to pulmonary diseases but its relationship with lung age has not been sufficiently studied. In addition, anthropometric variables have been associated with pulmonary dysfunction, highlighting the waist-to-height ratio (WHtR). The aim was to evaluate the relationship between MetS and: lung age, anthropometric variables and the alteration of lung function. A cross-sectional study was carried out in 1901 workers, evaluating lung function through lung age (Morris & Temple equation) and spirometric values. The diagnosis of MetS was based on the harmonized criteria. We measured anthropometric variables (WHtR, waist circumference, body mass index, waist to hip ratio), blood pressure and biochemical variables (glucose, cholesterol total, HDL, triglycerides). Workers suffering from MetS showed an accelerated lung aging (59.4 ± 18.7 years vs 49 ± 18.4 years). The WHtR ≥ 0.55 was significantly related to an increase in lung age (β = 6.393, p < 0.001). In addition, a significant linear trend was found between clinical categories of WHtR and lung dysfunction, restrictive and mixed pattern. MetS caused an accelerated lung aging and favored the presence of restrictive lung impairment. In addition, WHtR ≥ 0.55 has been shown as the best predictor for pulmonary health.

Metabolic Syndrome (MetS) is defined as a group of cardiometabolic disorders that increase the risk of suffering from cardiovascular diseases and type II diabetes mellitus. Its prevalence is over 30% in several countries 1-3. Abdominal obesity and insulin resistance are a key factor in the development of the characteristic alterations of MetS. Highlights include increased blood pressure, mixed dyslipidemia and impairment of different organs 4,5. Several studies have shown in recent years that insulin resistance and MetS could be associated with alterations in lung function. This has been observed both in subjects with established respiratory pathologies and in healthy populations, and it is associated with the development of asthma, restrictive diseases or chronic obstructive pulmonary disease 6,7. Pulmonary dysfunction is related to the appearance of cardiovascular diseases, both of them being among the leading causes of death worldwide. This has a high impact on the quality of life of people and the economic burden on health systems 8-11.

Therefore, early diagnosis of MetS and lung dysfunction is necessary for the prevention of cardiovascular complications and mortality associated with both diseases. However, the invasiveness or diagnostic complexity of the methods used complicates their application in the clinical setting. Concerning MetS, diverse works have developed instruments that facilitate its diagnosis through the use of anthropometric measurements. The waist-to-height ratio (WHtR) has been postulated as the best predictive measure for MetS for a cut-off point of 0.55 12,13.

Spirometry is the test of election for the assessment of lung function. For the interpretation of the results it provides, reference formulas for the calculation of normal or standard values are required. However, there is a wide variety of estimation equations, such as the Global Lung Initiative, which means that clinicians have to choose one among several. Also, they must take into consideration that not all are validated for all populations 14,15. All this could make it difficult for health care professionals to make a correct assessment 16.

In this sense, lung age, a parameter proposed for motivation in smoking cessation, is an easily interpreted variable by health professionals and patients for the early detection of pulmonary dysfunction. Several studies
have demonstrated that lung age is associated with the severity of asthmatic pathology and that it is sensitive to systemic pathological processes such as overweight and obesity, causing the aging of the lungs. However, their possible relationship with MetS has not been established at present17–19. As with MetS, the literature has shown how anthropometric indices of central obesity are associated with respiratory dysfunction. Nevertheless, despite the strong association that the waist-to-height ratio (WHtR) has shown with the alteration of lung function in healthy adults and the pediatric population, the cut-off point of 0.55 has not been assessed20–22. Therefore, the main objective of the study is to determine whether MetS is associated with respiratory dysfunction as measured by lung age. The initial hypothesis is that those subjects suffering from MetS present a higher lung aging. Also, the aim is to assess what type of pulmonary dysfunction is most prevalent amongst sufferers of MetS and to establish which of its components, anthropometric variables and pathological situations are significantly associated with lung aging.

Material and Methods

Study design and sample. We carry out a cross-sectional study on the working population of Córdoba City Council (Spain) that employs an average of 1,760 workers per year. The minimum sample size calculated was of 1,685 workers for a power of 80%, a precision of 1.5%, a confidence of 95%, and an expected prevalence of MetS of 14.9%. The final sample, stratified by age and sex, was composed of 1,901 workers selected randomly among those who had undergone an occupational health examination at the City Council Occupational Health Unit between 2015 and 2019.

The exclusion criteria were to suffer from an acute or chronic pulmonary pathology (asthma, chronic bronchitis, emphysema, pneumonia, chronic obstructive pulmonary disease) or any other pathology affecting lung function; and not to be capable of performing the spirometric test adequately. The total number of workers excluded due to pulmonary pathology was 168. Moreover, according to the specific occupational risk assessment of the workplaces, none of the selected workers was exposed to working conditions (risk of inhalation of inorganic or organic dust, aerosols, or substances of high molecular weight), which could cause the appearance of occupational pulmonary pathology.

Study variables. Pulmonary function (result variable) was studied through the lung age calculated by the formula proposed by Morris et al.17.

Women: Lung age(years) = 4.792 × height − (41.667 × FVC) − 118.883
Men: Lung age(years) = 5.920 × height − (40.00 × FVC) − 169.640

The height is expressed in inches (1 inch = 2.54 cm) and the forced vital capacity (FVC) in liters. We established the minimum lung age at 20 years, with no limitation on the maximum one. The difference between the lung age and the chronological age of the workers was calculated18.

Also, the spirometric parameters were collected: forced expiratory volume in the first second (FEV1), FVC and their quotient (FEV1/FVC). Theoretical values were calculated for each of the parameters in the aim of finding out the relationship with the values obtained in practice (FEV1, % of predicted and FVC% of predicted). The patients’ lung function status was classified according to the following criteria23:

- Normality: FEV1/FVC > 0.7 and %FVC of predicted > 0.8;
- Restrictive pattern: FEV1/FVC > 0.7 and %FVC of predicted < 0.8;
- Obstructive alteration: FEV1/FVC < 0.7 and %FVC of predicted > 0.8;
- Mixed pattern: FEV1/FVC < 0.7 and %FVC of predicted < 0.8.

The independent variables collected were age, gender and those grouped into:

- Lifestyles: smoking habit (non-smoker, ex-smoker and smoker); and physical activity (International Physical Activity Questionnaire, IPAQ) measured in METs and categorized as light, moderate and intense.
- Anthropometric variables: weight (kg), height (cm), body mass index (kg/m², BMI), waist circumference (cm, WC), hip circumference (cm, HC), body fat percentage (Deurenberg), waist to hip ratio (WHR), waist to height ratio (WHtR), systolic and diastolic blood pressure (SBP and DBP, mmHg). Also, we considered three clinical categories for the WHtR (< 0.5; 0.51–0.54, ≥ 0.55) following the cut-off points proposed by Romero-Saldana et al.24 and Ashwell et al.25. For the categorization of the BMI, the recommendation established by the World Health Organization was followed.
- Analytical variables: fasting plasma glucose (mg/dl), HDL-cholesterol (mg/dl) and triglycerides (mg/dl).

Evaluation and measurement of variables. MetS diagnosis was established based on the harmonized criteria that define it by the presence of three or more of the following alterations. WC ≥ 102 cm in men, WC ≥ 88 cm in women; High Blood Pressure (HBP) ≥ 130/85 mmHg or undergoing treatment for high blood pressure; triglycerides ≥ 150 mg/dl; HDL < 40 in women, and < 50 in men or being under pharmacological treatment; and fasting glucose ≥ 100 mg/dl or undergoing hypoglycemic treatment or diagnosis of Diabetes Mellitus1.

We obtained the spirometric values using the spirometer DATOSPIR 120 C (Silbemed; Barcelona; España), following the recommendations established by the Spanish Society of Pneumology and Thoracic Surgery (SEPAR)25. For the measurement, the worker was required not to use bronchodilators, not to smoke and not to do physical exercise in the previous hours. The test was performed with the worker sitting down, with his back straight and leaning against the chair back, and with a nose clip attached. We asked to inhale as much air as possible and to blow fast and strongly until it was indicated. The workers performed at least three acceptable tests, and the highest spirometric values were selected. We used the criteria of SEPAR to consider spirometry acceptable: rapid start (back-extrapolated volume less than 5% of the FVC) and without hesitation; continuous expiratory test...
with a duration not less than 6 seconds; no abrupt end (final changes in volume lower than 0.025 l for ≥1 s; and no anomalies in the technique (cough, new inhalation, among other). Two or three acceptable maneuvers were necessary for its interpretation in which the difference between the two best FVC and FEV1 was not more than 0.21.

The anthropometric measurements were recorded following the recommendations in the standardized anthropometry reference manual25. The weight and height were measured using a stadiometer and Atlántida S11 balance (Básculas y Balanzas Añó-Sayol, Barcelona, Spain), with a precision of 0.1 kg and 0.1 cm, respectively. WC was measured halfway between the last rib and the iliac crest after a normal exhalation. HC was measured at the widest point on the buttocks. Both measurements were taken with the worker standing, feet together, using a flexible steel tape. Blood pressure was measured as recommended in the Manual of Hypertension in Primary Care Clinical Practice26, using a calibrated digital sphygmomanometer (OMRON M3, OMRON Healthcare Europe, Spain). All the measures were recorded by experienced staff to decrease the variation coefficient, repeating each one three times and calculating the mean12,13.

**Legal and ethical aspects.** All the workers were informed, verbally and in writing, of the objectives of the health study to which they were being submitted, and an informed consent was obtained from each in compliance with the current regulations. The study's protocol complied with the Declaration of Helsinki for conducting research involving human subjects and was approved by the Bioethical Committee of Córdoba (Spain) (4427/Acta number 295).

**Statistical analyses.** The quantitative variables are presented as the mean and standard deviation, the qualitative values presented as frequencies and percentages27.

To contrast the goodness-of-fit to a normal distribution of the data from the quantitative variables, the Kolmogorov–Smirnov test with the Lilliefors correction was employed. The Student’s t-test for two means was performed for the bivariate hypothesis contrast, whereas for the qualitative variables, the z-test for independent proportions and the Chi-square and Fisher exact test were used when necessary. In addition, for the correlation between the quantitative variables, the Pearson’s correlation coefficient (r) was used27. The analysis of covariance (ANCOVA) was made to diminish the heterogeneity produced by the influence of the chronological age on lung age.

Adjusted multiple linear regressions were made according to age, gender, smoking habits, and physical activity, with each explanatory variable to determine their prediction capacity for lung age. To determine the goodness-of-fit of the models, we analyzed the standard error, the adjusted coefficient of determination, the F statistic, the linearity analysis, and the residues.

For all the statistical analyses, the probability of an α error of below 5% (p < 0.05) was considered statistically significant and the confidence interval was calculated at 95%. For the statistical analysis, IBM SPSS Statistics 22.0 software (IBM, Chicago, IL, USA) and Epidat 4.2. (Department of Sanidade, Xunta de Galicia, Galicia, Spain) were used.

**Results**

**Sample description.** Out of a total of 1,901 workers, 51.3% (95% CI 49–53.6%) were women. The mean age was 43.6 ± 10.9 years (95% CI 43.1–44.5 years). The mean BMI was 26.7 ± 5.4 kg/m² (95% CI 26.5–27 kg/m²). Based on the criteria established by the BMI, the prevalence of overweight (BMI ≥ 25 kg/m²) rose to 35% (95% CI 32.8–37.2%) and of obesity (BMI ≥ 30 kg/m²) to 22.9% (95% CI 21–24.8%).

The proportion of workers who smoked was 34.3% (95% CI 32.2–36.5%), being higher in women than in men (p < 0.001). The prevalence of HBP, type 2 diabetes mellitus and MetS reached 38.9% (95% CI 36.7–41.2%), 6% (95% CI 5–7.2%) and 18.3% (95% CI 16.5–20.1%), respectively. In all cases, it was significantly higher in men (p < 0.05).

Regarding pulmonary function status, the restrictive lung impairment was the most prevalent (13.5% [95% CI 12–15.1%]), with differences observed by sex (p < 0.01). Finally, lung age was 50.8 ± 20.3 years (95% CI 49.9–51.7 years), being higher in men (p < 0.001).

Table 1 contains a summary of all the variables collected stratified by sex.

**Metabolic syndrome and lung dysfunction.** The mean chronological age was significantly lower in workers suffering from metabolic syndrome (MetS[yes]) than in those who did not (MetS[no]) (p < 0.001). However, the mean lung age was 62.7 ± 19.1 years in the MetS[yes] compared to 48.3 ± 19.1 years in the MetS[no] (p < 0.001).

Introducing in the analysis of covariance (ANCOVA) the chronological age, the differences between both groups remained statistically significant (MetS[yes] vs MetS[no]; 59.4 ± 18.7 years vs 49 ± 18.4 years; p < 0.001) (Table 2). Also, analyzing the difference between lung age and chronological age, it was found that it was significantly higher in MetS[yes] (Table 2).

The study of lung dysfunction showed that these were more prevalent among workers suffering from MetS (p < 0.01) (Table 3). Focus the analysis on MetS[yes], the restrictive pattern was observed in a higher proportion (23.4%) than the obstructive (10.3%) and the mixed patterns (7.3%) (p < 0.001).

**Lung age and independent variables.** The multiple linear regressions showed that the WHR (β = 42.411, t (1817) = 8.874; p < 0.001) and the WHR (β = 41.438, t (1817) = 7.594; p < 0.001) were the variables that were best associated with lung age. With respect to pathologies, the results evidenced that MetS (β = 9.919, t (1817) = 8.727; p < 0.001) was the one that was most associated with lung aging, followed by type 2 Diabetes Mellitus (β = 9.041, t (1817) = 4.942; p < 0.001) and obesity (BMI ≥ 30 Kg/m²) (β = 5.993, t (1817) = 5.870; p < 0.001).
The variation estimated for lung age showed, to equality of the rest of variables, an increase of 4.2 and 4.1 years for each increase in 0.1 of the WHR and WHtR, respectively. Also, it was observed that a WHtR equal to or higher than 0.55 presented significantly greater lung aging (p < 0.001) (Table 4).

In extending the analysis to the clinical categories of the WHtR, it was found that workers who had a WHtR ≥ 0.55 (31.8%, 18.9%, 4.8%), than in 0.51–0.54 (23.2%, 9.9%, 3.4%) and ≤ 0.5 (20%, 10%, 1.2%) were associated with increased lung age. These results agree with previous studies which showed that the presence of MetS caused a significant reduction in FVC% of predicted and FEV1% of predicted. Also, it was observed that a WHtR equal to or higher than 0.55 was associated with a lung aging of 64 years (Table 4).

The prevalence of global lung dysfunction, restrictive and mixed patterns was significantly higher in group WHtR ≥ 0.55 (31.8%, 18.9%, 4.8%), than in 0.51–0.54 (23.2%, 9.9%, 3.4%) and ≤ 0.5 (20%, 10%, 1.2%) (p < 0.001). Also, Table 6 exhibits a significant linear trend in the prevalence ratio of lung dysfunction and its types and the clinical categories of WHtR (p < 0.001), except for in the obstructive alteration.

Discussion

The study aimed to determine whether the MetS is associated with respiratory dysfunction as measured by lung age; to evaluate what pulmonary dysfunction is more prevalent among those who suffer from MetS; and what MetS components, variables and pathologies are significantly associated with lung aging in the adult population.

Lung aging is a natural event that can be aggravated by local or systemic pathological processes, being the lung age a sensitive variable to them. About systemic processes, morbid obesity (BMI ≥ 40 kg/m²) has been linked to accelerated lung aging. In this respect, our results showed that elevation of BMI (β = 0.374; p < 0.001) and obesity (BMI ≥ 30 kg/m²; β = 5.993; p < 0.001) were associated with increased lung age. These results agree with those reported by Mehari et al., who found that an increase in BMI produced a reduction in the lung volume in the Afro-American population.

The association between the alteration of the lung function and the MetS has been widely demonstrated. In this sense, Cheng et al. showed that the presence of MetS caused a significant reduction in FVC% of predicted and FEV1% of predicted. Yong et al. observed that, in the lowest quartile of both parameters, there was an increase in MetS cases. According to these results, our study showed that workers with MetS had a higher mean lung age (59.4 ± 18.7 vs 49 ± 18.4 years; p < 0.001) and a greater difference between this and their chronological

| Variables                    | Total (n = 1901) | Women (n = 975–51.3%) | Men (n = 926–48.7%) | p        |
|------------------------------|------------------|-----------------------|--------------------|----------|
| Age (n = 1901)               | 43.6 (SD 10.9)   | 41.6 (SD 10.5)        | 45.6 (SD 10.9)     | <0.001   |
| Height (n = 1901)            | 167.8 (SD 9.4)   | 161.3 (SD 6.3)        | 174.8 (SD 6.7)     | <0.001   |
| Weight (n = 1901)            | 75.6 (SD 17.3)   | 68.4 (SD 15.8)        | 83.1 (SD 15.5)     | <0.001   |
| BMI (n = 1901)               | 26.7 (SD 5.4)    | 26.3 (SD 6)           | 27.2 (SD 4.7)      | <0.01    |
| Underweight                 | 42 (2.2%)        | 33 (3.4%)             | 9 (1%)             | <0.001   |
| Normo-weight                | 759 (39.9%)      | 452 (46.3%)           | 307 (33.1%)        | <0.001   |
| Overweight                  | 665 (35%)        | 263 (27%)             | 402 (43.4%)        | <0.001   |
| Obesity                     | 435 (22.9%)      | 227 (23.3%)           | 208 (22.5%)        |          |
| Waist (n = 1844)             | 89.5 (SD 14.2)   | 84.4 (SD 13.6)        | 94.9 (SD 12.8)     | <0.001   |
| Hip (n = 1869)               | 102.7 (SD 10.7)  | 102.9 (SD 11.5)       | 102.5 (SD 8.6)     | NS       |
| WHR (n = 1869)               | 0.87 (SD 0.09)   | 0.82 (SD 0.08)        | 0.92 (SD 0.07)     | <0.001   |
| WHtR (n = 1844)              | 0.53 (SD 0.08)   | 0.52 (SD 0.09)        | 0.54 (SD 0.08)     | <0.001   |
| %BF (n = 1901)               | 31.5 (SD 8.5)    | 35.8 (SD 7.8)         | 26.9 (SD 6.6)      | <0.001   |
| Non-Smoker                  | 929 (48.9%)      | 458 (47%)             | 471 (50.9%)        | <0.001   |
| Ex-smoker                   | 318 (16.7%)      | 126 (12.9%)           | 192 (20.8%)        | <0.001   |
| Smoker                      | 652 (34.3%)      | 390 (40%)             | 262 (28.3%)        |          |
| Glucose (n = 1886)           | 99.5 (SD 27.9)   | 98.6 (SD 28.5)        | 100.6 (SD 27.2)    | NS       |
| HDL (n = 1878)               | 63.2 (SD 14.5)   | 66.5 (SD 14.6)        | 59.7 (SD 13.4)     | <0.001   |
| Triglycerides (n = 1881)     | 108.3 (SD 68.3)  | 96.6 (SD 54.3)        | 120.6 (SD 78.7)    | <0.001   |
| HDL (n = 1900)               | 740 (38.9%)      | 263 (27%)             | 477 (51.5%)        | <0.001   |
| Type II DM (n = 1886)        | 114 (6%)         | 44 (4.5%)             | 70 (7.7%)          | <0.01    |
| Metabolic Syndrome (n = 1860)| 340 (18.3%)      | 153 (16%)             | 187 (20.6%)        | <0.05    |
| LD (n = 1856)                | 472 (25.4%)      | 216 (23%)             | 256 (27.9%)        | <0.05    |
| Restrictive                 | 250 (13.5%)      | 122 (13%)             | 128 (14%)          |          |
| Obstructive                 | 165 (8.9%)       | 76 (8.1%)             | 89 (9.7%)          | <0.01    |
| Mixed                       | 57 (3.1%)        | 18 (1.9%)             | 39 (4.3%)          |          |

Table 1. Sample characteristics. BMI: Body Mass Index; WHR: Waist to hip ratio; WHtR: Waist to height ratio; BF: Body fat; DM: Diabetes Mellitus; HBP: High Blood Pressure; LD: Lung Dysfunction; NS: Non-significative.
In addition, it is important to note that, according to our results, suffering from MetS was associated to a greater extent with lung aging ($\beta = 9.919; p < 0.001$) than with obesity ($\text{BMI} \geq 30 \text{ Kg/m}^2; \beta = 5.993; p < 0.001$). These results are consistent with those found in other studies, where a higher impact on pulmonary function when metabolic alterations are present with or without obesity, have been evidenced32,33.

These alterations in spirometric values due to MetS are clinically relevant through the appearance of pulmonary diseases6. In our study population, the total prevalence of lung dysfunction rose to 25.4%, with a significantly higher proportion among individuals suffering from MetS (41% vs 21.9%; $p < 0.001$). Furthermore, it is worth

| Variable | Total (n = 1816) | MetS [Yes] (n = 329) | MetS [No] (n = 1487) | p |
|----------|-----------------|----------------------|----------------------|---|
| Lung Dysfunction | 461 (25.4%) | 135 (41%) | 326 (21.9%) | <0.001 |
| Restrictive | 250 (13.5%) | 77 (23.4%) | 166 (11.2%) | <0.001 |
| Obstructive | 165 (8.9%) | 34 (10.3%) | 127 (8.6%) | NS |
| Mixed | 57 (3.1%) | 24 (7.3%) | 33 (2.2%) | <0.001 |

Table 3. Relation between Metabolic Syndrome and Lung Dysfunction. NS: Non-significative.

| Variable | $\beta$ | Standardized $\beta$ | t | $R^2$ adjusted | p |
|----------|---------|----------------------|---|----------------|---|
| Body Mass Index | 0.374 | 0.099 | 4.697 | 0.190 | <0.001 |
| Waist | 0.271 | 0.187 | 8.605 | 0.205 | <0.001 |
| Hip | 0.157 | 0.078 | 3.677 | 0.187 | <0.001 |
| Waist to Hip Ratio | 42.411 | 0.201 | 8.874 | 0.207 | <0.001 |
| Waist to Height Ratio | 41.438 | 0.165 | 7.594 | 0.206 | <0.001 |
| Waist to Height Ratio $\geq 0.55$ | 6.393 | 0.152 | 7.056 | 0.202 | <0.001 |
| % Body Fat | 0.312 | 0.129 | 4.697 | 0.190 | <0.001 |
| Glucose | 0.101 | 0.139 | 6.551 | 0.197 | <0.001 |
| HDL | -0.163 | -0.115 | -5.222 | 0.189 | <0.001 |
| Triglycerides | 0.049 | 0.164 | 7.569 | 0.203 | <0.001 |
| Obesity | 5.993 | 0.123 | 5.870 | 0.195 | <0.001 |
| High Blood Pressure | 2.767 | 0.066 | 2.854 | 0.184 | <0.001 |
| Diabetes Mellitus type 2 | 9.041 | 0.105 | 4.942 | 0.189 | <0.001 |
| Metabolic Syndrome | 9.919 | 0.187 | 8.727 | 0.212 | <0.001 |

Table 4. Lineal multiple regression for Lung Age. Models adjusted by age, smoking habit, sex and physical activity (dichotomized: light and active (moderate and intensity).

| Variable | ≤0.5 | 0.51–0.54 | ≥0.55 | p |
|----------|------|-----------|-------|---|
| Lung Age | 44.6 (17.3) | 50.1 (20) | 57.2 (21.6) | <0.001 |
| L. Age – C. Age | 5.2 (18.1)* | 5.1 (18.7)* | 10.1 (19.4) | <0.001 |

Table 5. WHtR Clinical Categories and lung age. *Without significant differences in post-hoc tests; L. Age – C. Age: Difference between Lung Age and Chronological Age; WHtR: Weight to height ratio.

age (15.6 ± 18.7 vs. 5.2 ± 18.4 years; $p < 0.001$). In addition, it is important to note that, according to our results, suffering from MetS was associated to a greater extent with lung aging ($\beta = 9.919; p < 0.001$) than with obesity ($\text{BMI} \geq 30 \text{ Kg/m}^2; \beta = 5.993; p < 0.001$). These results are consistent with those found in other studies, where a higher impact on pulmonary function when metabolic alterations are present with or without obesity, have been evidenced32,33.

These alterations in spirometric values due to MetS are clinically relevant through the appearance of pulmonary diseases6. In our study population, the total prevalence of lung dysfunction rose to 25.4%, with a significantly higher proportion among individuals suffering from MetS (41% vs 21.9%; $p < 0.001$). Furthermore, it is worth...
noting that the restrictive impairment was the most observed in this group (23.4%), a fact that the literature has amply evidenced.

Related to this, Ford et al. found that the prevalence rate of restrictive pattern was higher among those with MetS not occurring with the obstructive.

Moreover, the components of the MetS have been related to the alteration of the spirometric values. This fact is consistent with our findings since the change in the normal values of each component was associated, at a different magnitude, with an accelerated lung aging.

However, abdominal adiposity has been presented as a marker that permits the early detection of alteration in pulmonary function in different populations, emphasizing WC. Our findings have evidenced that the increase of the WC causes an increment in the lung age (β = 0.374; p < 0.001), mediated by the affection of the FVC implicated in its calculation. These results are consistent with those shown by other authors, pointing that the WC is that which has shown the strongest correlation with the reduction of spirometric values, and it is the most suitable variable for lung function prediction in general, and, in particular, for the restrictive impairment.

Nevertheless, the authors recommend the use of the WHtR as it permits the evaluation of the variation in WC in relation to height, and it is associated with the appearance of cardiovascular diseases. In addition, the literature has evidenced its predictive capacity in the diagnosis of MetS, with its highest validity index at the cut-off point of 0.55. With respect to lung dysfunction, our results showed that the increase in WHtR was related to accelerated lung aging (β = 42.411; p < 0.001).

The WHtR ≥ 0.55 increased lung age by 6.4 years and presented a difference between lung age and chronological age of 10 years compared to 5 years for the WHtR < 0.55. It should be pointed out that although the subjects with MetS showed aging of 9 years concerning those without it, only the WHtR was responsible for 6 of those 9 years. Namely, the abdominal adiposity (measured by the WHtR) was responsible for 66.7% of lung aging caused by MetS.

Although no studies have evaluated this cut-off point so far, the literature has shown that WHtR is related to the appearance of pulmonary function impairment and that shows the strongest correlation with FEV₁ and FVC in different populations. Also, on studying WHtR according to clinical categories, we observed a significant linear trend in prevalence ratios for global lung dysfunction and restrictive and mixed patterns.

This trend was not observed for obstructive lung impairment. This fact could be explained by the relationship between insulin resistance and abdominal obesity, which can be measured by WHtR. Insulin resistance is one of the pathophysiological mechanisms associated with restrictive alteration and MetS, however, this resistance does not appear in the obstructive alteration.

Early detection of pulmonary disorders and MetS is fundamental to prevent the appearance of pathologies secondary to them. For this reason, the WHtR is recommended as a marker of central obesity, the main axis in the development of the pathologies mentioned above. The fact that it is calculated non-invasively, its easy measurement and it has a cut-off point (WHtR ≥ 0.55) that permits to predict the patients’ cardiovascular and lung health status, turns it into a cost-effective tool that can allow early approaches in the clinical setting.

Finally, lung age has been shown to be sensitive to changes in lung function mediated by MetS and its components. In our opinion, this finding allows it to be considered as a valid clinical indicator that makes it possible for patients to know the improvement of their lung health visually.

Limitations. There is no study linking lung age to MetS, which made it difficult to compare ours results with other populations. However, we believe that this line of research could give interesting results in clinical settings, as well as facilitate the interpretation of results by healthcare professionals and patients.

Conclusions

The MetS caused accelerated lung aging, and a close relationship was found between the later and the appearance of a restrictive lung impairment pattern. The lung age and its difference with the chronological age, have been evidenced as reference variables that permit to find out the respiratory health status simply and intuitively.

The WHtR proved to be the best variable to predict lung dysfunction since the rise in its value was associated with a higher lung age and an increase in the prevalence of pulmonary impairment. In particular, individuals with a WHtR ≥ 0.55 presented significantly worse lung health than those with WHtR < 0.55.


table

| Variable     | ≤0.5       | 0.51–0.54 | ≥0.55 | p     | p     |
|--------------|------------|-----------|-------|-------|-------|
| Lung Dysfunction | 1 (Ref.)   | 1.2 (0.9–1.5) | 1.6 (1.3–1.9) | <0.001 | <0.001 |
| Restrictive   | 1 (Ref.)   | 1 (0.7–1.4)  | 1.9 (1.5–2.5) | <0.001 | <0.001 |
| Obstructive   | 1 (Ref.)   | 1.1 (0.8–1.6) | 0.9 (0.7–1.3) | NS     | NS    |
| Mixed        | 1 (Ref.)   | 2.9 (1.3–6.9) | 4.1 (1.9–8.8) | <0.001 | <0.001 |

Table 6. Prevalence ratios for WHtR clinical categories. Ref.: Reference; L. Age – C. Age: Difference between Lung Age and Chronological Age; WHtR: Weight to height ratio; NS: Non-significative.

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**Author contributions**

R.M.L. contributed to conception and design of the research, analysis and interpretation of data and drafted the manuscript. M.R.S. contributed to Acquisition and interpretation of data and revised the manuscript. C.A.F., E.R.G. and A.H.R. contributed to acquisition of data. G.M.R. contributed to interpretation of data and revised the manuscript. All authors read and approved the final text.

**Competing interests**

The authors declare no competing interests.
Additional information

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