ORIGINAL RESEARCH

Diagnostic Potential of Oscillometry: A Population-based Approach

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Abstract

Rationale: Respiratory resistance (Rrs) and reactance (Xrs) as measured by oscillometry and their intrabreath changes have emerged as sensitive parameters for detecting early pathological impairments during tidal breathing.

Objectives: This study evaluates the prevalence and association of abnormal oscillometry parameters with respiratory symptoms and respiratory diseases in a general adult population.

Methods: A total of 7,560 subjects in the Austrian LEAD (Lung, hEart, sociAl, boDy) Study with oscillometry measurements (computed with the Resmon Pro FULL; Restech Srl) were included in this study. The presence of respiratory symptoms and doctor-diagnosed respiratory diseases was assessed using an interview-based questionnaire. Rrs and Xrs at 5 Hz, their inspiratory and expiratory components, the area above the Xrs curve, and the presence of tidal expiratory flow limitation were analyzed. Normality ranges for oscillometry parameters were defined.

Measurements and Main Results: The overall prevalence of abnormal oscillometry parameters was 20%. The incidence of abnormal oscillometry increased in the presence of symptoms or diagnoses: 17% (16–18%) versus 27% (25–29%), $P < 0.0001$. All abnormal oscillometry parameters except Rrs at 5 Hz were significantly associated with respiratory symptoms/diseases. Significant associations were found, even in subjects with normal spirometry, with abnormal oscillometry incidence rates increasing by 6% (4–8%; $P < 0.0001$) in subjects with symptoms or diagnoses.

Conclusions: Abnormal oscillometry parameters are present in one-fifth of this adult population and are significantly associated with respiratory symptoms and disease. Our findings underscore the potential of oscillometry as a tool for detecting and evaluating respiratory impairments, even in individuals with normal spirometry.

Keywords: epidemiological study; lung function; forced oscillation technique; respiratory symptoms; respiratory diseases

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At a Glance Commentary

Scientific Knowledge on the Subject: Emerging evidence supports using respiratory resistance (Rrs) and reactance (Xrs) measured by oscillometry to identify the initial stages of respiratory diseases. However, large studies examining the prevalence of abnormal Rrs and Xrs, and their association with symptoms and respiratory diagnoses, are missing.

What This Study Adds to the Field: In our large general adult population selected unbiasedly, 20% of subjects presented abnormal oscillometry, whereas 13% had abnormal spirometry. Abnormal oscillometry was significantly associated with an increased risk of presenting respiratory symptoms and diagnoses. Xrs appeared to be a more sensitive indicator of symptoms and diseases compared with Rrs. Alterations of inspiratory lung mechanics were more present in subjects with asthma, whereas abnormal expiratory lung mechanics were mainly related to chronic obstructive pulmonary disease. These associations were also present in the subset of subjects with normal spirometry.

Oscillometry, formerly known as forced oscillation technique (FOT), is emerging as a potentially helpful technique for patient monitoring and treatment personalization (1). Oscillometry allows measurements of the respiratory system's impedance (Zrs) by applying a small-amplitude pressure oscillation at the mouth during spontaneous breathing. Physiologically, measurement of this impedance quantifies how easily the air moves in and out of the respiratory system. It is composed of respiratory resistance (Rrs), related to the resistive properties of the respiratory system, and reactance (Xrs), linked to the elastic and inertial properties of the system (2).

The measure is performed during quiet breathing without the requirement for an additional respiratory maneuver, allowing measurements in noncooperative subjects such as neonates, elderly people, or very sick patients. It is an appealing technique, because it is easy to perform and not time consuming. Moreover, it does not require a highly trained operator and can even be performed on oneself (3).

Oscillometry is sensitive to small airway involvement in both chronic obstructive pulmonary disease (COPD) (4) and asthma (5) and can identify lung mechanics changes at the initial stages of respiratory diseases (6–8) and during disease progression and worsening (1, 9). Also, the evaluation of the frequency dependence and the intrabreath (or within-breath) oscillometry parameters derived by monofrequency oscillometry are emerging as sensitive approaches for detecting pathological impairment (10–16).

The vast majority of published studies have compared oscillometry with spirometry as a gold standard (17, 18). However, published data suggest that the two techniques can present different sensitivities to respiratory conditions (19). Moreover, studies have been generally conducted on subjects with respiratory diseases, making the prevalence of abnormal oscillometry in the general population unknown. Similarly, whether specific oscillometry parameters may help to objectify symptoms remains to be assessed. The Austrian LEAD (Lung, hEart, sociAl, boDy) Study offers an unparalleled opportunity to evaluate the association between abnormal oscillometry, respiratory symptoms, and reported diseases in a large, general population. The aim of this study is to provide insights to the medical and scientific communities regarding the prevalence of abnormal oscillometry and its potential utility as a tool to objectively assess respiratory conditions in routine medical practices.

Some of the results of this study have been previously reported in the form of an abstract (20). A detailed description of the design and rationale of the Austrian LEAD Study (ClinicalTrials.gov ID: NCT01727518) has been previously published (21).

Methods

Study Design and Participants

The LEAD Study enrolled a randomized stratified sample (by age, sex, and residential area) of the inhabitants of Vienna and registered inhabitants of six villages in Lower Austria. Since November 2017, oscillometry has been part of standardized data acquisition. We included the adult (≥18 yr) LEAD Study population with oscillometry measurements for the present analysis.

Data Acquisition

During the visit, the study investigators assessed information about the presence of respiratory symptoms and patient-reported diagnosis of respiratory diseases using a standardized questionnaire (Table 1). Baseline characteristics including height, weight, age, and smoking habits were recorded. We performed oscillometry measurements using a multifrequency signal comprising 5, 11, and 19 Hz provided by a device compliant with European Respiratory Society technical standards (Resmon Pro FULL; Restech Srl) (2). Subjects underwent a single oscillometry measurement in a seated position, wearing a nose clip and supporting cheeks to decrease upper airway shunt compliance. After excluding the first three breaths, we analyzed at least 10 artifact-free breaths that were automatically selected by the oscillometry device, ensuring a recording time of more than 30 seconds for breathing frequencies up to 20 breaths per minute and the inclusion of only complete breathing cycles. Spirometry was performed after oscillometry and according to international guidelines (22).

Data Analysis

The following oscillometry parameters were considered in the analysis: Rrs and Xrs at 5 Hz (R5 and X5, respectively); their within-breath inspiratory (R5insp and X5insp, respectively) and expiratory (R5exp and X5exp, respectively) components; and the area above the Xrs curve from 5 Hz to resonant frequency (or, Fres) (AX). An internal algorithm of the Resmon Pro computed AX by extrapolating beyond the measured frequencies to 37 Hz (23).

We excluded oscillometry measurements that presented negative R5 or a breath-by-breath R5 coefficient of variation more than 30% to account for measurement artifacts. R5, R5insp, R5exp, and AX were classified as "abnormal" if their *z* scores were higher than 1.64. X5, X5insp, and X5exp were classified as "abnormal" if

This article has a related editorial.

This article has an online supplement, which is accessible from this issue's table of contents at www.atsjournals.org.

Table 1. Respiratory Questionnaire

Symptom/Diagnosis	Questions
Wheezing	Have you had a wheezing, whistling, or rattling in your chest in the past 12 mo?
Breathlessness	Do you sometimes experience breathlessness when doing physical exertion? OR Do you sometimes experience breathlessness when upset? OR Do you sometimes suffer from breathlessness in typical everyday situations?
Chronic cough	Have you had a regular (almost daily) cough in the past 12 mo (except when you had a cold)?
Asthma	Have you ever had bronchial asthma? OR Have you ever had asthmatic bronchitis? OR Have you ever had allergic bronchitis? AND Did a doctor make this diagnosis? AND Do you still have the disease?
Chronic bronchitis	Have you ever had chronic bronchitis? AND Did a doctor make this diagnosis?
COPD	Have you ever had COPD? AND Did a doctor make this diagnosis?
Other diagnoses	Do you have interstitial lung disease (lung tissue disease)? OR Do you have bronchiectasis? OR Have you ever had emphysema? OR Has a doctor ever told you that you have an alpha-1 antitrypsin deficiency?

Definition of abbreviation: COPD = chronic obstructive pulmonary disease.

their z scores were lower than -1.64. The z scores were computed according to Oostveen and colleagues (24). In the absence of intratidal R5 and X5 reference equations, equations reported for R5 and X5 were also applied for their inspiratory (R5insp, X5insp) and expiratory values (R5exp, X5exp). Tidal expiratory flow limitation (EFL_T) was defined as X5insp − X5exp (ΔXrs) > 2.8 (25).

Subjects were divided according to the normality/abnormality of their oscillometry parameters. Subjects with at least one abnormal oscillometry parameter were then further divided into subjects presenting the following: *1*) abnormal R5 and normal X5; *2*) normal R5 and abnormal X5; *3*) both abnormal R5 and X5; *4*) abnormal values only during inspiration (R5insp or X5insp); *5*) abnormal values only during expiration (R5exp or X5exp); *6*) abnormal values through all the respiratory cycle; *7*) EFL_T and *8*) abnormal AX.

The associations between abnormal oscillometry parameters and respiratory symptoms (e.g., wheezing, breathlessness, and chronic cough) or self-reported diagnosis of respiratory diseases (e.g., asthma, chronic bronchitis, and COPD) were initially examined by stratifying subjects on the basis of the presence and number of respiratory symptoms and reported diagnosis of respiratory diseases. Then, the relationship between abnormal oscillometry parameters and a specific respiratory symptom or diagnosis was analyzed.

We finally repeated the evaluation of the associations between abnormal oscillometry parameters and the presence of respiratory symptoms and diagnosis after excluding subjects with abnormal spirometry. We defined abnormal spirometry as the z score of the FVC or z score of the ratio of the FEV_1 to the FVC (FEV_1/FVC) < -1.64 (26). The reference values that were used correspond to those of the Global Lung Function Initiative (27).

Statistical Analysis

Data were tested for normality using the Shapiro–Wilks test. According to data distribution, the rank-sum test tested differences in continuous variables among normal/abnormal oscillometry groups. Differences in categorical variables among groups were tested using the chi-square test with Yates' continuity correction. The Spearman correlation evaluated the correlation between parameters.

The associations between abnormal oscillometry parameters and the presence of respiratory symptoms and reported diagnosis of respiratory diseases were tested by logistic regression for nominal responses with the subjects divided into groups presenting *1*) normal and abnormal oscillometry; *2*) normal oscillometry, abnormal R5 only, abnormal X5 only, and abnormal R5 and X5; *3*) normal oscillometry, abnormal inspiratory parameters only, abnormal expiratory parameters only, and abnormal inspiratory and expiratory parameters; *4*) normal oscillometry and EFL_T, and *5*) normal oscillometry and abnormal AX. Anthropometric parameters were not included as inputs of the models, as groups were defined according to the z scores of oscillometry parameters, which accounts for anthropometrics. Odds ratios (ORs) and 95% confidence interval (CI) values were computed. Incidence rate and 95% CI were computed and compared using the chi-square test. Data were analyzed using MATLAB R2020b (MathWorks).

Results

At the time of the analysis, oscillometry measurements had been collected for 7,980 subjects who were part of the LEAD Study. Measures from 5% of the individuals were discarded because of the inadequate quality of the oscillometry measurements, resulting in 7,560 subjects (ages 18–90 years; height, 1.43–2.04 m; BMI, 14–59 kg/m^2) included in

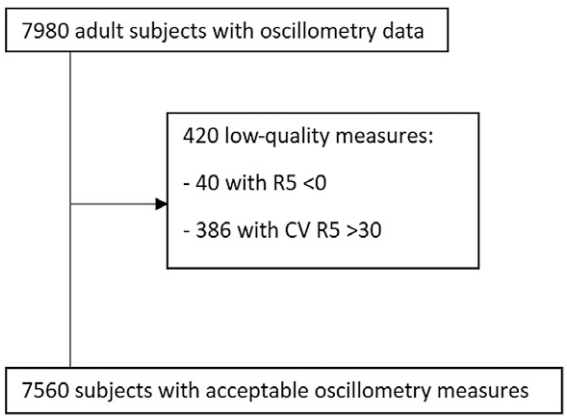

Figure 1. Included participants. CV = coefficient of variation; R5 = respiratory system resistance at 5 Hz.

Table 2. Participant Characteristics

Characteristic	Normal Oscillometry	Abnormal Oscillometry
n (%)	6,054 (80.1)	1,506 (19.9)
Age, yr, median (IQR)	47.2 (30.8–61.0)	52.8 (31.5–67.8)*
Female, *n* (%)	3,219 (53)	764 (51)
Weight, kg, median (IQR)	73.5 (63.4–84.2)	74.6 (62.9–88.1)*
Height, cm, median (IQR)	170 (164–177)	170 (163–178)
BMI, kg/m^2, median (IQR)	25.1 (22.5–28.2)	25.6 (22.3–29.4)*
R5, % predicted, median (IQR)	92 (78–109)	147 (123–168)
X5, % predicted, median (IQR)	75 (57–95)	146 (121–185)
$R5_{insp}$, % predicted, median (IQR)	88 (74–105)	126 (104–154)
$X5_{insp}$, % predicted, median (IQR)	82 (60–105)	123 (87–161)
$R5_{exp}$ % predicted, median (IQR)	95 (80–114)	160 (133–183)
$X5_{exp}$, % predicted, median (IQR)	69 (51–90)	156 (120–220)
AX, % predicted, median (IQR)	98 (60–147)	380 (261–583)
ΔX, cm $H_2O \cdot s/L$, median (IQR)	−0.16 (−0.33 to 0.04)	0.38 (−0.12 to 1.2)

Definition of abbreviations: AX = the area above the reactance curve from 5 Hz to resonant frequency; BMI = body mass index; IQR = interquartile range; R5 = respiratory resistance at 5 Hz; $R5_{exp}$ = R5 within-breath expiratory component; $R5_{insp}$ = R5 within-breath inspiratory component; X5 = respiratory reactance at 5 Hz; $X5_{exp}$ = X5 within-breath expiratory component; $X5_{insp}$ =X5 within-breath inspiratory component.
Continuous variables are expressed as median (IQR). Dichotomous variables are expressed as *n* (%). Statistical differences are not indicated for oscillometry parameters, as they were used to define the groups. (*See* Figure E1 for the distribution of oscillometry parameters in the two groups.)
*$P < 0.05$ with normal oscillometry.

the analysis (Figure 1). The overall prevalence of abnormal oscillometry parameters was 19.9%. Subjects with abnormal oscillometry parameters were older and had higher BMI values (Table 2) compared with those with normal values (*see* Figure E1 in the online supplement for the distribution of oscillometry parameters in the two groups).

A total of 2,171 subjects reported respiratory symptoms or diagnoses, with 587 (27.0%) of them presenting abnormal oscillometry, 483 (22.2%) of them presenting abnormal spirometry and 840 (38.7%) of them presenting abnormal oscillometry or spirometry (Figure 2).

Subjects without respiratory symptoms or diagnoses were less likely to present with an abnormal oscillometry parameter (OR = 0.55; 95% CI = 0.49–0.62), with the incidence (95% CI) of abnormal oscillometry increasing from 17.1% (16.0–18.2) to 27.0% (24.9–29.3) in the presence of symptoms or diagnoses ($P < 0.0001$). The odds of abnormal oscillometry increased with the number of symptoms and diagnoses of respiratory diseases (Figure 3) as, in comparison with subjects reporting only one symptom, the incidence rate of abnormal oscillometry increased by 7.8% (2.6–13.0) in the presence of more symptoms ($P = 0.0032$) and by 12.4% (7.5–17.2) with a diagnosis of respiratory diseases ($P < 0.0001$). Considering the different oscillometry parameters, abnormal X5 was associated with either respiratory symptoms or diseases, whereas R5 was not. Abnormal expiratory parameters were related to the presence of even one symptom, whereas abnormal inspiratory values were more likely found in subjects experiencing multiple symptoms or with a diagnosed respiratory condition (Figure 3). EFL_T was associated with the highest risk of presenting respiratory conditions (Figure 3). Odd ratios of abnormal AX were not different from those of abnormal X5 in all the tested conditions (Figure 3). Incidence rate differences between abnormal X5 and AX were 1.2% (95% CI = 0.09–2.4) in subjects without symptoms or diagnosed diseases ($P = 0.03$), 0.5% (95% CI = −2.3 to 3.3) in subjects with symptoms but not diagnosed diseases ($P = 0.71$), and 4.5% (95% CI = −1.0 to 10.0) in subjects with diagnosed diseases ($P = 0.11$).

All abnormal oscillometry parameters except R5 were associated with wheezing, breathlessness, and cough (Figure 4, left), with EFL_T being especially related to breathlessness (OR = 8.3; 95% CI = 6.1–11.4). Abnormal oscillometry parameters were related to the self-reported diagnoses of asthma, chronic bronchitis, and COPD (Figure 4, right). Self-reported diagnoses of

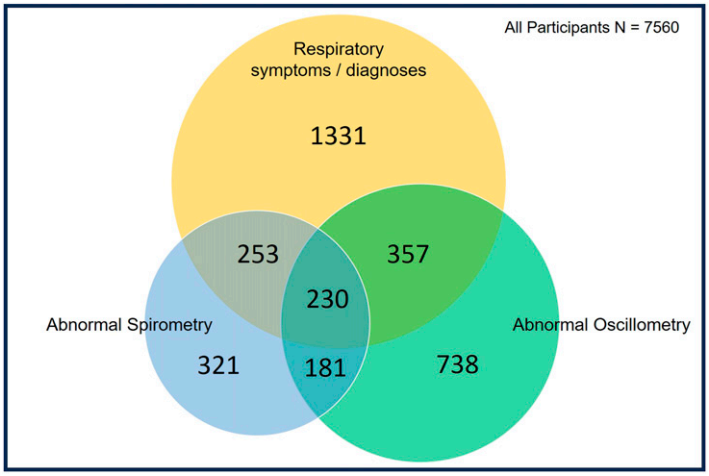

Figure 2. Venn diagram of participants with respiratory symptoms/diagnoses, abnormal spirometry, and abnormal oscillometry.

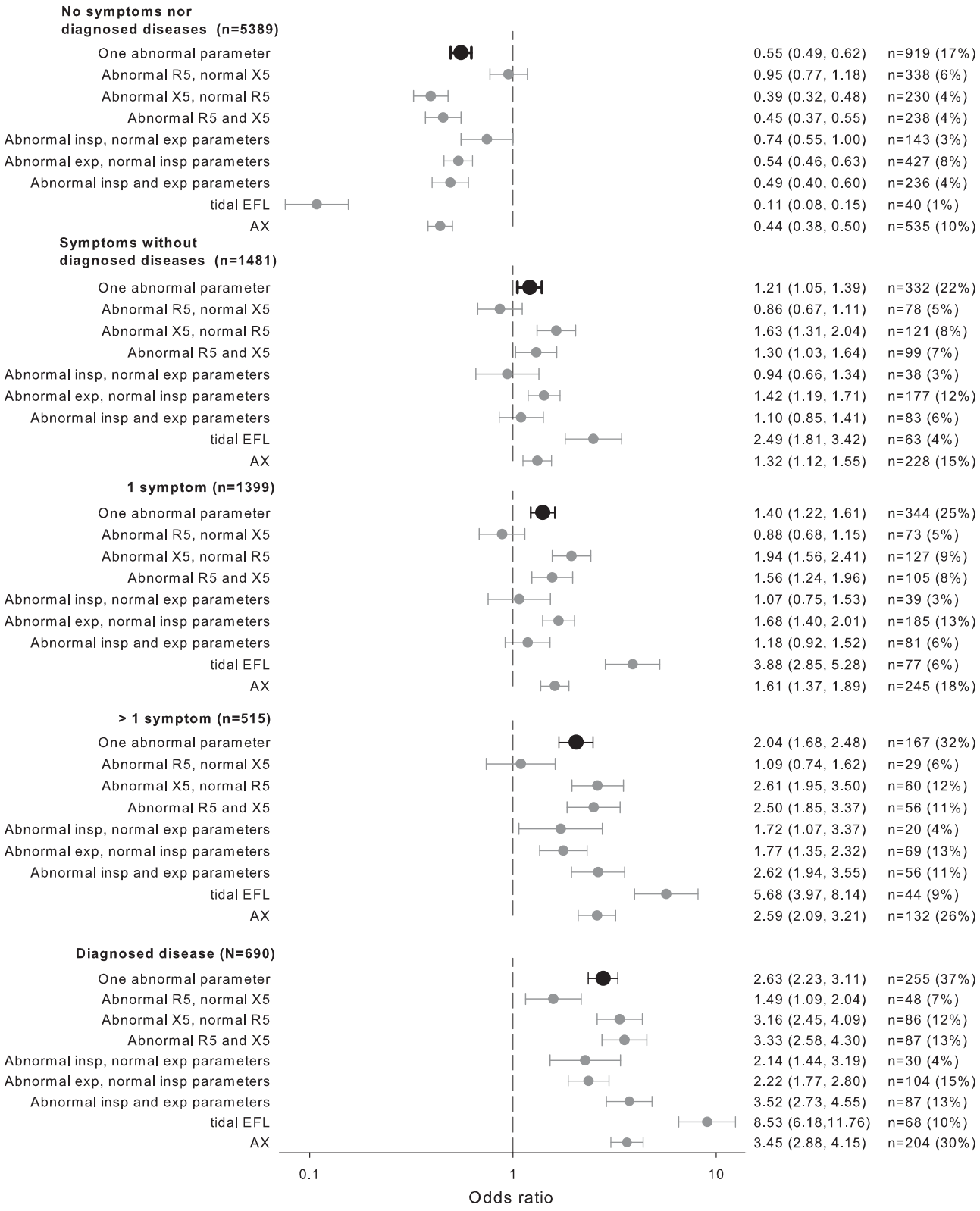

Figure 3. Odds ratio (95% confidence interval) between the presence of respiratory symptoms or diagnosed respiratory diseases and abnormal impedance parameters in a general adult population. AX = the area above the reactance curve from 5 Hz to resonant frequency; EFL = expiratory flow limitation; exp = within-breath expiratory component; insp = within-breath inspiratory component; R5 = respiratory system resistance at 5 Hz; X5 = respiratory system reactance at 5 Hz.

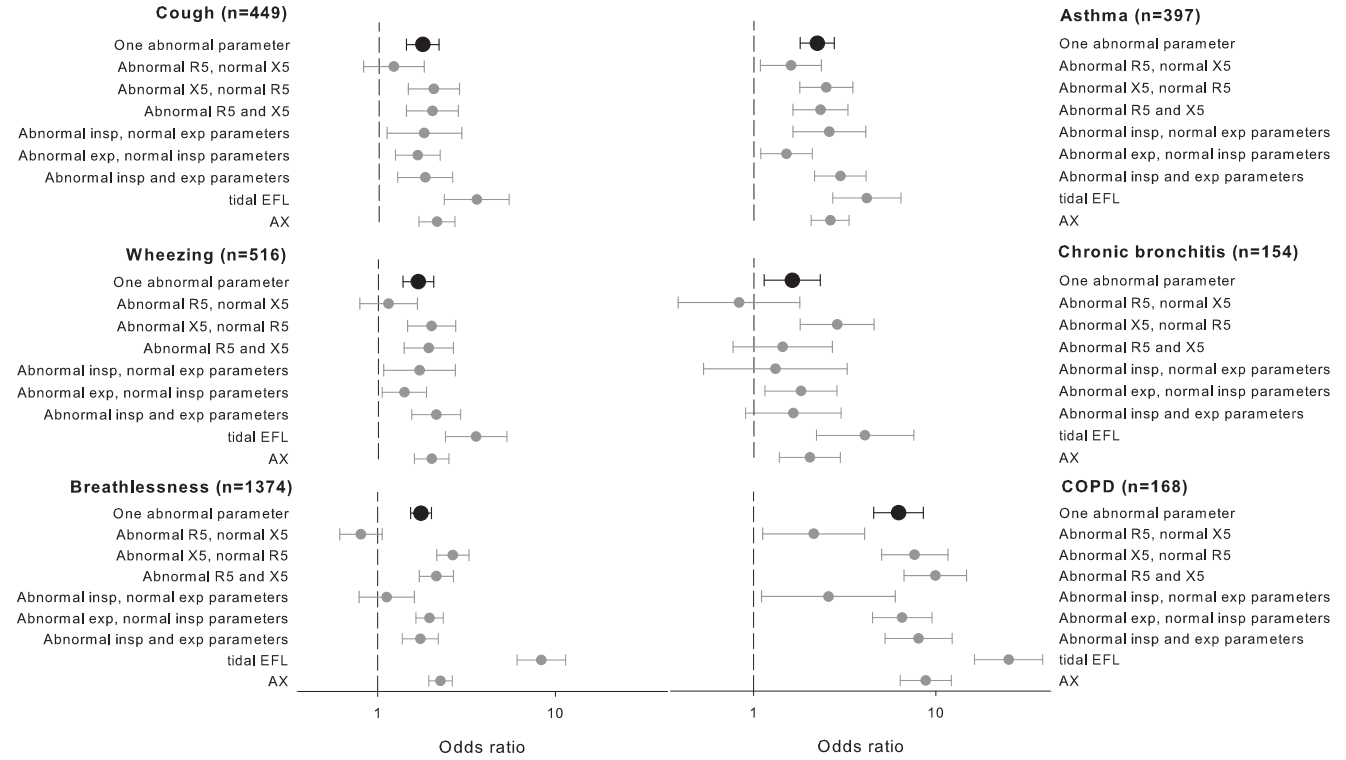

Figure 4. Odds ratios between presenting specific respiratory symptoms (left) or specific respiratory diagnoses (right) and abnormal oscillometry parameters in a general adult population. AX = the area above the reactance curve from 5 Hz to resonant frequency; COPD = chronic obstructive pulmonary disease; EFL = expiratory flow limitation; exp = within-breath expiratory component; insp = within-breath inspiratory component; R5 = respiratory system resistance at 5 Hz; X5 = respiratory system reactance at 5 Hz.

other respiratory diseases were very rare: Eight patients reported interstitial lung disease, 7 patients reported bronchiectasis, 18 reported emphysema, and 14 reported alpha-1 antitrypsin deficiency. Therefore, we did not perform a specific analysis on this group. Subjects with self-reported COPD presented the highest incidence rate of abnormal parameters (59.5%; 95% CI = 48.4–72.4), followed by asthma (34.5%; 95% CI = 29.0–41.0). Subjects with COPD diagnoses were likelier to present abnormal X5 than R5 (incidence rate difference = 20.1%; 95% CI = 6.9–34.8; $P = 0.0034$) and abnormal expiratory than inspiratory parameters (incidence rate difference = 25.6%; 95% CI = 12.7–38.5; $P = 0.0001$). Subjects with asthma presented a similar incidence rate of abnormal inspiratory parameters (17.6% [95% CI = 13.7–22.3] vs. 23.8% [95% CI = 17.0–32.4]; $P = 0.13$) but a lower expiratory one (23.4% [95% CI = 19.0–29.0] vs. 49.4% [95% CI = 39.3–61.2]; $P < 0.0001$). EFL_T and abnormal AX were present for all the reported respiratory diagnoses. EFL_T was especially associated with COPD (OR = 25.1; 95% CI = 16.3–38.8), as its incidence rate increased by 21.9% (95% CI = 20.1–23.7) in COPD in comparison with subjects without respiratory symptoms/diagnoses (22.6% [95% CI = 16.0–31.1] vs. 0.7% [95% CI = 0.5–1.0]; $P < 0.0001$). The overall prevalence of abnormal spirometry parameters was 13.0%. The association between abnormal oscillometry and self-reported respiratory respiratory conditions was confirmed by a subanalysis including only subjects with normal spirometry ($n = 6{,}575$) (Figure 5). The incidence (95% CI) of abnormal oscillometry increased from 15.1% (14.0–16.2) to 21.1% (19.0–23.5) in the presence of symptoms or diagnoses, resulting in an incidence rate difference by 6.1% (3.8–8.3), $P < 0.0001$.

Discussion

This is the largest epidemiologically based study to use the emerging lung function test of oscillometry in the general population. This cohort study showed that abnormal oscillometry parameters were present in 19.9% of the general population and significantly associated with respiratory symptoms and patient-reported diagnosis of respiratory diseases such as asthma, chronic bronchitis, and COPD. Differentiating subjects according to abnormal Rrs or Xrs parameters revealed that reactance appears to be a more sensitive indicator of symptoms and diseases compared with Rrs. Abnormal expiratory lung mechanics were more strongly related to COPD. EFL_T is associated with the highest risk of presenting respiratory diagnoses. It is interesting that these associations were still present even in the subset of subjects with normal spirometry.

Previous smaller studies reported a correlation between oscillometry values and respiratory conditions. Abnormal oscillometry parameters were associated with cough, wheeze, or dyspnea in a convenience series of ironworkers (28) and exposed individuals to dust and fumes during the World Trade Center attacks (29, 30). Abnormal oscillometry was also associated with dyspnea, tightness, and wheezing during methacholine challenge in asthmatic subjects (31); with breathlessness severity and asthma symptom control in obese subjects

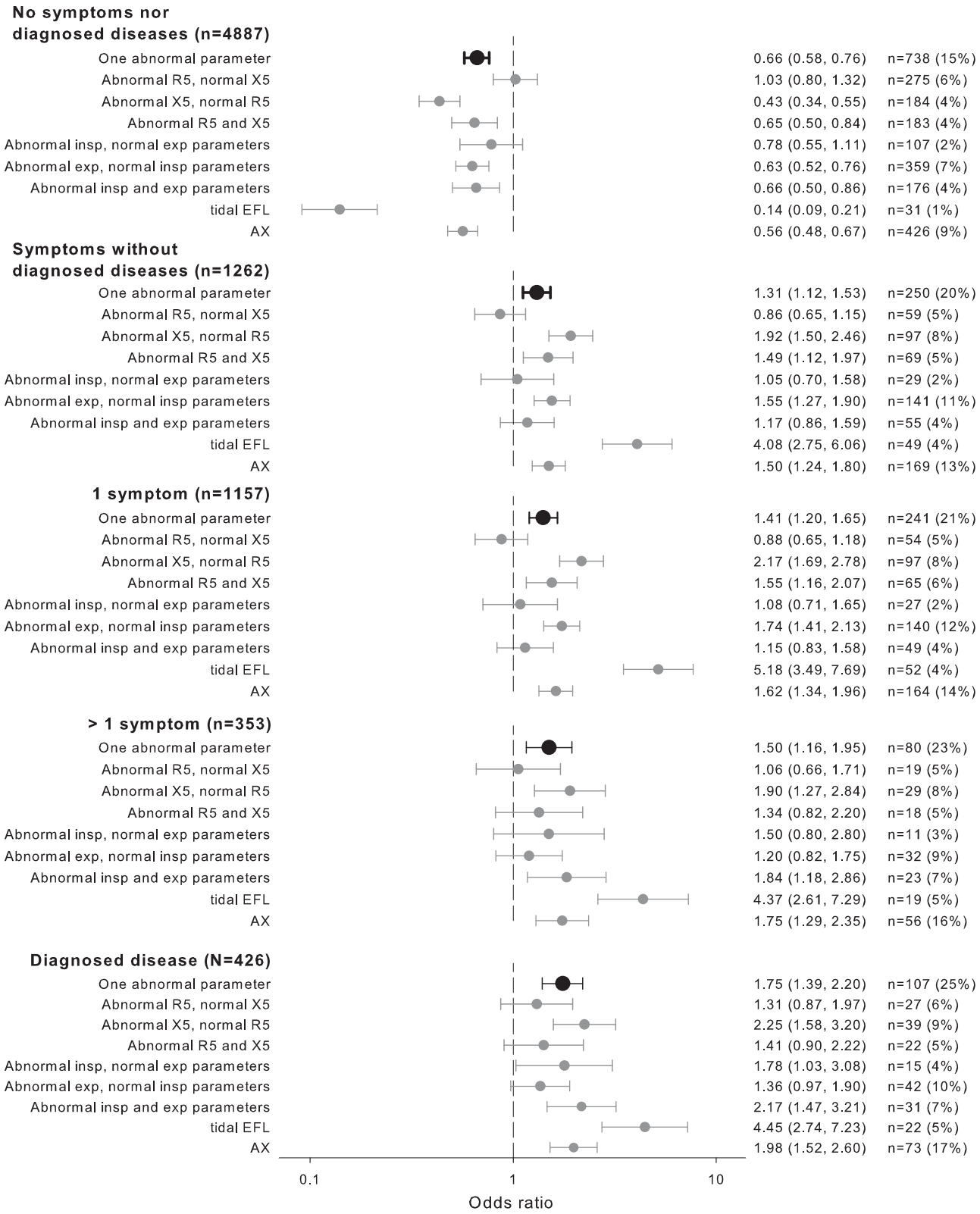

Figure 5. Odds ratio (95% confidence interval) of presenting respiratory symptoms and diagnoses in subjects with normal spirometry. For definition of abbreviations, *see* Figure 3.

(32); with self-reported symptoms suggestive of COPD (33); and with exercise performance deterioration, exacerbation rate, and mortality in COPD (34). Abnormal oscillometry parameters were associated with symptoms (35), small airway dysfunction (13), asthma (36), and active smoking (37, 38), specifically in subjects with preserved spirometry. All these works showed the additive role of oscillometry in diagnosing airway dysfunction in subjects with normal spirometry. Also, a close link was reported between oscillometry parameters and the underlying inflammation process in both asthma and COPD (39, 40). Finally, in a recent large-scale, epidemiologically based study, a significant association between abnormal oscillometry and respiratory symptoms was observed after the administration of salbutamol, even considering only subjects with preserved spirometry (19). The study reported a prevalence of abnormal oscillometry (16%) and abnormal spirometry (19%) that differed from our findings. However, these disparities can be attributed to significant differences in study design, such as the salbutamol administration before the measurements, a different definition of abnormal spirometry, the use of normality ranges defined on a subgroup of "healthy" subjects within their studied population, and a narrower age range.

Our finding confirmed the association between abnormal oscillometry parameters and respiratory symptoms and diseases in a general population, and even considering only subjects with preserved spirometry. In our dataset, the addition of oscillometry to spirometry measurements allowed an additional 17% of the population with symptoms/diagnoses to be identified with abnormal lung mechanics. These results support the concept of integrating oscillometry into the clinical diagnostic routine to objectively identify early abnormalities (41). This is particularly relevant as spirometry, despite its widespread use as a single diagnostic test, may not capture certain aspects of respiratory abnormalities that specifically affect small airways (42, 43). Another aspect to consider is that oscillometry can have a role in situations where spirometry cannot be performed or outside of major academic centers, where the quality of spirometry can be poor and where technicians, as well as patients, would prefer not to perform the test. Also, in the post-COVID era, there is resistance to performing the aerosol-generating maneuver required for spirometry. However, Figure 2 suggests that oscillometry and spirometry are not mutually exclusive and add value and insight.

Abnormal X5 values were more indicative of symptoms than abnormal R5. R5 is mainly determined by airway calibers and the presence of heterogeneous ventilation (2). Conversely, X5 reflects the apparent elasticity resulting from the total communicating lung volume and, therefore, is more sensitive to peripheral airway closure (44). This may support respiratory symptoms being partially linked to small airway disease, as previously suggested (45) and in line with R5R19 results reported elsewhere (*see* the online supplement).

Measuring oscillometry parameters separately during the inspiratory and expiratory phases has theoretical advantages, as specific pathophysiological phenomena can be amplified in one of the two phases. For example, EFL_T and vocal cord dysfunction affect the inspiratory and the expiratory phases differently (1, 46). In our dataset, abnormal expiratory values are more typical of breathlessness. Also, we reported a similar increased incidence rate of abnormal inspiratory parameters in asthma and COPD, whereas the incidence rate of abnormal expiratory parameters was higher in COPD. These results align with those of previous studies reporting worse expiratory parameters in COPD than asthma but similar inspiratory parameters (47, 48). These may suggest that inspiratory parameters better reflect intrinsic airway disease, in accordance with previous observations (49). The further increased presence of abnormal expiratory parameters and EFL_T in COPD reflects dynamic airway narrowing that is due to a loss of elastic recoil becoming more evident at lower volumes (25, 50). EFL_T is associated with the highest risk of presenting respiratory diagnoses. During spontaneous breathing in humans, EFL_T is manifested in dynamic hyperinflation, which limits the inspiratory capacity, and can be linked to dyspnea, impaired gas exchange, and exercise tolerance (51). The association of EFL_T detected by oscillometry with increased hyperinflation, dyspnea, and reduced exercise performance has been reported previously (52). The advantage of this parameter is to consider changes in Xrs during natural breathing conditions using the inspiratory values as a reference (ΔXrs). Similarly, increased ΔXrs can already detect the presence of mechanical alteration without reaching the threshold for fully developed EFL_T (53).

Our results also revealed that the odds of having symptoms or diseases were similar for subjects with abnormal AX and X5 and that AX and X5 are strongly correlated (correlation coefficient = -0.92; $P < 0.001$; *see* Figure E2). These results suggest that impedance at 5 Hz may convey the majority of information about lung function alteration when evaluated in the general adult population. However, when measuring Xrs using multifrequency stimulation, AX has the advantage of being less affected by artifacts generated by the breathing activity specifically affecting the lowest frequencies. Nevertheless, single-frequency measurements improve the signal-to-noise ratio of the measure, making the results less influenced by the breathing signal, and they can be obtained using simple and affordable devices suitable for large-scale applications such as screening in primary care.

Strengths and Limitations

To our knowledge, this is the first study to report the prevalence of abnormal oscillometry in a large general adult population selected unbiasedly, as well as its association with both symptoms and respiratory diagnoses.

As the study began before the publication of international recommendations requiring a between-measurements Rrs coefficient of variation less than 10%, oscillometry measurements were not always performed in triplicate. We could not exclude measures as for technical standards, nor could we perform any between-measurements variability analysis. The device used for data acquisition had an embedded quality check algorithm examining each breath on the basis of Rrs, Xrs, breath duration, and amplitude. We additionally excluded any measures with a within-measurement Rrs coefficient of variation greater than 30% to account for residual artifacts. This led to a rejection rate in line with the findings of a previous study that was performed with another device where measurements were excluded according to technical standards (54). Also, a recent publication suggested that a single measurement may suffice in epidemiological studies (55).

We acknowledge that our results are critically dependent on the normative data equations used. We chose equations derived utilizing a plurality of different devices on the

population most closely approximating our population as per guidelines (2). To test the sensitivity of our findings, we repeated the analysis using another set of equations derived using a different device and a different population (54). The results reported (*see* Figures E3–E5) showed no changes in the significance of the relationships and minor changes in the odds ratio. Also, abnormal R5R19 results were not considered in the manuscript, because their reference equation was not available. However, we included them in the analysis reported in the online supplement (Figures E3–E5) using alternative reference equations. Also, the impact of considering the Fres on the results is reported in the online supplement (*see* Figure E6). We obtained Fres and AX values by extrapolating Xrs values beyond the measured frequencies in 1,022 subjects having Fres values greater than 19 Hz. Although such an approach was shown not to introduce a systematic bias in the results (23), we could not exclude the presence of residual errors in these calculations.

In the absence of reference values for inspiratory and expiratory parameters, we used the values for Rrs and Xrs for intrabreath parameters. However, it should be noted that healthy individuals breathing quietly typically have minimal impedance variations within a single breath. Therefore, we would expect minimal differences between within-breath and whole-breath normality ranges as reported in the Indian population (56). Nevertheless, we acknowledge that a potential classification bias could affect our results because of possible overestimation and underestimation of subjects with abnormal expiratory and inspiratory parameters, respectively. Also, we limited our intrabreath analysis to 5 Hz as lower frequencies are more sensitive to peripheral changes; however, higher frequencies may be required for subjects with faster breathing frequencies, such as newborns (30–40 breaths per minute).

Rrs values may be influenced by the flow rate at which measurements were performed (57). We found 1,148 measurements performed with minute ventilation higher than 20 L/min. However, excluding these measurements from the analysis did not impact the results. Also, we did not compute the intrabreath oscillometry under zero-flow conditions, an emerging approach to obtain Rrs values less dependent on the breathing pattern (15, 16, 58).

Symptoms and diagnosis were assessed with an interview-based questionnaire, which is a strength, but the presence of disease was self-reported without objective supportive data. Finally, the present dataset does not have statistical power to assess oscillometry performance in patients with restrictive conditions. Furthermore, although all participants were in stable condition, the contribution of congestive heart failure to symptoms cannot be completely ruled out.

Conclusions

This study strongly supports oscillometry as a simple, feasible, and sensitive point-of-care method to objectify respiratory symptoms in the general population. Our results underscore the value of integrating oscillometry into routine respiratory assessments to detect and manage respiratory diseases early, particularly in individuals with preserved spirometry. Last, future studies including oscillometry in the battery of patient-related outcomes are likely to yield unique insights. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

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