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Lung function and metabolic syndrome: Findings of National Health and Nutrition Examination Survey 2007–2010*

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Abstract

Background—Considerable uncertainty remains about obstructive lung function (OLF) in adults with metabolic syndrome (MetS). The aim of the present study was to examine pulmonary function status in adults with and without MetS.

Methods—We used data from 3109 participants aged ≥20 years of the National Health and Nutrition Examination Survey 2007–2010. Subjects' MetS status was established on the basis of the 2009 harmonizing definition. Participants received spirometry.

Results—After age adjustment, 79.3% (SE 1.1) of participants with MetS had normal lung function, 8.7% (0.9) had restrictive lung function (RLF), 7.1% (0.8) had mild OLF, and 4.8% (0.6) had moderate OLF or worse. Among participants without MetS, these estimates were 78.7% (1.2), 3.9% (0.6), 10.9% (1.1), and 6.4% (0.8), respectively. After multiple adjustment, participants with MetS were more likely to have RLF (adjusted prevalence ratio [aPR] 2.20; 95% confidence interval [CI] 1.67, 2.90) and less likely to have any OLF (aPR 0.73; 95% CI 0.62, 0.86) than those without MetS. Furthermore, participants with MetS had lower mean levels of forced expiratory volume in one second (FEV_1), FEV_1 % predicted, forced vital capacity (FVC), and FVC % predicted, but a higher FEV_1/FVC ratio than participants without MetS. Mean levels of FEV_1, FEV_1 % predicted, FVC, and FVC % predicted declined significantly, but not the FEV_1/FVC ratio, as the number of components increased.

Conclusions—Compared with adults without MetS, spirometry is more likely to show a restrictive pattern and less likely to show an obstructive pattern among adults with MetS.

*The findings and conclusions in this article are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

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Disclosure

The authors declare no conflict of interests.

Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site

Keywords

chronic obstructive pulmonary disease; cross-sectional studies; metabolic syndrome; spirometry

Introduction

The metabolic syndrome comprises a constellation of cardiometabolic abnormalities, including abdominal obesity, hypertriglyceridemia, low high-density lipoprotein–cholesterol (HDL-C), elevated blood pressure, and hyperglycemia. The syndrome is highly prevalent in many countries, including the US, where approximately 35% of adults have the metabolic syndrome based on the 2009 harmonizing definition.[1] In general, adults with metabolic syndrome show clinical or subclinical evidence of dysfunction of multiple organs. However, with regard to the pulmonary system, questions remain about potential differences in pulmonary function in adults with and without metabolic syndrome. Most of the large-scale studies investigating the associations between pulmonary function and metabolic syndrome have been conducted in Asian populations and, in the aggregate, indicate that metabolic syndrome is characterized by restrictive rather than obstructive lung function.[2–8] The associations between metabolic syndrome components and respiratory patterns have received less attention. Because information about the association between the metabolic syndrome and pulmonary function from population-based studies in the US is relatively scarce and an improved understanding of lung function in people with metabolic syndrome may have implications for their clinical management, we examined this issue in a national sample of adults.

Methods

The present study included data from the National Health and Nutrition Examination Survey (NHANES) 2007–2010. A stratified multistage probability sampling design was used to select participants. Those who agreed to participate were interviewed in their homes and asked to have an examination in the mobile examination center. During the examination, attendees completed additional questionnaires, underwent a series of examinations, and had phlebotomy. Response rates for the interview and examination were 78% and 75%, respectively, in NHANES 2007–2008 and 79% and 77%, respectively, in NHANES 2009–2010. Details about the surveys may be found elsewhere.[9] Because we used data freely available in the public domain, our study was exempt from human subjects review.

Metabolic syndrome was defined according to criteria published in the 2009 Joint Scientific Statement.[10] Waist circumference was measured at the high point of the iliac crest at minimal respiration to the nearest 0.1 cm. Abdominal obesity was defined using the following thresholds: waist circumference ≥102 cm in men and ≥88 cm in women for participants who were white, African American or of another race, and a waist circumference ≥90 cm in men and ≥80 cm in women for participants who were Mexican American or another Hispanic ethnicity. Serum triglyceride concentrations were measured enzymatically after hydrolyzation to glycerol (Roche Modular P chemistry analyzer, Roche, Indianapolis, IN, USA), and HDL-C was measured after non-HDL-C fractions were

complexed with a magnesium–dextran sulfate solution (Roche Modular P chemistry analyzer). Plasma glucose concentrations were measured using the hexokinase assay (Roche Modular P chemistry analyzer). For participants who had three blood pressure measurements, the average of the last two measurements of blood pressure was used. For participants with two measurements, the last measurement was used, and for participants who had one measurement, that single measurement was used to establish high blood pressure status. Diabetes was defined as diagnosed diabetes or, among adults without diagnosed diabetes,a fasting plasma glucose concentration ≥126 mg/dL.

Spirometry was offered to participants aged 6–79 years in NHANES 2007–2010, and we used data only for adults aged 20–79 years. Exclusion criteria included: current chest pain; physical problems with forceful expiration; the use of supplemental oxygen; recent surgery of the eye, chest or the abdomen; recent heart attack, stroke, tuberculosis exposure or coughing up of blood; and history of detached retina, collapsed lung, or aneurysm. Spirometry was performed with Ohio 822/827 dry-rolling seal volume spirometers (Ohio Medical Instrument Company), and participants were asked to provide three acceptable maneuvers.

Predictive equations for calculating forced expiratory volume in 1 s (FEV_1) and forced vital capacity (FVC) were based on those developed from NHANES III data.[11] Using the Global Initiative for Chronic Obstructive Lung Disease (GOLD) classification of chronic obstructive pulmonary disease (COPD) severity, which is based on post-bronchodilator spirometric results, we defined severe obstructive impairment as FEV_1/FVC <0.70 and FEV_1 <50% predicted, moderate obstructive impairment as FEV_1/FVC <0.70 and FEV_1 between 50% and <80% predicted, and mild obstructive impairment as FEV_1/FVC <0.70 and FEV_1 ≥80% predicted.[12] Participants with an FEV_1/FVC ratio ≥0.70 were divided into those with normal pulmonary function if their FVC was ≥80% predicted and those with restrictive function if their FVC was <80% predicted.

Covariates included age, gender, race or ethnicity (white, African American, Mexican American, and other), educational status (<12 years, high school graduate or equivalent, education beyond high school), smoking status (current, former, never), recreational physical activity, alcohol use, C-reactive protein (CRP) concentration, and body mass index (BMI). A current smoker was defined as someone who had smoked at least 100 cigarettes during his or her lifetime and reported currently smoking. A former smoker was defined as someone who had smoked at least 100 cigarettes during his or her lifetime but reported having stopped smoking. A never smoker was defined as someone who had not smoked at least 100 cigarettes during his or her lifetime. Metabolic equivalent (MET)-hours of recreational physical activity were calculated by summing the products of reported weekly hours of moderate and vigorous physical activity multiplied by their respective MET levels. The daily intake of alcohol drinks was established from a series of questions about the frequency of consumption of alcoholic beverages and average number of drinks on days that alcoholic beverages were consumed. Concentrations of CRP were measured using high-sensitivity nephelometry (N Latex CardioPhase hsCRP Reagent [Siemens Healthcare Diagnostics, Deerfield, IL, USA] and Dade Behring Nephelometer II Analyzer System

(BNII) [Dade Behring Diagnostics, Somerville, NJ, USA]). Body mass index was calculated from measured weight and height.

Analyses were limited to men and non-pregnant women aged ≥20 years. The direct method was used to calculate age-adjusted estimates of the prevalence of pulmonary function categories by using the projected Year 2000 US population. Analysis of covariance was used to calculate age-adjusted and multiple-adjusted mean levels of FEV_1, FVC, % predicted FEV_1, % predicted FVC, and FEV_1/FVC ratio. The significance of differences between mean values was tested with *t*-tests. The significance of differences for dichotomous variables was tested with Chi-squared tests or Wald Chi-squared tests in log-linear models. Tests for trend for pulmonary function parameters by number of cardiometabolic components were conducted with linear regression analyses. Data were managed using SAS (SAS Institute, Cary, NC, USA), and final estimates using sampling weights were produced with SUDAAN (RTI International, Research Triangle Park, NC, USA) to account for the complex sampling design.

Results

Of the 4932 men and non-pregnant women aged ≥20 years who attended the morning examination, data to establish metabolic syndrome and pulmonary function status were available for 4626 and 3846 participants, respectively (3721 had complete information for both). Subsequent deletions for missing covariate values reduced the analytic sample size to 3553. Limiting the sample to participants who had acceptable spirometric efforts resulted in a final analytic sample size of 3109 participants.

Among all 3109 participants, the unadjusted prevalence of metabolic syndrome was 34.3% (SE 1.2). Furthermore, 79.3% (1.1) had normal lung function, 6.0% (0.6) had a restrictive pattern, 9.0% (0.8) had mild obstructive impairment, 5.1% (0.6) had moderate obstructive impairment, and 0.6% (0.2) had severe or very severe obstructive impairment.

Compared with participants who did not have metabolic syndrome, those with metabolic syndrome were older, more likely to be male, and more likely to have less education (Table 1). Significant differences in mean age and the percentage of men, whites, and adults with >12 years of education were present among categories of pulmonary function status.

Adults with metabolic syndrome showed evidence of having more restrictive lung impairment and less mild obstructive impairment than those without metabolic syndrome (Table 2). Among the metabolic syndrome components, this pattern was replicated for abdominal obesity, hypertriglyceridemia, and low HDL-C. A higher percentage of participants with hyperglycemia also showed evidence of restrictive lung impairment than those with normoglycemia. In multivariate regression models, metabolic syndrome and all five components were significantly associated with the presence of restrictive impairment (Table 3). In contrast, metabolic syndrome, abdominal obesity, and hypertriglyceridemia were inversely associated with any obstructive impairment.

After adjusting for a series of covariates, participants with metabolic syndrome had lower mean levels of FEV_1, FEV_1 % predicted, FVC, and FVC % predicted but a higher

FEV_1/FVC ratio than participants without metabolic syndrome (Table 4). Most of these differences persisted after adjusting for BMI as well. For the individual components, the pattern of significant differences proved somewhat variable. Low HDL-C and elevated blood pressure had the most consistent pattern of significant differences. After adjusting for metabolic syndrome components, several of the differences were attenuated to the point of losing statistical significance. Mean levels of FEV_1, FEV_1 % predicted, FVC, and FVC % predicted decreased significantly as the number of components increased (Table 5). Results stratified by BMI categories corresponding to Tables 4 and 5 are presented in Tables S1 and S2, respectively, available as Supporting Information for this paper.

We also examined pulmonary function among four categories of metabolic syndrome and diabetes status (Table 6). Because a high percentage of adults with diabetes have metabolic syndrome, the number of diabetic participants without metabolic syndrome was relatively small. Participants with both conditions had the lowest mean levels of FEV_1, FEV_1 % predicted, FVC, and FVC % predicted, but the highest FEV_1/FVC ratio. Although that pattern persisted among adults with a BMI between 25 and <30 kg/m^2, only differences for FVC % predicted remained significant (Table S3). Comparisons among the four groups for adults with a BMI between 18.5 and <25 kg/m^2 and those with a BMI ≥30 kg/m^2 were not feasible because of small sample sizes in some groups.

The prevalence of metabolic syndrome and all five components was highest among participants with a restrictive impairment (Table 7). The prevalence of metabolic syndrome, abdominal obesity, and lipid abnormalities was lowest among participants with obstructive impairment, and the prevalence of elevated blood pressure and hyperglycemia was lowest among participants with a normal pulmonary function test. Upon multivariate analysis, restrictive impairment was associated with prevalence of metabolic syndrome and all five components (Table 7). However, mild obstructive impairment was associated with a reduced prevalence of metabolic syndrome, abdominal obesity, and hypertriglyceridemia. Any obstructive impairment was also associated with a reduced prevalence of metabolic syndrome (adjusted prevalence ratio [aPR] 0.77; 95% confidence interval [CI] 0.67, 0.88), abdominal obesity (aPR 0.85; 95% CI 0.77, 0.93), and hypertriglyceridemia (aPR 0.67; 95% CI 0.55, 0.83).

Discussion

Our analyses indicate that US adults with metabolic syndrome tend to be characterized by a restrictive pattern on spirometry and have a lower prevalence of an obstructive pattern. Furthermore, mean levels of FEV_1, FEV_1 % predicted, FVC, and FVC % predicted were lower among participants with metabolic syndrome compared with those without metabolic syndrome, but the reverse was evident for the FEV_1/FVC ratio. Furthermore, participants with both metabolic syndrome and diabetes had the lowest mean levels of FEV_1, FEV_1 % predicted, FVC, and FVC % predicted and the highest FEV_1/FVC ratio. Conversely, the prevalence of metabolic syndrome was higher among participants with a restrictive lung function pattern and lower among participants with obstructive impairment than participants with normal lung function.

Previous studies have produced mixed findings regarding pulmonary function in adults with and without metabolic syndrome. In a case control study (38 patients with COPD, 34 control patients), 47% of patients with COPD and 21% of controls had metabolic syndrome.[13] In a Taiwanese study that included 46 514 participants aged ≥20 years from 1998 to 2000, restrictive lung function (odds ratio [OR] 1.221 [95% CI 1.086, 1.3272]; and OR 1.150 [95% CI: 1.047–1.264]), but not obstructive lung function or mixed lung function, was significantly associated with metabolic syndrome.[3] The analyses were adjusted for age, gender, BMI, alcohol use, smoking, and physical activity. In a cross-sectional study of 159 non-diabetic elderly adults during 2002–03, a restrictive pattern (OR 3.23; 95% CI 1.23, 8.48), but not an obstructive one, was associated with prevalent metabolic syndrome after adjustment for age, gender, waist circumference, and BMI.[14] A study from Japan that included 2396 apparently healthy adults aged 30–80 years found that a restrictive pattern, but not an obstructive one, was associated with metabolic syndrome.[2] Three definitions of metabolic syndrome were used in that study, and ORs ranged from 1.95 to 2.56 after adjustment for age, gender, height, and smoking status. An analysis of the Korean National Health and Nutrition Survey from 2001 included 4001 participants aged ≥18 years.[4] A restrictive pattern, but not an obstructive one was associated with metabolic syndrome (OR 1.40; 95% CI 1.01, 1.98). The results were adjusted for age, gender, pack-years of smoking, physical activity, alcohol intake, socioeconomic status, and waist/height ratio. However, a subsequent analysis of the 2001 Korean National Health and Nutrition Examination Survey that included 1215 participants aged ≥40 years reported that ORs for the presence of COPD were elevated among those with metabolic syndrome (OR 1.78 [95% CI 1.00, 3.16] in men; OR 1.39 [95% CI 0.66, 2.95] in women).[5] Age, alcohol intake, education, household income, and smoking status were included as adjustment factors. Another Korean study included 1951 non-smoking men aged ≥30 years in 2008 and found that the prevalence of metabolic syndrome decreased as FVC increased.[6] A fourth Korean study of 9581 healthy non-smoking men (mean age 40.9 years) who underwent a health examination in 2005 reported that the metabolic syndrome was a significant predictor of a restrictive pattern (OR 1.55; 95% CI 1.12, 2.14). but not an obstructive one (OR 1.39; 95% CI 0.66, 2.94).[7] The results were adjusted for age, BMI, physical activity, and CRP. A Chinese study that included 7358 adults aged ≥50 years from 2003 to 2006 observed that participants with COPD (OR 1.47; 95% CI 1.12–1.92) and notably participants with severe airflow obstruction (OR 2.34; 95% CI 1.39–3.95) had significantly increased odds of having metabolic syndrome.[8] The results were adjusted for age, gender, education, smoking, physical activity, and BMI. Restrictive lung disease was not examined in that study. Thus, the preponderance of studies have found that metabolic syndrome is associated with a restrictive pattern and not with an obstructive one. Our findings agree with this assessment.

A couple of other studies reported on spirometric parameters as a function of the metabolic syndrome status. Among 2396 participants of the Strong Heart Study, mean levels of FEV % predicted and FVC % predicted were lower in participants with metabolic syndrome than in those without it.[15] Adjustments were made for age, gender, education, smoking status, abdominal obesity, height, hypertension, physical activity, and center. In a Korean study that included 1370 patients aged 20–70 years who had a health examination in 2008, men who had metabolic syndrome had higher mean levels of FEV_1 and FVC than men without

metabolic syndrome, and women with metabolic syndrome had higher levels of FEV_1 and FEV_1/FVC than women without metabolic syndrome.[16] Furthermore, FEV_1 and FVC both declined as a function of the number of metabolic syndrome components in men, but the pattern in women was irregular. Physical activity and smoking status were controlled for in the analyses. Our results generally agree with the findings of these studies.

Several studies have examined prevalent metabolic syndrome as a function of pulmonary parameters such as FEV_1, FVC, and FEV_1/FVC. A Korean study that included 4905 men aged >40 years who received an annual medical check-up during 2005–08 showed that the OR for having metabolic syndrome increased as a function of declining quartiles of FVC % predicted and FEV_1 % predicted after adjustment for age, smoking status, and BMI.[17] In a study of 237 firefighters in New York City who were being monitored as a result of exposures received during 11 September 2001, the prevalence of metabolic syndrome was higher among firefighters with FEV_1 % predicted less than the lower limit of normal (27%) than among those with an FEV_1 % predicted greater than the lower limit of normal (16%; $P = 0.07$).[18] In a Japanese study of 273 working men (mean age 44 years), the prevalence of metabolic syndrome increased as a function of decreasing FEV_1 and FVC after adjustment for age, smoking status, and BMI.[19]

Our results indicate that patients presenting with metabolic syndrome are unlikely to have obstructive lung disease in excess of what physicians may expect to encounter in their patient populations in general. Instead, these patients are somewhat more likely to present with restrictive lung disease. Restrictive lung disease can result from a variety of causes, such as idiopathic fibrosis, sarcoidosis, chest wall deformities, scoliosis, neuromuscular disorders, and obesity. Because abdominal obesity is the major component of metabolic syndrome among US adults, excess weight is the most likely cause for restrictive lung function among patients with metabolic syndrome, and weight loss should improve pulmonary function in many patients with metabolic syndrome and alleviate symptoms caused by restrictive lung functioning.

In our analyses, participants with obstructive pulmonary functioning did not have an excess of metabolic syndrome. Because approximately 25% of adults who have obstructive lung disease also have metabolic syndrome, metabolic syndrome is a common comorbidity in these patients despite the fact that it does not occur more frequently in obstructive impairment than in adults without obstructive impairment. Nevertheless, patients with metabolic syndrome are likely to be treated for high blood pressure, dyslipidemias, and hyperglycemia. Thus, the potential for polypharmacy in patients with both COPD and metabolic syndrome is a challenge that physicians need to take into account when treating patients with COPD.

Suboptimal sample size was a limitation for analyses exploring the associations between severe obstructive impairment and metabolic syndrome and its components, as well as analyses that stratified by covariates. Because we only used prebronchodilator data, our analyses included some percentage of participants with a reversible airways limitation. Although post-bronchodilator spirometry was conducted, asizable percentage of participants did not participate in this part of the protocol and, therefore, we did not use these data.

In conclusion, participants with metabolic syndrome were more likely to have a restrictive pattern on spirometry than those without metabolic syndrome. Obstructive impairment did not differ significantly between participants with and without metabolic syndrome. Because restrictive impairment is likely to be caused by abdominal obesity in many of the adults with metabolic syndrome, weight loss should prove helpful in improving pulmonary function and alleviating respiratory symptoms.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Significant findings of the study

Compared with adults who did not have metabolic syndrome (MetS), adults who did have MetS were significantly more likely to have a restrictive pattern of lung function, but not an obstructive pattern. Participants with both MetS and diabetes had the lowest mean levels of forced expiratory volume in one second (FEV_1), FEV_1% predicted, forced vital capacity (FVC), and FVC % predicted and the highest FEV_1/FVC ratio.

What this study adds

Lung function in adults with MetS remains poorly characterized, and this study provides new insights into the associations between MetS and lung function in a representative sample of adults in the US.

Table 1

Unadjusted means (SE) or percentages (SE) of selected sociodemographic characteristics among US adults aged >20 years, by metabolic syndrome and pulmonary function status, National Health and Nutrition Examination Survey 2007–2010

				Pulmonary function status					
	Metabolic syndrome					Obstructive impairment			
	Yes (*n*= 1239)	No (*n*= 1870)	*P*-value	Normal (*n* = 2452)	Restrictive (*n* = 215)	Mild (*n* = 259)	Moderate (*n*= 157)	Severe/very severe (*n* = 26)	*P*-value (Wald Chi-squared)
Age (years)	50.8 (0.6)	41.9 (0.6)	<0.001	42.9 (0.5)	49.9 (1.5)	54.4 (1.0)	52.3 (1.5)	60.9 (1.4)	<0.001
Male (%)	54.1 (1.7)	48.6 (1.5)	0.048	48.3 (1.1)	55.9 (5.2)	61.2 (3.9)	59.2 (4.7)	50.2 (16.1)	0.013
White (%)	71.6 (3.0)	72.0 (2.1)	0.815	70.1 (2.2)	61.6 (5.3)	86.7 (1.9)	83.2 (4.0)	78.9 (10.0)	<0.001
Education >12 years (%)	52.5 (2.3)	65.6 (2.0)	<0.001	63.5 (1.7)	51.6 (6.3)	56.8 (3.7)	46.5 (5.0)	36.8 (10.1)	0.043

Table 2

Age-adjusted prevalence of pulmonary function categories among US adults aged ≥20 years, by metabolic syndrome and its components status, National Health and Nutrition Examination Survey 2007–2010

		Normal	Restrictive	Mild obstructive impairment	Moderate or worse obstructive impairment
Metabolic syndrome	Yes	79.3 (1.1)	8.7 (0.9)	7.1 (0.8)	4.8 (0.6)
	No	78.7 (1.2)	3.9 (0.6)	10.9 (1.1)	6.4 (0.8)
	P-value	0.697	<0.001	0.007	0.073
Abdominal obesity	Yes	80.9 (1.0)	6.6 (0.6)	7.3 (0.7)	5.2 (0.6)
	No	75.6 (1.7)	4.4 (0.8)	13.5 (1.3)	6.5 (1.1)
	P-value	0.003	0.003	<0.001	0.245
Hypertriglyceridemia	Yes	78.7 (1.8)	8.9 (1.3)	7.3 (0.8)	5.0 (0.8)
	No	78.7 (1.2)	4.8 (0.6)	10.4 (0.9)	6.1 (0.7)
	P-value	0.983	0.003	0.013	0.245
Low HDL-C	Yes	77.4 (2.1)	9.7 (1.2)	7.0 (1.2)	5.9 (1.2)
	No	79.4 (1.2)	4.4 (0.6)	10.5 (0.8)	5.8 (0.6)
	P-value	0.360	<0.001	0.012	0.925
Elevated blood pressure	Yes	74.1 (3.1)	6.8 (1.0)	11.3 (1.6)	7.8 (2.4)
	No	80.1 (1.1)	4.7 (0.8)	9.2 (0.9)	6.0 (0.8)
	P-value	0.064	0.076	0.253	0.482
Hyperglycemia	Yes	77.1 (1.6)	7.0 (0.7)	9.8 (1.0)	6.0 (0.9)
	No	80.6 (1.3)	4.6 (0.9)	9.2 (1.2)	5.7 (0.7)
	P-value	0.102	0.010	0.674	0.737

Data show percentages, with the SE in parentheses.

HDL-C, high-density lipoprotein–cholesterol.

Table 3

Adjusted prevalence ratios (95% confidence intervals) for associations between restrictive and obstructive impairment (dependent variable) and metabolic syndrome and its components (independent variables) among US adults aged ≥20 years, National Health and Nutrition Examination Survey 2007–2010

Predictor	Restrictive impairment	Any obstructive impairment
Age-adjusted models		
Metabolic syndrome (%)	2.36 (1.78, 3.12)	0.75 (0.63, 0.88)
Abdominal obesity (%)	1.34 (0.95, 1.88)	0.65 (0.54, 0.78)
Hypertriglyceridemia (%)	1.79 (1.27, 2.54)	0.76 (0.62, 0.94)
Low HDL-C (%)	2.35 (1.81, 3.05)	0.91 (0.66, 1.26)
Elevated blood pressure (%)	1.87 (1.38, 2.54)	1.04 (0.85, 1.27)
Hyperglycemia (%)	1.79 (1.26, 2.54)	1.13 (0.89, 1.44)
Multiple-adjusted models*		
Metabolic syndrome (%)	2.20 (1.67, 2.90)	0.73 (0.62, 0.86)
Abdominal obesity (%)	1.66 (1.24, 2.23)	0.75 (0.64, 0.89)
Hypertriglyceridemia (%)	1.52 (1.10, 2.12)	0.69 (0.56, 0.84)
Low HDL-C (%)	2.02 (1.57, 2.59)	0.86 (0.62, 1.20)
Elevated blood pressure (%)	1.84 (1.35, 2.50)	1.02 (0.86, 1.22)
Hyperglycemia (%)	1.52 (1.07, 2.17)	0.98 (0.77, 1.25)

*Adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, and concentration of C-reactive protein.

HDL-C, high-density lipoprotein–cholesterol.

Table 4

Age-adjusted and multiple-adjusted mean levels (SE) of pulmonary function parameters among US adults aged ≥20 years, by status of metabolic syndrome and its components, National Health and Nutrition Examination Survey 2007–2010

	Age-adjusted			**Multiple-adjusted***			**Multiple-adjusted†**		
	Metabolic syndrome			**Metabolic syndrome**			**Metabolic syndrome**		
Lung function parameter	**Yes**	**No**	***P*-value**	**Yes**	**No**	***P*-value**	**Yes**	**No**	***P*-value**
FEV_1 (mL)	3235.3 (32.3)	3256.0 (24.3)	0.600	3215.1 (20.3)	3266.6 (19.0)	0.015	3218.0 (22.7)	3265.1 (19.0)	0.056
FEV_1, % predicted	93.4 (0.5)	96.7 (0.6)	<0.001	93.9 (0.5)	96.4 (0.5)	<0.001	94.1 (0.6)	96.3 (0.5)	0.003
FVC (mL)	4130.1 (44.0)	4214.4 (31.2)	0.110	4100.5 (25.8)	4229.8 (25.1)	<0.001	4110.9 (28.6)	4224.4 (25.1)	0.001
FVC, % predicted	95.3 (0.5)	100.1 (0.6)	<0.001	95.8 (0.5)	99.9 (0.5)	<0.001	96.3 (0.6)	99.6 (0.5)	<0.001
FEV_1/FVC (%)	78.3 (0.2)	77.4 (0.2)	0.001	78.4 (0.2)	77.3 (0.2)	<0.001	78.2 (0.2)	77.4 (0.2)	0.029
	Abdominal obesity			Abdominal obesity			Abdominal obesity		
	Yes	No		Yes	No		Yes	No	
FEV_1 (mL)	3186.7 (22.1)	3329.2 (35.5)	0.001	3267.7 (18.6)	3224.7 (24.2)	0.097	3282.8 (18.9)	3205.2 (24.8)	0.007
FEV_1, % predicted	95.2 (0.4)	96.1 (0.8)	0.201	94.9 (0.4)	96.5 (0.6)	0.012	95.2 (0.4)	96.0 (0.6)	0.260
FVC (mL)	4078.8 (31.9)	4323.0 (44.2)	<0.001	4201.8 (23.0)	4164.3 (33.2)	0.294	4224.7 (23.4)	4134.9 (34.2)	0.025
FVC, % predicted	97.6 (0.4)	99.6 (0.8)	0.004	97.4 (0.4)	99.8 (0.7)	<0.001	97.9 (0.4)	99.2 (0.6)	0.029
FEV_1/FVC (%)	78.2 (0.2)	77.0 (0.3)	<0.001	77.9 (0.2)	77.4 (0.3)	0.151	77.9 (0.2)	77.5 (0.3)	0.321
	Hypertriglyceridemia			Hypertriglyceridemia			Hypertriglyceridemia		
	Yes	No		Yes	No		Yes	No	
FEV_1 (mL)	3278.3 (36.3)	3238.1 (23.1)	0.336	3217.8 (21.9)	3260.4 (20.4)	0.121	3233.2 (24.1)	3254.7 (20.5)	0.486
FEV_1, % predicted	93.8 (0.7)	96.2 (0.6)	0.002	94.7 (0.6)	95.9 (0.5)	0.109	95.5 (0.6)	95.6 (0.5)	0.925
FVC (mL)	4203.2 (48.4)	4178.9 (31.6)	0.674	4108.1 (29.5)	4214.0 (25.4)	0.004	4126.4 (32.6)	4207.2 (25.8)	0.054
FVC, % predicted	96.0 (0.6)	99.4 (0.5)	<0.001	96.7 (0.6)	99.1 (0.5)	0.001	97.6 (0.6)	98.8 (0.5)	0.114
FEV_1/FVC (%)	78.0 (0.2)	77.6 (0.2)	0.209	78.3 (0.2)	77.5 (0.2)	0.005	78.3 (0.2)	77.5 (0.2)	0.004
	Low HDL-C			Low HDL-C			Low HDL-C		
	Yes	No		Yes	No		Yes	No	

	Age-adjusted			**Multiple-adjusted***			**Multiple-adjusted†**		
	Metabolic syndrome			**Metabolic syndrome**			**Metabolic syndrome**		
Lung function parameter	**Yes**	**No**	***P*-value**	**Yes**	**No**	***P*-value**	**Yes**	**No**	***P*-value**
FEV_1 (mL)	3152.9 (34.8)	3288.8 (20.5)	0.001	3199.6 (24.6)	3269.4 (19.2)	0.015	3203.2 (27.5)	3267.9 (18.9)	0.040
FEV_1, % predicted	92.9 (0.7)	96.7 (0.6)	<0.001	93.8 (0.6)	96.3 (0.5)	0.004	94.1 (0.6)	96.2 (0.5)	0.018
FVC (mL)	4059.8 (46.7)	4237.6 (26.5)	<0.001	4115.9 (33.1)	4214.3 (23.2)	0.007	4136.0 (38.5)	4206.0 (22.7)	0.098
FVC, % predicted	95.6 (0.7)	99.7 (0.5)	<0.001	96.4 (0.6)	99.3 (0.5)	<0.001	97.2 (0.7)	99.0 (0.5)	0.026
FEV_1/FVC (%)	77.7 (0.3)	77.7 (0.2)	0.920	77.8 (0.3)	77.7 (0.2)	0.680	77.5 (0.3)	77.8 (0.2)	0.528
	Elevated blood pressure			Elevated blood pressure			Elevated blood pressure		
	Yes	No		Yes	No		Yes	No	
FEV_1 (mL)	3189.5 (45.4)	3270.0 (17.6)	0.069	3186.8 (31.8)	3271.0 (15.6)	0.005	3187.6 (32.1)	3270.7 (15.3)	0.006
FEV_1, % predicted	93.6 (0.8)	96.2 (0.5)	<0.001	93.9 (0.7)	96.2 (0.4)	0.001	94.3 (0.7)	96.0 (0.4)	0.010
FVC (mL)	4093.9 (59.7)	4218.0 (25.2)	0.041	4090.6 (38.9)	4219.2 (21.6)	0.001	4095.4 (40.5)	4217.4 (20.8)	0.003
FVC, % predicted	96.2 (0.6)	99.3 (0.5)	<0.001	96.5 (0.6)	99.2 (0.4)	<0.001	97.1 (0.6)	99.0 (0.4)	0.002
FEV_1/FVC (%)	77.9 (0.3)	77.6 (0.2)	0.370	77.9 (0.2)	77.6 (0.2)	0.359	77.8 (0.2)	77.6 (0.2)	0.606
	Hyperglycemia			Hyperglycemia			Hyperglycemia		
	Yes	No		Yes	No		Yes	No	
FEV_1 (mL)	3323.0 (29.8)	3183.5 (32.5)	0.005	3225.3 (21.1)	3269.8 (22.2)	0.108	3229.3 (20.9)	3266.2 (22.3)	0.188
FEV_1, % predicted	94.0 (0.7)	97.0 (0.6)	0.001	94.5 (0.6)	96.5 (0.6)	0.018	94.8 (0.6)	96.2 (0.6)	0.089
FVC (mL)	4290.6 (38.3)	4092.7 (42.1)	0.002	4151.2 (22.8)	4215.7 (29.3)	0.041	4160.2 (22.6)	4207.8 (28.9)	0.133
FVC, % predicted	96.7 (0.5)	100.0 (0.6)	<0.001	97.2 (0.4)	99.6 (0.6)	0.001	97.7 (0.4)	99.2 (0.5)	0.017
FEV_1/FVC (%)	77.6 (0.3)	77.8 (0.2)	0.510	77.8 (0.2)	77.6 (0.2)	0.558	77.7 (0.2)	77.7 (0.2)	0.862

*Adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, and concentration of C-reactive protein (CRP).

†Models for metabolic syndrome were adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, concentration of CRP, and body mass index. Models for metabolic syndrome components were adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, concentration of CRP, and other components of metabolic syndrome.

HDL-C, high-density lipoprotein–cholesterol; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity.

Table 5

Age-adjusted and multiple-adjusted mean levels (SE) of pulmonary function parameters among US adults aged ≥20 years, by number of metabolic syndrome components, National Health and Nutrition Examination Survey 2007–2010

	No. metabolic syndrome components						
Lung function parameter	**0 (*n* = 439)**	**1 (*n* = 685)**	**2 (*n* = 746)**	**3 (*n* = 676)**	**4 (*n* = 383)**	**5(*n*= 180)**	***P*-value (Wald Chi-squared)**
Age-adjusted							
FEV_1 (mL)	3230.2 (48.9)	3264.9 (36.2)	3267.9 (32.1)	3305.0 (39.0)	3164.1 (40.2)	3108.1 (62.9)	<0.001
FEV_1, % predicted	97.8(1.1)	97.0(0.7)	95.5 (0.7)	95.3 (0.7)	91.1 (1.0)	90.5 (1.0)	<0.001
FVC (mL)	4128.8(65.7)	4256.8(47.3)	4236.3 (40.7)	4217.2 (53.9)	4044.6 (53.1)	3974.2 (93.7)	<0.001
FVC, % predicted	100.4(1.1)	101.0(0.7)	99.0 (0.6)	97.2 (0.6)	93.0 (0.9)	92.4 (1.2)	<0.001
FEV_1/FVC	78.2 (0.4)	76.9 (0.4)	77.3 (0.4)	78.3 (0.3)	78.3 (0.3)	78.4 (0.7)	<0.001
Multiple-adjusted*							
FEV_1 (mL)	3269.4 (37.9)	3254.5 (24.8)	3279.2 (25.7)	3253.1 (24.8)	3177.5 (29.1)	3137.0 (39.7)	<0.001
FEV_1, % predicted	96.9(1.1)	96.9(0.6)	95.7 (0.6)	95.4 (0.6)	91.8 (0.9)	91.5 (0.9)	<0.001
FVC (mL)	4185.7(47.5)	4241.8(33.0)	4251.3 (27.5)	4146.6 (29.5)	4065.8 (36.6)	3998.5 (60.1)	<0.001
FVC, % predicted	99.6(1.0)	100.9(0.6)	99.1 (0.5)	97.4 (0.6)	93.9 (0.8)	93.1 (1.2)	<0.001
FEV_1/FVC	78.0 (0.4)	76.9 (0.4)	77.3 (0.3)	78.4 (0.3)	78.3 (0.3)	78.6 (0.7)	<0.001
Multiple-adjusted†							
FEV_1 (mL)	3266.2 (40.5)	3253.3 (25.4)	3279.5 (25.7)	3254.9 (24.9)	3180.1 (34.3)	3140.5 (45.5)	0.016
FEV_1, % predicted	96.8 (1.2)	96.8 (0.6)	95.7 (0.6)	95.5 (0.6)	92.0 (1.0)	91.6 (1.1)	<0.001
FVC (mL)	4163.1 (48.2)	4233.5 (34.9)	4253.9 (27.4)	4160.0 (29.9)	4084.0 (40.5)	4023.2 (64.4)	<0.001
FVC, % predicted	98.8(1.1)	100.6(0.6)	99.2 (0.5)	97.8 (0.6)	94.4 (0.9)	93.9 (1.2)	<0.001
FEV_1/FVC	78.5 (0.5)	77.1 (0.4)	77.2 (0.3)	78.1 (0.4)	77.9 (0.4)	78.1 (0.6)	<0.001

*Adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, and concentration of C-reactive protein (CRP).

†Adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, concentration of CRP, and body mass index.

FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity.

Table 6

Age-adjusted and multiple-adjusted mean levels (SE) of pulmonary function parameters among US adults aged ≥20 years, by combinations of metabolic syndrome and diabetes status, National Health and Nutrition Examination Survey 2007–2010

Lung function parameter	MetS−, DM− (*n* = 1793)	MetS+, DM− (*n* = 868)	MetS−, DM+ (*n* = 77)	MetS+, DM+ (*n* = 371)	*P*-value (Wald Chi-squared)
Age-adjusted					
FEV_1 (mL)	3254.6 (25.7)	3289.6 (30.7)	3361.8 (105.0)	3055.7 (60.4)	<0.001
FEV_1, % predicted	96.8 (0.6)	94.8 (0.6)	94.7 (1.5)	88.8 (1.1)	<0.001
FVC (mL)	4213.5 (33.4)	4219.8 (42.5)	4342.4 (138.7)	3831.5 (78.0)	<0.001
FVC, % predicted	100.3 (0.6)	97.2 (0.5)	97.5 (1.3)	89.2 (1.0)	<0.001
FEV_1/FVC	77.3 (0.2)	78.0 (0.3)	77.4 (0.9)	79.7 (0.4)	<0.001
Multiple-adjusted*					
FEV_1 (mL)	3271.8 (19.3)	3256.9 (20.1)	3168.9 (52.9)	3067.2 (32.4)	<0.001
FEV_1, % predicted	96.5 (0.5)	95.2 (0.6)	95.6 (1.6)	89.5 (1.0)	<0.001
FVC (mL)	4238.8 (25.6)	4172.5 (24.0)	4064.6 (65.6)	3845.5 (44.1)	<0.001
FVC, % predicted	100.0 (0.5)	97.5 (0.5)	98.2 (1.3)	89.9 (1.0)	<0.001
FEV_1/FVC	77.3 (0.2)	78.0 (0.2)	77.9 (1.0)	79.7 (0.4)	<0.001
Multiple-adjusted†					
FEV_1 (mL)	3272.1 (19.1)	3256.4 (22.7)	3169.0 (53.1)	3066.6 (33.6)	<0.001
FEV_1, % predicted	96.4 (0.5)	95.3 (0.6)	95.5 (1.6)	89.7 (1.0)	<0.001
FVC (mL)	4236.2 (25.3)	4176.6 (26.8)	4063.5 (65.9)	3852.3 (46.7)	<0.001
FVC, % predicted	99.8 (0.5)	97.9 (0.6)	98.1 (1.3)	90.5 (0.9)	<0.001
FEV_1/FVC	77.4 (0.2)	77.9 (0.3)	78.0 (0.9)	79.4 (0.4)	0.001

*Adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, and concentration of C-reactive protein (CRP).

†Adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, concentration of CRP, and body mass index.

MetS, metabolic syndrome; DM, diabetes mellitus; FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity

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Table 7

Age-adjusted prevalence (SE) of metabolic syndrome and its components by pulmonary function status and adjusted prevalence ratios (95% confidence interval) for associations between metabolic syndrome and its components (dependent variables) and pulmonary function status (independent variable) among US adults aged ≥20 years, National Health and Nutrition Examination Survey 2007–2010

			Obstructive impairment		
	Normal	**Restrictive**	**Mild**	**≥Moderate**	***P*-value (Wald Chi-squared)**
Age-adjusted prevalence					
Metabolic syndrome (%)	35.1 (1.2)	54.3 (3.4)	24.8 (3.4)	27.8 (3.4)	–
Abdominal obesity (%)	58.9 (1.4)	63.5 (3.8)	42.5 (3.5)	47.0 (4.2)	–
Hypertriglyceridemia (%)	27.2 (1.1)	41.9 (4.6)	20.5 (2.6)	19.6 (3.3)	–
Low HDL-C (%)	28.8 (1.2)	51.7 (3.2)	20.0 (3.7)	33.8 (7.1)	–
Elevated blood pressure (%)	26.7 (1.2)	35.8 (3.4)	30.0 (3.2)	28.9 (2.8)	–
Hyperglycemia (%)	46.3 (1.3)	56.8 (4.4)	50.1 (5.5)	49.5 (5.2)	–
Age-adjusted models					
Metabolic syndrome (%)	1.00	1.53 (1.34,1.76)	0.74 (0.59,0.93)	0.93 (0.79,1.09)	<0.001
Abdominal obesity (%)	1.00	1.11 (1.00,1.24)	0.73 (0.63,0.85)	0.88 (0.75,1.04)	<0.001
Hypertriglyceridemia (%)	1.00	1.51 (1.20,1.89)	0.74 (0.57,0.95)	0.86 (0.64,1.16)	<0.001
Low HDL-C (%)	1.00	1.80 (1.52,2.13)	0.77 (0.54,1.10)	1.16 (0.79,1.72)	<0.001
Elevated blood pressure (%)	1.00	1.32 (1.16,1.50)	0.99 (0.84,1.18)	1.06 (0.91,1.23)	0.001
Hyperglycemia (%)	1.00	1.29 (1.13,1.46)	1.06 (0.92,1.23)	1.09 (0.91,1.29)	0.002
Multiple-adjusted models*					
Metabolic syndrome (%)	1.00	1.47 (1.27,1.70)	0.72 (0.57,0.90)	0.85 (0.72,1.02)	<0.001
Abdominal obesity (%)	1.00	1.15 (1.05,1.26)	0.80 (0.69,0.91)	0.93 (0.81,1.07)	0.001
Hypertriglyceridemia (%)	1.00	1.32 (1.06,1.63)	0.66 (0.50,0.86)	0.70 (0.52,0.92)	<0.001
Low HDL-C (%)	1.00	1.59 (1.38,1.85)	0.79 (0.55,1.13)	1.04 (0.69,1.58)	<0.001
Elevated blood pressure (%)	1.00	1.28 (1.14,1.45)	0.92 (0.78,1.09)	1.01 (0.87,1.17)	<0.001
Hyperglycemia (%)	1.00	1.20 (1.03,1.38)	0.97 (0.83,1.13)	0.97 (0.82,1.15)	0.076
Multiple-adjusted models†					
Metabolic syndrome (%)	1.00	1.13 (0.97,1.32)	0.85 (0.70,1.03)	0.88 (0.75,1.02)	0.023
Abdominal obesity (%)	1.00	0.90 (0.83,0.99)	0.93 (0.82,1.05)	0.97 (0.86,1.09)	0.056
Hypertriglyceridemia (%)	1.00	1.18 (0.94,1.47)	0.71 (0.54,0.94)	0.72 (0.55,0.94)	0.006

			Obstructive impairment		
	Normal	**Restrictive**	**Mild**	**≥Moderate**	***P*-value (Wald Chi-squared)**
Low HDL-C (%)	1.00	1.39 (1.21,1.60)	0.87 (0.61,1.25)	1.08 (0.72,1.62)	<0.001
Elevated blood pressure (%)	1.00	1.10 (0.98,1.23)	1.02 (0.85,1.22)	1.03 (0.90,1.18)	0.396
Hyperglycemia (%)	1.00	1.07 (0.93,1.22)	1.05 (0.89,1.23)	1.00 (0.83,1.19)	0.795

*Adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, and concentration of C-reactive protein (CRP).

†Adjusted for age, gender, race or ethnicity, educational status, smoking status, physical activity, alcohol use, concentration of CRP, and body mass index.

HDL-C, high-density lipoprotein–cholesterol.