



Research Article



Oscillometry and Artificial Intelligence (AI) Detected Adventitious Lung Sounds During Exercise Induced Bronchoconstriction in Children

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Abstract

Background: Exercise Induced Bronchoconstriction (EIB) is a common cause of exercise limitation in children, yet adventitious lung sounds after exercise are often scarce and poorly correlated with spirometric impairment. Artificial Intelligence (AI) assisted electronic stethoscopes may improve sound detection, while oscillometry provides sensitive measures of small airway mechanics. Whether post exercise adventitious sounds relate to oscillometric changes in pediatric patients remains unclear.

Objectives: To evaluate whether AI detected adventitious lung sounds after exercise reflect oscillometric or spirometric changes in children with exercise induced symptoms and to assess agreement between AI assisted and physician auscultation.

Methods: Children with recurrent exercise induced symptoms underwent baseline assessments, treadmill exercise testing and post exercise spirometry, oscillometry and AI assisted lung sound recordings (StethoMe®). Adventitious sounds (wheezes/rhonchi) were compared with lung function outcomes and with physician auscultation. EIB was defined as a $\geq 10\%$ fall in FEV₁. Associations between sound intensity and oscillometric parameters were evaluated.

Results: Eighty nine children (mean age 11.6 ± 2.6 years) completed the protocol; 21 (23.6%) had EIB. Adventitious sounds were infrequent overall but more common after exercise. Agreement between the AI stethoscope and the physician was substantial for rhonchi ($\kappa = 0.77$) and excellent for wheezes ($\kappa = 0.92$) post exercise. Children with any post exercise adventitious sound ($n = 18$) showed higher expiratory R (R5, Fdep) and markedly lower expiratory X across all frequencies compared with those without sounds, whereas spirometric indices did not differ. Sound intensity correlated with

post exercise expiratory R5, Fdep and especially expiratory X5. Inspiratory oscillometric values showed no meaningful associations.

Conclusion: AI detected adventitious lung sounds after exercise reflect expiratory oscillometric abnormalities but are not linked to spirometry defined EIB. Expiratory reactance, in particular, mirrors the presence and intensity of wheezes and rhonchi. Integrating AI assisted auscultation with oscillometry may provide complementary insights into small airway mechanics during exercise induced airway narrowing.

Keywords: Exercise Induced Bronchoconstriction; Oscillometry; Artificial Intelligence; Adventitious Lung Sounds; Electronic Stethoscope; Pediatrics; Small Airway Dysfunction; Reactance

Abbreviations

AI: Artificial Intelligence; EIB: Exercise-Induced Bronchoconstriction; FeNO: Fractional Exhaled Nitric Oxide; FEV₁: Forced Expiratory Volume in 1 second; R: Resistance; X: Reactance; R5: Resistance at 5 Hz; X5: Reactance at 5 Hz; Fdep: Frequency Dependence of Resistance

Introduction

Exercise-Induced Bronchoconstriction (EIB) is a frequent cause of exercise limitation in children and may significantly affect participation in play and sports. Although commonly associated with asthma, EIB can also occur in non-asthmatic individuals [1]. When symptoms such as cough, dyspnea or chest tightness recur during physical activity, objective testing is recommended to support diagnosis and guide management [1,2].

Electronic stethoscopes equipped with Artificial Intelligence (AI) have emerged as useful tools for detecting adventitious lung sounds in children with recurrent respiratory symptoms, including for home monitoring [3-5]. However, despite their utility in identifying asthma exacerbations, it remains unclear whether wheezes and rhonchi recorded during or after exercise reliably reflect the degree of bronchoconstriction. Traditional auscultation has limited sensitivity for airflow obstruction and the correlation between wheezing and spirometric impairment is generally weak [6]. Whether AI-assisted sound analysis can improve the identification of EIB remains to be established. Comparing AI-detected lung sounds with respiratory function changes during standardized exercise testing may help clarify their diagnostic value.

A positive exercise challenge is typically defined by a post-exercise FEV₁ decrease $\geq 10\%$ from baseline [7]. If sound analysis were shown to reflect this response, it could support out-of-hospital screening of children reporting exercise-induced symptoms. Oscillometry may offer additional insights, as it provides sensitive measures of respiratory system Resistance (R) and Reactance (X) during quiet breathing and is particularly suited to pediatric populations [8,9]. Its ability to detect small-airway dysfunction suggests that oscillometric changes during EIB could relate more closely to adventitious sounds than spirometric indices alone.

This study aimed to evaluate oscillometry and spirometry responses to exercise in pediatric patients, comparing outcomes by EIB status and by the presence or absence of adventitious sounds. A further objective was to assess the agreement between AI-assisted sound detection (StethoMe®) and physician auscultation.

Methodology

Study Design

Observational

Participants/Subjects

Children attending the pediatric pulmonology clinic at Sant' Andrea Hospital who reported recurrent symptoms during physical exercise were eligible. In these patients-both those with suspected asthma and those with a prior asthma diagnosis-an exercise test was required to evaluate exercise-induced bronchoreactivity and guide preventive and therapeutic decisions.

Exclusion criteria included suspected Exercise-Induced Laryngeal Obstruction (EILO) or any condition impairing correct execution of the exercise test. Inclusion criteria were normal baseline respiratory function, absence of symptoms or respiratory infections in the previous 4 weeks and no recent anti-inflammatory (steroids, antileukotrienes) or antihistamine therapy according to recommended washout intervals [10]. Parents provided informed consent and the Institutional Ethical Review Board approved the study.

Data Collection

During a single visit, the following procedures were performed in sequence: medical examination, completion of questionnaires and skin prick testing. After reading the prick tests, the StethoMe® device was applied to a conventional area (right anterior hemithorax) and a 2 minute recording was obtained. Oscillometry, exhaled Nitric Oxide (FeNO) and baseline spirometry were then performed. An incremental treadmill exercise test was subsequently conducted (6 km/h, 10% incline) until reaching at least 85% of the predicted maximal heart rate ($220 - \text{age}$), under controlled environmental conditions [7]. Spirometry was repeated at 1, 5, 10, 15 and 20 minutes post-exercise; oscillometry at 3 and 18 minutes; and a StethoMe® recording at 7 minutes post-exercise.

After completion of the test, 200 mcg of salbutamol was administered via metered-dose inhaler with spacer. Fifteen minutes later, lung sounds were recorded again (StethoMe®), followed by oscillometric and spirometric measurements.

At each step-baseline, post-exercise and post-bronchodilation-the right anterior hemithorax was auscultated by a pediatric trainee before each StethoMe® recording. The presence or absence of adventitious sounds (wheezes or rhonchi) was documented in a registry prior to knowing the AI-stethoscope output.

EIB was defined as a $\geq 10\%$ fall in FEV₁ from baseline, according to international guidelines [7]. Spirometric and oscillometric variables were expressed as percentages of predicted values and z-scores, respectively [11,12].

Measurements

Skin Prick Test

Common inhaled and food allergens were assessed using standard skin prick testing with positive (histamine) and negative (glycerol) controls. Wheals ≥ 3 mm were considered positive.

FeNO

Fractional exhaled nitric oxide was measured in triplicate using the HyPair FENO system (Medisoft Group, Sorinnes, Belgium), following recommended procedures [13].

Oscillometry

Multifrequency oscillometry at 5, 11 and 19 Hz was performed using the Resmon Pro Full device (ResTech, Milan, Italy). Triplicate baseline measurements with a coefficient of variation $\leq 15\%$ were required. Inspiratory and expiratory resistance (R) and reactance (X) were expressed as z-scores based on reference values [12].

Spirometry

Spirometry was performed using a Quark PFT system (Cosmed Srl, Rome, Italy) according to ATS/ERS guidelines [14]. Dynamic flows and volumes were expressed as percentages of predicted values [11].

Lung Sound Assessment

An AI-enabled electronic stethoscope (StethoMe®, StethoMe sp. z o.o., Poznań, Poland) was used to record wheezes and rhonchi from the right anterior chest wall using the device's "asthma control" mode. Sound files were transferred wirelessly to a dedicated mobile application where anonymized patient data were stored. The AI module analyzed the recordings and provided the intensity of each adventitious sound (0-100 scale), along with Heart Rate (HR), Respiratory Rate (RR) and inspiratory-to-expiratory duration ratio (I/E) [4,5]. For each patient, at least one noise-free recording of ≥ 30 seconds was obtained at baseline, 7 minutes post-exercise and after bronchodilation. The number of pathological events and their mean intensity were used for analysis.

Data Analysis

Based on previous findings in children with recurrent respiratory symptoms, an EIB prevalence of 25-35% was expected [10]. Using the variability of R and X z-scores for EIB diagnosis, with 95% confidence intervals and a 5% margin of error, a sample size of 86 children was calculated. Normality was assessed using the Kolmogorov-Smirnov test. Variables were expressed as means \pm standard deviation or medians with Interquartile Ranges (IQRs). Between-group comparisons were performed using the Mann-Whitney U test, while categorical variables were compared using the χ^2 test or Fisher's exact test. Agreement between physician auscultation and AI-stethoscope detection was assessed using Cohen's kappa (κ), with κ values of 0.00-0.20 indicating poor agreement and 0.80-1.00 indicating excellent agreement. Associations between lung sound intensity and lung function variables were evaluated using Spearman's rank correlation. Analyses were performed using SPSS version 30 (SPSS Inc., Chicago, IL). A p-value < 0.05 was considered statistically significant.

Results

A total of 89 patients (M/F: 60/29; mean age 11.6 ± 2.6 years) completed all assessments; EIB was identified in 21 (23.6%). Children

with EIB more frequently reported household tobacco exposure, exercise induced cough, a history of rhinitis and borderline features for an asthma diagnosis. They also showed higher FeNO levels, lower baseline lung function and a greater bronchodilator response compared with children without EIB (Table 1,2).

Demographics and Clinical Data	Without EIB (n=68)	EIB (n=21)	P-value
Gender (M/F)	45/23	15/6	0.654
Age, years	11.4 ± 2.4	12.4 ± 3.0	0.095
Height, cm	150.5 ± 14.1	155.6 ± 17.9	0.209
BMI percentile	65.7 ± 28.9	71.1 ± 25.2	0.639
Parents smoke, n (%)	31 (45.6)	16 (76.2)	0.014
Asthma diagnosis, n (%)	32(47.1)	15 (71.4)	0.051
Rhinitis, n (%)	37 (54.4)	17 (81.0)	0.030
Atopy, n (%)	48 (70.6)	18 (85.7)	0.218
FeNO, ppb	18.8 ± 22.7	26.9 ± 16.8	0.004
Exercise-induced symptoms			
-Cough	26 (38.2)	14 (66.7)	0.022
-Dyspnea	37 (54.4)	16 (76.2)	0.075
-Chest pain	6 (8.8)	4 (19.0)	0.238
Therapy past 12 months, n (%)			
-Antileukotriens	25 (36.8)	8 (38.1)	0.912
-Antihistamines	38 (55.9)	14 (66.7)	0.381
-ICs+SABA/LABA	46 (67.6)	17 (81.0)	0.241
Statistical differences were assessed using Fisher's exact test or the Mann-Whitney test.			
ICs: inhaled corticosteroids; SABA/LABA: short-/long-acting β agonists.			
EIB: exercise-induced bronchoconstriction.			

Table 1: Subjects' characteristics by exercise challenge outcomes.

Baseline	Without EIB (n=68)	EIB (n=21)	P-value
FEV ₁ %	104.7 ± 11.0	99.2 ± 13.6	0.040
FVC%	102.9 ± 11.8	100.1 ± 14.1	0.439
FEF ₂₅₋₇₅ %	101.9 ± 18.3	92.2 ± 20.3	0.026
sR5	0.66 ± 0.97	0.59 ± 0.92	0.862
sR11	0.62 ± 1.03	0.59 ± 1.06	0.908
sR19	0.48 ± 1.11	0.45 ± 1.16	0.977
sFdep5_19	0.67 ± 0.79	0.02 ± 1.23	0.575
sX5	-0.18± 1.12	-0.01 ± 1.21	0.713
sX11	-0.80 ± 1.06	-0.86± 1.45	1.000
sX19	-0.71 ± 0.92	-0.58 ± 1.15	0.692
Post-exercise changes			
Fall in FEV ₁ (%)	-3.1 ± 3.2	-17.6 ± 9.2	<0.001
Fall in FEF ₂₅₋₇₅ (%)	-10.7 ± 9.4	-30.9 ± 10.8	<0.001
Rise in sR5	0.13 ± 0.79	1.15 ± 1.24	<0.001
Rise in sR11	0.14 ± 0.78	0.94 ± 1.16	0.005
Rise in sR19	0.25 ± 0.92	0.57 ± 0.93	0.220
Rise in sFdep5_19	0.09 ± 0.69	0.75 ± 0.81	0.002
Fall in sX5	-0.10 ± 1.14	-1.73 ± 2.03	<0.001
Fall in sX11	-0.06 ± 0.81	-1.61 ± 1.82	<0.001
Fall in sX19	-0.03 ± 1.02	-1.34 ± 1.76	<0.001

Bronchodilator responses			
Rise in FEV1 (%)	6.2± 5.9	15.6 ± 11.0	<0.001
Rise in FEF 25-75 (%)	21.4 ± 16.2	40.3 ± 26.0	0.001
Fall in sR5	-0.96 ± 0.77	-1.55 ± 1.80	0.475
Fall in sR11	-0.90 ± 0.68	-1.37 ± 1.45	0.206
Fall in sR19	-0.65± 0.69	-0.93 ± 1.14	0.315
Fall in s Fdep5_19	-0.57 ± 0.85	-0.97 ± 1.60	0.315
Rise in sX5	0.68 ± 0.79	1.75 ± 2.17	0.020
Rise in sX11	0.81 ± 0.55	1.77 ± 2.03	0.024
Rise in sX19	0.83 ± 0.73	1.37± 1.73	0.195
Statistical differences were assessed using the Mann-Whitney test. Respiratory resistance (R) and reactance (X), at 5, 11 and 19 Hertz and the frequency dependence of R (Fdep5_19), are expressed as z-scores (“s” prefix).			

Table 2: Pulmonary function and post exercise/post bronchodilator changes in children with and without EIB.

Adventitious lung sounds were overall infrequent. At baseline, the AI stethoscope detected wheezes in 3 children (3.4%) and rhonchi in 10 (11.2%). After exercise, wheezes were identified in 8 (9.0%) and rhonchi in 13 (14.6%); after bronchodilation, no wheezes were detected, while rhonchi persisted in 10 children (11.2%). Although pathological sounds were more common among children with EIB, these differences did not reach statistical significance (Table 3).

Number of Events	Without EIB (n=68)	EIB (n=21)	P (X² Fisher)
Baseline, n (%)			
-Wheezes	1 (1.5)	2 (9.5)	0.137
-Rhonchi	7 (10.3)	3 (14.3)	0.695
-Wheezes or rhonchi	7 (10.3)	4 (19.0)	0.280
After exercise, n (%)			
-Wheezes	5 (7.4)	3 (14.3)	0.386
-Rhonchi	7 (10.3)	6 (28.6)	0.070
-Wheezes or rhonchi	11 (16.2)	7 (33.3)	0.119
Bronchodilation, n (%)			
-Wheezes	0 (0.0)	0 (0.0)	–
-Rhonchi	6 (8.8)	4 (19.0)	0.238
-Wheezes or rhonchi	6 (8.8)	4 (19.0)	0.238

Table 3: Adventitious lung sounds detected by the AI stethoscope during the challenge protocol by EIB incidence.

Cohen’s kappa for agreement between the AI stethoscope and the physician (n = 82) was mild to moderate at baseline and post bronchodilation, but ranged from substantial to excellent post exercise: $\kappa = 0.77$ for rhonchi and $\kappa = 0.92$ for wheezes (Table 4). In two cases, the AI stethoscope identified adventitious sounds that were not detected by the physician. Using physician auscultation as the reference, the AI stethoscope demonstrated a sensitivity of 100.0% (76.8-100.0), specificity of 97.1% (89.8-99.6), accuracy of 97.6% (91.5-99.7), positive predictive value of 87.5% (64.1-96.5) and negative predictive value of 100.0% (94.6-100.0).

Adventitious Sounds	Physician	StethoMe®	Cohen’s Kappa
Baseline (n)			
-Wheezes	0	3	-
-Rhonchi	4	9	0.59
-Wheezes or rhonchi	4	10	0.54
After exercise (n)			
-Wheezes	6	7	0.92

-Rhonchi	8	11	0.77
-Wheezes or rhonchi	14	16	0.92
Bronchodilation (n)			
-Wheezes	0	0	-
-Rhonchi	5	9	0.69
-Wheezes or rhonchi	5	9	0.69
Levels of agreement: 0.01-0.20: none-to-scarce; 0.21-0.40: mild; 0.41-0.60: moderate; 0.61-0.80: fair/substantial; 0.81-1.00: excellent.			

Table 4: Agreement between the physician and the AI stethoscope in 82 subjects.

Because adventitious sounds were scarce, lung function was not compared by specific sound type or by baseline/post bronchodilator status. Instead, children with at least one adventitious sound after exercise (n = 18) were compared with those without detected sounds (n = 71). The lowest post exercise FEV₁ and FEF₂₅₋₇₅ values did not differ between groups. In contrast, children with adventitious sounds showed higher post exercise z scored R (R5 and Fdep) and, most notably, lower X across all frequencies (Table 5). These differences were driven by expiratory rather than inspiratory values, resulting in a widened within breath X5 difference (expiratory - inspiratory).

Post-Exercise Values ¹	No adventitious sounds (n=71)	Wheezes/rhonchi (n=18)	P (Mann-Whitney)
Lowest FEV ₁ %	97.9± 14.3	92.5± 14.9	0.159
Lowest FEF ₂₅₋₇₅ %	85.0± 19.7	80.3± 23.0	0.317
sR5i	0.83±1.62	1.24±1.19	0.186
sR5e	0.90±1.26	1.65±1.13	0.017
sR5	0.88±1.32	1.53±1.15	0.038
sR11	0.86 ±1.36	1.30 ± 1.16	0.168
sR19	0.76 ± 1.31	0.95 ± 1.05	0.343
sFdep5_19	0.31 ± 1.19	0.73 ± 0.70	0.016
sX5i	-0.57±1.37	-0.72±1.09	0.322
sX5e	-0.56±1.79	-1.46±1.02	<0.001
X5e-X5i, cmH ₂ O/L/s	-0.43±0.63	-1.00±1.10	0.027
sX5	-0.51±1.65	-1.07±0.92	0.002
sX11	-1.06± 1.53	-1.94± 0.93	<0.001
sX19	-0.84 ± 1.48	-1.74 ± 0.90	0.001
¹ Lowest spirometry, reactance (X) and highest resistance (R) values. Z-scores ("s" prefix) are used for inspiratory or expiratory R, X, at 5 Hz, their total values at 5, 11 and 19 Hz and the frequency dependence of R (Fdep5_19). Absolute values are used for the widest within-breath difference in X5.			

Table 5: Pulmonary function by StethoMe® detection of any post exercise adventitious sound.

To complement these findings, we examined correlations between post exercise lung function and the intensity of adventitious sounds. Post exercise z scores of R5, Fdep and especially X at all frequencies correlated with sound intensity. These associations were again confined to expiratory measurements, particularly expiratory X5 (Table 6, Fig. 1).

Post- exercise values	Correlation (r)	p-value
Lowest FEV ₁ %	-0.17	0.120
Lowest FEF ₂₅₋₇₅ %	-0.13	0.235
sR5i	0.13	0.227
sR5e	0.25	0.018
sR5	0.21	0.045
sR11	0.13	0.210

sR19	0.04	0.716
sFdep5_19	0.25	0.018
sX5i	-0.12	0.275
sX5e	-0.37	<0.001
sX5	-0.34	0.001
sX11	-0.36	<0.001
sX19	-0.35	<0.001

Values are z-scores ("s" prefix) of inspiratory or expiratory resistance (Ri, Re) and reactance (Xi, Xe), at 5 Hertz; similarly, are expressed total values of R and X at every wave frequency and the frequency dependence of R (Fdep5_19).

Table 6: Spearman's correlations with adventitious sound intensity (0-100) detected by the AI stethoscope.

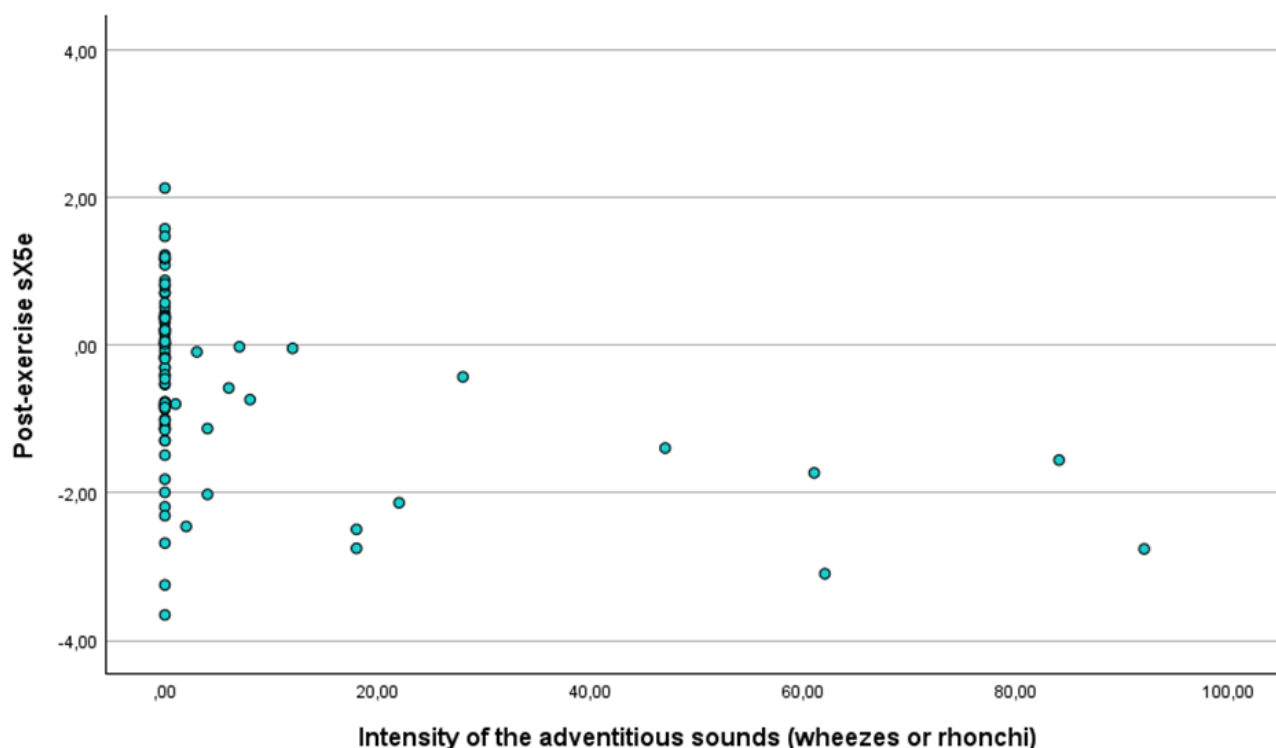


Figure 1: Relationship between the z score value ("s" prefix) of expiratory reactance at 5 Hz (sX5e) and the intensity of adventitious sounds detected by the AI stethoscope after exercise ($r = -0.37$, $p < 0.001$).

Discussion

In this cohort of children with recurrent exercise induced symptoms, adventitious lung sounds after exercise were relatively uncommon, even among those with confirmed EIB. The AI stethoscope detected more post exercise pathological sounds than the physician, although agreement for wheezes was excellent. The most notable finding was that oscillometry-rather than spirometry-distinguished children with post exercise adventitious sounds. Expiratory measures of R and, especially, X correlated with the intensity of wheezes and/or rhonchi recorded after exercise. Children with EIB exhibited more clinical and inflammatory markers of airway hyperresponsiveness than those without EIB. However, adventitious sounds also occurred in children without EIB, reinforcing concerns about relying solely on auscultation to diagnose EIB [2,15]. Previous pediatric studies have shown that post exercise wheezes or rhonchi do not correlate with the magnitude of FEV₁ decline nor predict the presence or severity of EIB [16]. Several factors may explain this: post exercise bronchoconstriction may be mild and thus inaudible; the timing of sound generation and bronchoconstriction may not overlap; and auscultation may occur after bronchoconstriction has already begun to resolve. These considerations apply to spirometry based definitions of EIB. As highlighted in early work, acoustic signals from the lungs convey aspects of airway functional status that differ qualitatively from those captured by spirometry [17]. This motivated our evaluation of post exercise adventitious sounds alongside oscillometric changes.

A substantial body of evidence shows that AI based models outperform physicians in detecting adventitious lung sounds [18-21]. The AI stethoscope used in this study (StethoMe®) employs a neural network trained on more than 10,000 pediatric respiratory recordings and has been clinically validated in children. Its algorithm has also identified acoustic events recorded by other electronic stethoscopes (Clinicloud and Littmann) with high sensitivity (80-90%) and specificity (97%) [18,21].

To our knowledge, no prior studies have evaluated agreement between an AI stethoscope and physicians specifically for exercise induced adventitious sounds. In children with spontaneous pathological lung sounds, agreement between electronic devices and clinicians has been reported as moderate for wheezes and the clinical recognition of wheezes is known to depend on the examiner's expertise, with wheezes and rhonchi often being misclassified for one another [22,23]. In our study, post exercise agreement was substantial for rhonchi and excellent for wheezes. Differences across studies may reflect the context (spontaneous vs. exercise induced sounds), device characteristics or variability in clinical auscultation. Physicians may also be more inclined to classify post exercise sounds as "wheezes," whereas the AI stethoscope quantifies wheezes and rhonchi separately.

Clinical auscultation is inherently subjective and prone to inter observer variability, yet it remains central to respiratory assessment [24]. By evaluating AI assisted auscultation during an exercise challenge-a proxy for routine clinical practice-we found that the AI stethoscope can enhance post exercise evaluation and provide complementary information to conventional lung function testing.

A key question is whether oscillometry reflects the presence of adventitious sounds. Experimental studies indicate that wheezes arise from viscid flutter in collapsible small airways during flow limitation, disappearing when airway walls approximate too closely, as in severe obstruction [25,26]. Additional mechanisms include airflow vortices generating alternating pressures [27]. These mechanisms may explain why oscillometry distinguished children with post exercise adventitious sounds: expiratory R and especially X differed markedly, suggesting contributions from fluttering airway walls and endoluminal secretions during expiration. The widened within breath X5 difference supports this interpretation [28]. Fdep5-19, a marker of small airway obstruction and ventilation heterogeneity was also increased [9].

We also found an inverse correlation between sound intensity and expiratory X. Although no studies have combined AI assisted sound analysis with oscillometry during EIB, some work in asthma suggests that oscillometry better reflects airway obstruction than spirometry when paired with tracheal sound analysis [29]. Impedance measurements during quiet breathing avoid the bronchodilatory effect of deep inspirations. In adults with asthma, relationships have been reported between low frequency sound power (100-195 Hz), the E/I sound pressure ratio and within breath oscillometric changes [30]. Differences in methodology prevent direct comparison, but our findings highlight the potential value of integrating sound analysis with oscillometry.

This study has limitations. The low number of pathological sound recordings was unexpected given the high prevalence of clinical and inflammatory risk factors. This limited our ability to analyze sound types separately or to identify diagnostic thresholds for sound intensity. Strengths include demonstrating that multifrequency oscillometry-particularly expiratory parameters and within breath X5-better reflects adventitious sounds during EIB than spirometry. The inverse relationship between expiratory reactance and sound intensity warrants further investigation.

Conclusion

Adventitious lung sounds recorded with an AI stethoscope after exercise are reflected in oscillometric parameters, especially expiratory reactance. These sounds are not linked to spirometry defined EIB. The clinical value of quantifying the relationship between wheeze/rhonchus intensity and expiratory reactance merits further study.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical Statement

The project did not meet the definition of human subject research under the purview of the IRB according to federal regulations and therefore was exempt.

Informed Consent Statement

Informed consent was obtained from all participants included in the study.

Authors' Contributions

All authors contributed equally to this paper.

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