ORIGINAL ARTICLE

Exercise-Induced Airway Obstruction in Young Asthmatics Measured by Impulse Oscillometry

JH Lee, YW Lee, YS Shin, YH Jung, CS Hong, and JW Park

Division of Allergy and Immunology, Department of Internal Medicine, Institute of Allergy, Brain Korea 21 Project for Medical Science, Yonsei University College of Medicine, Seoul, Republic of Korea

Abstract

Background: Impulse oscillometry (IOS) is a good method for measuring airway resistance. It does not require special breathing skills and it can reflect different aspects of airway obstruction to those revealed by spirometry, which is an effort-dependent maneuver.
Objective: To evaluate the characteristics of airway obstruction in young asthmatics after an exercise bronchial provocation test (EBPT) using IOS.
Methods: Forty-seven young adults were enrolled in the study. All the participants underwent a methacholine bronchial provocation test (MBPT) and an EBPT for the evaluation of their asthma. IOS and spirometric parameters were collected at baseline and at 0, 5, 10, 20, and 30 minutes post-EBPT. The participants were divided into 2 groups according to MBPT positivity: an airway hyperresponsiveness (AHR) group and a no-AHR group.
Results: There were differences in the percent decrease in forced expiratory volume in the first second (FEV_1) between the 2 groups at 5, 10, and 20 minutes after exercise. Resistance at 5 Hz (R_5) increased in the AHR group but not in the no-AHR group at 5 and 10 minutes after exercise. Integration of reactance from 5 Hz to resonance frequency (area of reactance, AX) was also increased in the AHR group at only 5 and 10 minutes post-EBPT. ΔR_5 and ΔAX at 5 and 10 minutes post-exercise were well correlated with the percent decrease in FEV_1.
Conclusions: IOS parameters, especially ΔR5 and ΔAX, may be useful for performing objective evaluations and improving our understanding of exercise-induced airway obstruction in young asthmatics.

Key words: Impulse oscillometry. Exercise-induced bronchoconstriction. Asthma.

Resumen

Antecedentes: La oscilometría de impulsos (IOS) es un buen método para determinar la resistencia de las vías respiratorias. No requiere una técnica de respiración especial y puede reflejar aspectos de la obstrucción de las vías respiratorias distintos de los revelados por la espirometría, una maniobra dependiente del esfuerzo.
Objetivo: Evaluar las características de la obstrucción de las vías respiratorias en jóvenes asmáticos tras una prueba de provocación bronquial con ejercicio físico (PPBE) mediante IOS.
Métodos: En el estudio participaron cuarenta y siete adultos jóvenes. Todos los participantes se sometieron a una prueba de provocación bronquial con metacolina (PPBM) y a una PPBE para evaluar el asma. Se recopilaron los parámetros espirométricos y de la IOS al inicio del estudio y a los 0, 5, 10, 20 y 30 minutos tras la PPBE. Los participantes se dividieron en dos grupos según la positividad de la PPBM: un grupo con hiperreactividad de las vías respiratorias (HRVR) y un grupo sin HRVR.
Resultados: Se observaron diferencias en la disminución porcentual de volumen espiratorio máximo en el primer segundo (VEM_1) entre los dos grupos a los 5, 10 y 20 minutos tras el ejercicio físico. La resistencia a 5 Hz (R_5) aumentó en el grupo con HRVR pero no en el grupo sin HRVR a los 5 y 10 minutos tras el ejercicio físico. La integración de la reactancia desde 5 Hz hasta la frecuencia de resonancia (área de reactancia, AX) también aumentó en el grupo con HRVR a los 5 y 10 minutos después de la PPBE. Los parámetros ΔR5 y ΔAX a los 5 y 10 minutos tras el ejercicio físico mostraron una buena correlación con la disminución porcentual de VEM_1.
Conclusiones: Los parámetros de la IOS, especialmente ΔR_5 y ΔAX, pueden ser útiles para realizar evaluaciones subjetivas y mejorar el conocimiento de la obstrucción de las vías respiratorias inducida por el ejercicio físico en jóvenes asmáticos.

Palabras clave: Oscilometría de impulsos. Broncoconstricción inducida por el ejercicio físico. Asma.

© 2010 Esmon Publicidad

Introduction

Exercise is an important exacerbating factor in bronchial asthma, especially in children and young adults because of their high level of physical activity [1]. The exercise bronchial provocation test (EBPT) has been used to confirm exercise-induced bronchoconstriction (EIB) [2]. In this test, serial spirometric data are collected after 5 to 10 minutes of exercise. A decrement in forced expiratory volume in the first second (FEV_1) from baseline is the most important diagnostic value, with a decrease of 10% or more indicating a diagnosis of EIB [3].

In allergic airway diseases such as asthma and allergic rhinitis, airway hyperresponsiveness (AHR) caused by nonspecific airway irritation is a characteristic finding [4]. However, there is controversy regarding whether or not exercise can induce or increase nonspecific AHR [5-7]. Although not all asthmatics present EIB, the EBPT is a necessary test, especially in pre-recruitment physical examinations for military conscription [8].

In many countries, including Korea, Turkey, and Switzerland, military reinforcement is supplied by obligatory recruitment [9], and the detection of draft evaders is important. In many other countries, however, such as the United States, England, and Japan, military forces are entirely made up of career soldiers [9]. In these countries, pre- and post-recruitment physical examinations are important when choosing suitable young men and women for the physically demanding tasks required in the military.

Spirometry is used to detect EIB [10] but because it is an effort-dependent forced maneuver, those undergoing this test can theoretically manipulate results [11]. Another technique known as the forced oscillation technique (FOT) offers a reliable means of measuring airway resistance. The FOT is useful for evaluating disease status or severity in chronic obstructive pulmonary disease and bronchial asthma [12] and is used with children and elderly patients unable to cooperate with forced expiration [13]. FOT measurements are taken during tidal breathing and therefore cannot be manipulated by those undergoing the test.

In this study, we evaluate exercise-induced airway characteristics measured by impulse oscillometry (IOS), a commercially-available FOT, in young asthmatics with nonspecific AHR.

Methods

Patients

Forty-seven individuals who visited the Allergy-Asthma Clinic at our institution between September 2006 and July 2008 were enrolled in the study. They were all male and wished to have their asthma status evaluated prior to mandatory military recruitment by the Korean Military Manpower Administration. The inclusion criterion was defined as the presence of intermittent asthma or mild persistent asthma as defined by the Global Initiative for Asthma guidelines [14]. Individuals on long-acting β_2 agonists and who had taken rescue medication within 48 hours before the examination, or who had had an upper respiratory infection in the 4 previous weeks, were excluded. Those enrolled were divided into 2 groups according to their methacholine bronchial provocation test (MBPT) results: an AHR group (those with a PC20 [amount of methacholine required to cause a 20% reduction in FEV_1 from baseline] of <25 mg/mL; n=35) and a no-AHR group (those with a PC_{20} of ≥25 mg/mL; n=12) (Table 1). The Institutional Review Board of Yonsei University approved the study (IRB protocol no. 4-2009-0241) and informed consent was obtained from all participants.

Exercise Bronchial Provocation Test

The exercise challenge was performed using a free-running test on a treadmill. The participants ran for 10 minutes or until 80% to 90% of their estimated maximum heart rate was achieved. Maximum heart rate was calculated using the equation (205-(1/2)×age) [15]. Heart rate was assessed using a heart rate monitor (VIASYS Healthcare, Höchberg, Germany). IOS and spirometry parameters were obtained at baseline and at 0, 5, 10, 20, and 30 minutes after the exercise challenge.

Impulse Oscillometry

IOS parameters were collected before conventional spirometry using the MasterLab IOS System (Erich Jaeger Co., Würzburg, Germany). Calibration was performed using a single volume of air (3 L) at different flow rates and a reference resistance device (0.2 kPa/L/s). The individuals wore a nose clip and a manufacturer-provided oval hard plastic mouthpiece to prevent expired air from escaping. They were also asked to support their cheeks with their hands to decrease shunt compliance. Artifacts caused by coughing, breath-holding, swallowing, and vocalization were not included. A single, experienced, respiratory technician performed all the IOS measurements. The parameters evaluated were resonance frequency (R_{freq}), resistance at 5 Hz (R_5), resistance at 10 Hz (R_{10}), resistance at 20 Hz (R_{20}), difference in resistance between 5 Hz and 20 Hz (R_5-R_{20}), reactance at 5 Hz (X_5), and area of reactance (AX; area integrated from 5 Hz to R_{freq}). With the exception of R_{freq}, all of the above values were used to calculate differences from baseline.

Spirometry

Spirometric parameters were measured immediately after IOS measurements in all individuals. A pneumotachometer system with a Lilly head (MasterScreen system; Erich Jaeger Co.) was used to measure maximum expiratory flow volume. The spirometric flow-volume curve was obtained using international criteria [16]. All the individuals wore a nose clip and performed standard forced expiratory maneuvers. At least 3 acceptable attempts were included and the best was selected for the final analysis.

Methacholine Bronchial Provocation Test

The MBPT was also performed in all cases according to international guidelines [2]. Methacholine powder was distilled and diluted in isotonic saline and administered using a handheld

© 2010 Esmon Publicidad

nebulizer (Devilbis 646; Devilbis Health Care Inc, Somerset, England) connected to a Rosental dosimeter (Devilbis Health Care Inc). For each dose, each individual inhaled 5 times from functional residual capacity without holding their breath after a full inspiration. The first concentration of administered methacholine was 0.075 mg/mL, and a dose-response curve was plotted by serial doubling in the concentration of methacholine up to 25 mg/mL. The PC_{20} was calculated using linear interpolation between the last 2 points on the dose-response curve. When this value was lower than 25 mg/mL, AHR was considered to be present. The MBPT was conducted 2 weeks before the EBPT.

Statistical Analysis

Data were analyzed using version 12 of the SPSS statistical software (SPSS Inc, Chicago, Illinois, USA). Nonparametric statistical methods were used. The Mann-Whitney U test was used for comparing means and the Spearman rank correlation test was used for analyzing correlations. The discriminative properties of the different IOS parameters to identify AHR patients were evaluated using receiver operating characteristic (ROC) curves. To compare each variable, areas under the curve (AUC) with 95% confidence intervals (CIs) were determined. Significance was defined as $P<.05$. The data are shown as means±SEM. Logistic regression analysis was used to compare IOS parameters with FEV_1 values.

Results

Changes in Spirometry and Impulse Oscillometry Parameters After the Exercise Bronchial Provocation Test

There were no differences between the AHR group and the no-AHR group in terms of baseline spirometry results (forced vital capacity [FVC], FEV_1, or FEV_1/FVC), or IOS parameters. Baseline Rfreq and AX values were slightly higher in the AHR group but the differences were not statistically significant (Table 1).

Significant differences were found between the groups in the EBPT, with considerable differences found for time-related patterns of spirometry and IOS parameters. In the AHR group, FEV_1 fell immediately after the exercise challenge with a maximum decrement of –9.96±1.74% (0.11±0.97% in the no-AHR group, $P<.001$) at 5 minutes and recovery of normal ranges at 10 to 30 minutes after the exercise challenge. There were no changes in FEV_1 in the no-AHR group (Figure 1A). R_{freq} was significantly higher in the AHR group than in the no-AHR group at 5 minutes (15.1±0.6 Hz vs 12.8±0.8 Hz, $P=.034$), 10 minutes (13.9±0.7 Hz vs 10.7±0.7 Hz, $P=.010$), 20 minutes (12.6±0.6 Hz vs 9.5±0.6 Hz, $P=.025$), and 30 minutes (12.2±0.7 Hz vs 9.1±0.5 Hz, $P=.033$) after exercise (Figure 1B). In addition, increments of resistance at 5 Hz (ΔR5) were also much higher in the AHR than in the no-AHR group at 5 minutes

Table 1. Characteristics of Study Patients[a]

	AHR (n=12)	No-AHR (n=35)	*P* Value
Age, y	20.7 (0.9)	20.3 (1.7)	.129
Sex (male:female)	12:0	33:0	
Height, cm	174.2 (6.1)	174.5 (5.3)	.625
Weight, kg	72.8 (11.5)	70.4 (10.7)	.575
Body mass index, kg/m^2	23.9 (3.3)	23.1 (3.1)	.584
FVC, L	4.68 (0.76)	4.53 (0.44)	.843
FEV_1, L	4.05 (0.72)	3.84 (0.42)	.337
FVC, % predicted	92.6 (9.4)	91.1 (7.9)	.843
FEV_1, % predicted	94.5 (13.5)	91.6 (10.0)	.342
FEV_1/FVC ratio, %	86.4 (7.2)	85.0 (7.5)	.433
R_{freq}	10.6 (3.5)	12.0 (3.3)	.143
R_5	0.27 (0.05)	0.27 (0.08)	.723
R_{10}	0.24 (0.05)	0.23 (0.06)	.669
R_{20}	0.20 (0.05)	0.19 (0.05)	.462
R_5-R_{20}	0.07 (0.03)	0.08 (0.06)	.722
X_5	-0.08 (0.05)	-0.10 (0.06)	.704
AX	0.18 (0.14)	0.33 (0.41)	.209
PC_{20}, mg/mL[b]	>25.00	2.78 (2.72)	<.001

Abbreviations: AHR, airway hyperresponsiveness; AX, area of reactance (area integrated from 5 Hz to R_{freq}); FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; PC_{20}, amount of methacholine required to cause a 20% decrease in FEV_1 from baseline; R_5, resistance at 5 Hz; R_{freq}, resonance frequency; X_5, reactance at 5 Hz.
[a]All data are shown as means (SD).
[b]$P<.01$.

 © 2010 Esmon Publicidad

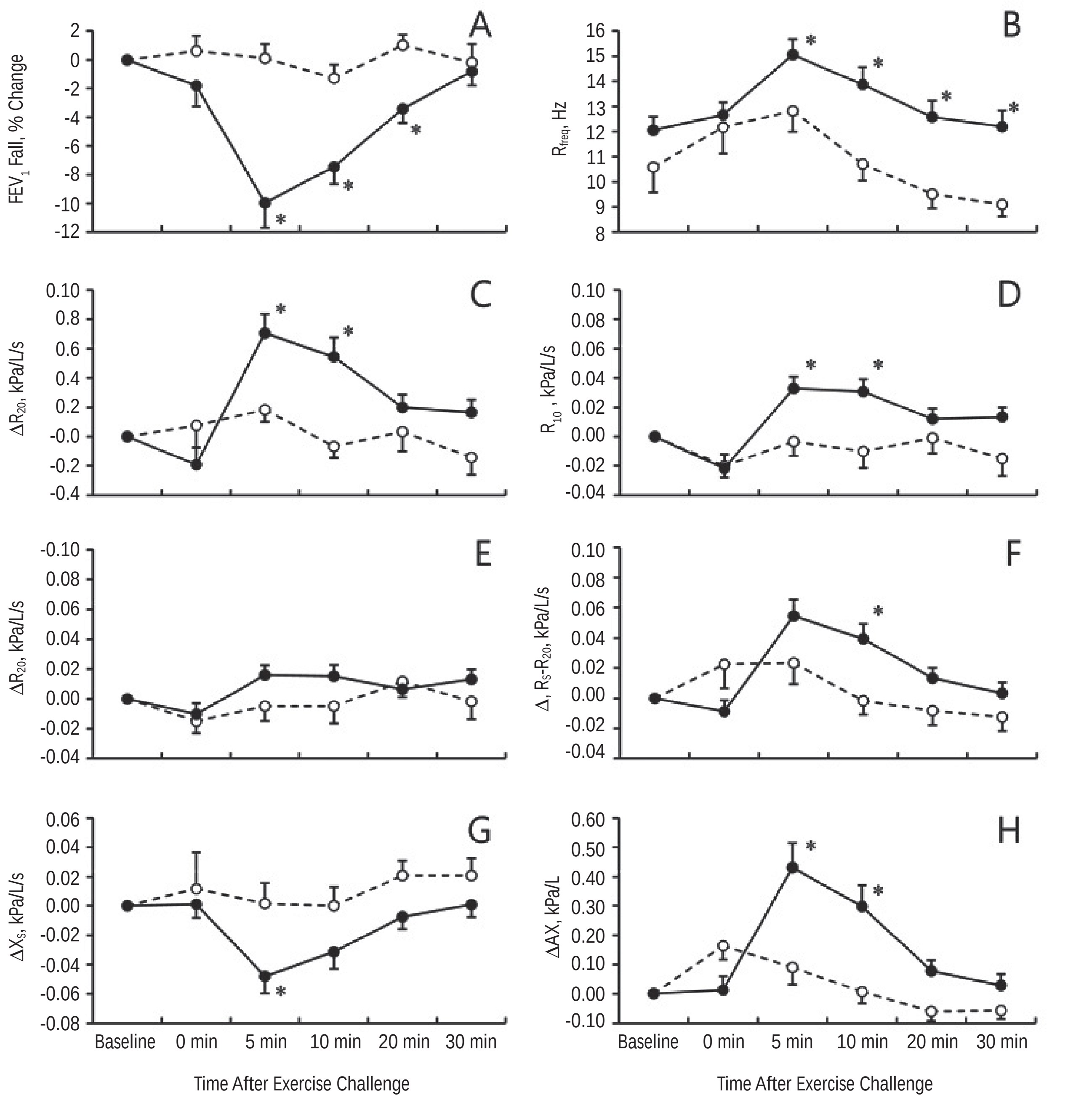

Figure 1. Serial changes in fall in forced expiratory volume in the first second (FEV_1) (A); R_{freq} (B); R_5 (C); R_{10} (D); R_{20} (E); (R_5-R_{20}) (F); X_5 (G); and AX (H) according to time after exercise bronchial provocation test. All data are shown as means±SEM. (P<.05). Open circles indicate the group without airway hyperresponsiveness (AHR) and closed circles, the group with AHR. AX indicates area of reactance (area integrated from 5 Hz to R_{freq}); R_5, resistance at 5 Hz; R_{freq}, resonance frequency; X_5, reactancy at 5 Hz.

(0.071±0.013 kPa/L/s vs 0.018±0.008 kPa/L/s, *P*=.027) and 10 minutes (0.055±0.013 kPa/L/s vs –0.007±0.008 kPa/L/s, *P*<.001) post-challenge (Figure 1C). Increments of resistance at 10 Hz (ΔR10) at both 5 minutes (0.033±0.008 kPa/L/s vs –0.003±0.010 kPa/L/s, *P*=.011) and 10 minutes (0.031±0.008 kPa/L/s vs –0.010±0.011 kPa/L/s, *P*=.005), in addition to Δ(R5-R20) values (frequency dependency of airway resistance) at 10 minutes (0.039±0.010 kPa/L/s vs –0.002±0.009 kPa/L/s, *P*=.009) were also significantly higher in the AHR group than in the no-AHR group (Figures 1D, 1F). The decrease in reactance at 5 Hz (ΔX5) at 5 minutes after the exercise challenge was greater in the AHR group than in the no-AHR

© 2010 Esmon Publicidad

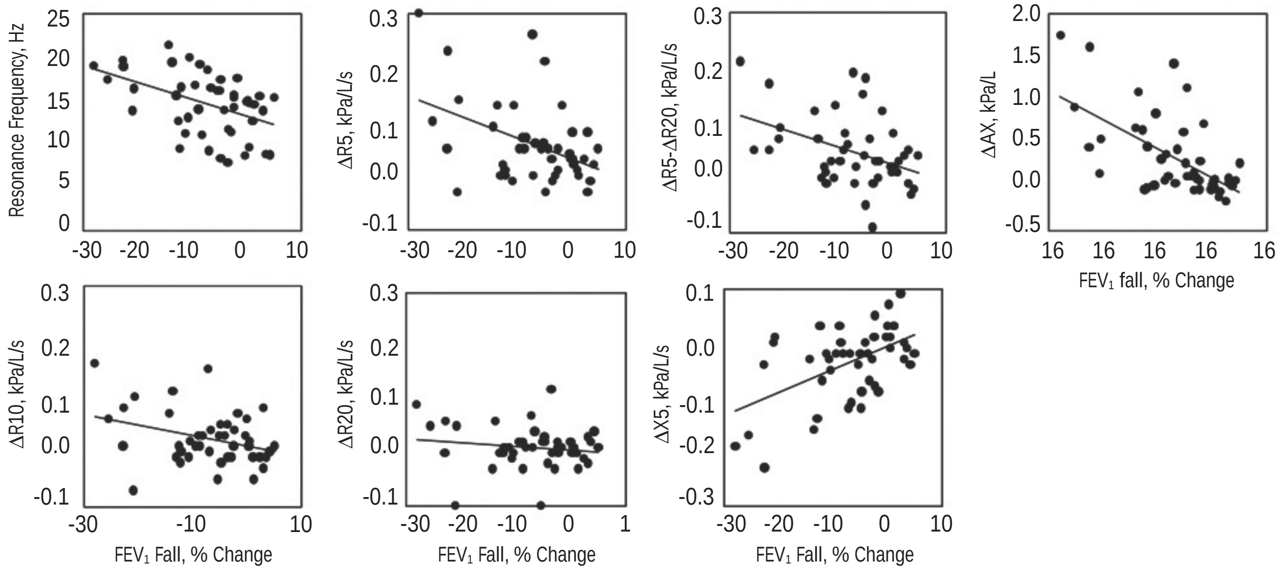

Figure 2. Correlations between fall in forced expiratory volume in the first second (FEV_1) vs. impulse oscillometry (IOS) parameters at 5 minutes after exercise challenges. R_{Freq}, R_5, R_5-R_{20}, AX, and X_5 were all well correlated with FEV_1. The exceptions were R_{10} and R_{20}. AX indicates area of reactance (area integrated from 5 Hz to R_{freq}); R_5, resistance at 5 Hz; R_{freq}, resonance frequency; X_5, reactance at 5 Hz.

Table 2. Correlation Coefficients (ρ) and *P* values of Fall in FEV_1 vs IOS Parameters

IOS Parameters		Time After Exercise Bronchial Provocation Test				
		0 min	5 min	10 min	20 min	30 min
R_{freq}	ρ	0.040	-0.456[b]	-0.412[b]	-0.346[a]	-0.159
	P	.791	.001	.004	.017	.287
ΔR5	ρ	0.156	-0.314[a]	-0.367[a]	-0.323[a]	0.030
	P	.296	.032	.011	.027	.839
ΔR10	ρ	0.038	-0.278	-0.302[a]	-0.296[a]	-0.021
	P	.801	.059	.039	.043	.889
ΔR20	ρ	0.266	-0.104	-0.293[a]	-0.145	0.064
	P	.071	.487	.046	.330	.669
Δ(R5-R20)	ρ	-0.097	-0.375[b]	-0.328[a]	-0.308[a]	-0.136
	P	.517	.009	.024	.035	.363
ΔAX	ρ	-0.025	-0.545[b]	-0.441[b]	0.455[b]	-0.229
	P	.867	<.001	.002	.001	.121
ΔX5	ρ	-0.171	0.396[b]	0.190	0.138	0.084
	P	.249	.006	.201	.355	.577

Abbreviations: AX, area of reactance (area integrated from 5 Hz to R_{freq}); FEV_1, forced expiratory volume in the first second; IOS, impulse oscillometry; R_5, resistance at 5 Hz; R_{freq}, resonance frequency; X_5, reactance at 5 Hz.
[a]$P<.05$.
[b]$P<.01$.

group (–0.048±0.012 kPa/L/s vs 0.002±0.014 kPa/L/s, *P*=.040) (Figure 1G). Finally, AX values in the AHR group compared to the no-AHR group were also significantly increased at 5 minutes (0.431±0.083 kPa/L vs 0.091±0.060 kPa/L, *P*=.010) and 10 minutes (0.298±0.072 kPa/L vs 0.007±0.039 kPa/L, *P*=.031) after the exercise (Figure 1H).

Correlation Analysis of Spirometry and Impulse Oscillometry Parameters

The IOS parameters R_{freq}, ΔR_5, $\Delta(R_5–R_{20})$, ΔAX, and ΔX_5 were all well correlated with the decrease in FEV_1 at 5 minutes after exercise (Figure 2). At 10 minutes, ΔR10 but not X5 was

 © 2010 Esmon Publicidad

correlated with this decrease. Specific correlation coefficients and *P* values are presented in Table 2. The correlations between the decrease in FEV_1 and R_{freq}, ΔR_5, $\Delta(R_5–R_{20})$, and ΔAX were maintained from 5 minutes to 20 minutes after the exercise challenge.

Receiver Operating Characteristic Analysis

The ΔR_5 value at 10 minutes after exercising was the best parameter for distinguishing methacholine-induced AHR (AUC: 0.818, *P*=.001 with 95% CI 0.699-0.936) but ΔAX at 5 minutes also had distinguishing power (AUC, 0.746; *P*=.012; 95% CI, 0.595-0.898). A cutoff of 0.035 kPa/L/s for ΔR_5 at 5 minutes was capable of distinguishing between patients with AHR and those without with 63% sensitivity and 100% specificity. Furthermore, on analyzing maximum post-EBPT nominal changes, ΔR5max was also useful for distinguishing between AHR and no-AHR (AUC, 0.755; *P*=.009; 95% CI, 0.612-0.898). A cutoff of 0.055 kPa/L/s for ΔR_{5max} had 71% sensitivity and 75% specificity.

Logistic Regression Analysis

Each sequential IOS parameter and decrease in FEV_1 was analyzed for the probability with which it could predict MBPT positivity. ΔR5 (at 5 and 10 minutes), ΔAX (at 5, 10, and 20 minutes), and R_{freq} (at 10, 20 and 30 minutes) values proved to be capable of predicting MBPT positivity. These results support the ROC analysis explained above (data not shown).

Discussion

Many clinical studies have reported the usefulness of the FOT to evaluate airway obstruction in a variety of physiologic or pathologic conditions [15,17-21]. Although spirometry has reference values and high reproducibility, IOS can reflect other aspects of bronchial obstruction such as airway resistance and reactance. There are many reports of the FOT being used to describe airway characteristics in children and adults [15,18-20]. The technique has been used not only to assess the degree of airway obstruction, but also to evaluate bronchodilation or AHR induced by a nonspecific airway irritant such as methacholine. Song et al [18,19] reported that IOS parameters were significantly correlated with spirometry in asthmatic children, especially those with atopy. IOS could thus be a useful diagnostic tool in pediatric asthma and a helpful outcome measure for asthma treatment [18-19]. Mansur et al [20] suggested that IOS parameters during MBPT correlated better with asthma symptoms than spirometry parameters.

Some reports have suggested that the FOT is useful for evaluating exercise-induced bronchoconstriction or asthma [15,22]. Malmberg et al [15] reported that time-related patterns of exercise-induced changes in IOS parameters in children after a free running test. They also suggested that a 35% increase in R5 might be an abnormal response. IOS parameters can detect airway obstruction not only after exercise, but also in eucapnic voluntary hyperventilation. In particular, R5 has been found to be significantly correlated with a decrease in FEV_1 [23]. In addition, Schweitzer et al [22] showed that deep inhalation measured by respiratory conductance could reverse EIB.

Our results support that IOS can measure exercise-induced airway characteristics in adults as well as spirometry, with exercise-induced airway resistance parameters measured by IOS correlating well with spirometry parameters. The most powerful marker for discriminating between patients with AHR and those without was ΔR5 at 10 minutes after the exercise challenge, with a 0.035 kPa/L/s elevation from baseline. Also of value for this purpose were ΔAX at 5 minutes after exercise and maximum post-exercise changes in R_5 (ΔR_{5max}). These results support findings reported by Malmberg et al [15]. Yet our results are expressed as a numeric increment rather than a percent increment. ΔX_5 is well known as an IOS parameter that has large interindividual differences [15,21]. In our study, however, ΔX_5 did not show any statistical differences between individuals with AHR and those without, although resonance frequency did show meaningful differences after exercise. Because temperature increases during exercise may minimally affect IOS parameters after the EBPT [24], all the exercise challenges in the current study were performed in an air-conditioned room to minimize this effect.

IOS following an EBPT is a practical method for use in pre-recruitment physical examinations because it does not require forced maneuvers. This is important as individuals may attempt to manipulate spirometry results to their benefit in such tests. IOS, in contrast, is free from this risk. In Korea, all 18-year-old males must undergo a pre-recruitment physical examination at the Military Manpower Administration, even though they can be drafted at any age between 18 and 35 years. In addition, some young men attempt to evade their military service obligation.

The measurement of airway resistance by IOS does, however, have some limitations. The results, for instance, can be adversely affected by cheek movement, or by the use of vocal cords or the muscles of the pharyngeal wall [25]. Furthermore, in adults, the proportion of upper airway resistance in total airway resistance would be higher than that in children [26]. These technical limitations may result in considerable interobserver differences [27] and lower reproducibility compared with spirometry [28-29].

In conclusion, IOS revealed airway characteristics in individuals that performed an EBPT that were well correlated with those detected by spirometry. ΔR5 and ΔAX were useful measurements for distinguishing between asthmatics presenting EIB and healthy individuals. The measurement of exercise-induced airway resistance using the IOS method would be useful to confirm exercise-induced airway obstruction in asthmatics without the need for effort-dependent forced expiration maneuvers.

Acknowledgments

This study was supported by grant A040153 from the Korea Healthcare Technology R&D Project, Ministry for Health, Welfare and Family Affairs, Republic of Korea.

© 2010 Esmon Publicidad

Previous Presentation: The abstract of this article was presented as a poster presentation at the 2009 American Thoracic Society Annual International Conference held in San Diego, California, USA held on May 15-20, 2009 (poster presentation; board C34; publication page, A5083).

References

1. Randolph C. Exercise-induced asthma: update on pathophysiology, clinical diagnosis, and treatment. Curr Problems Pediatr. 1997;27(2):53-77.
2. Crapo RO, Casaburi R, Coates AL, Enright PL, Hankinson JL, Irvin CG, MacIntyre NR, McKay RT, Wanger JS, Anderson SD, Cockcroft DW, Fish JE, Sterk PJ. Guidelines for methacholine and exercise challenge testing-1999. Am J Resp Crit Care Med. 2000;161(1):309-29.
3. Weiler JM, Bonini S, Coifman R, Craig T, Delgado L, Capão-Filipe M, Passali D, Randolph C, Storms W. American Academy of Allergy, Asthma & Immunology Work Group report: exercise-induced asthma. J Allergy Clin Immunol. 2007;119(6):1349-58.
4. Berend N, Salome CM, King GG. Mechanisms of airway hyperresponsiveness in asthma. Respirol. 2008;13(5):624-31.
5. Cockcroft DW, Davis BE. Mechanisms of airway hyperresponsiveness. J Allergy Clin Immunol. 2006;118(3):551-9; quiz 560-1.
6. Mannix ET, Roberts MA, Dukes HJ, Magnes CJ, Farber MO. Airways hyperresponsiveness in high school athletes. J Asthma. 2004;41(5):567-74.
7. Langdeau JB, Turcotte H, Bowie DM, Jobin J, Desgagne P, Boulet LP. Airway hyperresponsiveness in elite athletes. Am J Respir Crit Care Med. 2000;161(5):1479-84.
8. Morris MJ, Schwartz DS, Nohrenberg JL, Dooley SN. Airway hyperreactivity in asymptomatic military personnel. Military Med. 2007;172(11):1194-7.
9. Chon WK HS, Cho BY, Chang KS. The Conscription systems of major countries in the world. Seoul: The Korean Office of Military Manpower Administration; 2005. (Korean)
10. American Thoracic Society. Lung function testing: selection of reference values and interpretative strategies. Am Rev Respir Dis. 1991;144(5):1202-18.
11. Harm DL, Marion RJ, Creer TL, Kotses H. Effects of instructions on pulmonary function values. J Asthma. 1985;22(6):289-94.
12. Zerah F, Lorino AM, Lorino H, Harf A, Macquin-Mavier I. Forced oscillation technique vs spirometry to assess bronchodilatation in patients with asthma and COPD. Chest. 1995;108(1):41-7.
13. Dubois AB, Brody AW, Lewis DH, Burgess BF. Oscillation mechanics of lungs and chest in man. J Appl Physiol. 1956;8(6):587-94.
14. Global Initiative for asthma. Global strategy for asthma management and prevention. 2002. p. 02-3659.
15. Malmberg LP, Mäkelä MJ, Mattila PS, Hammarén-Malmi S, Pelkonen AS. Exercise-induced changes in respiratory impedance in young wheezy children and nonatopic controls. Pediatr Pulmonol. 2008;43(6):538-44.
16. American Thoracic Society. Standardization of Spirometry, 1994 Update. Am J Respir Crit Care Med. 1995;152(3):1107-36.
17. Park JW, Lee YW, Jung YH, Park SE, Hong CS. Impulse oscillometry for estimation of airway obstruction and bronchodilation in adults with mild obstructive asthma. Ann Allergy Asthma Immunol. 2007;98(6):546-52.
18. Song TW, Kim KW, Kim ES, Park JW, Sohn MH, Kim KE. Utility of impulse oscillometry in young children with asthma. Pediatr Allergy Immunol. 2008;19(8):763-8.
19. Song TW, Kim KW, Kim ES, Kim KE, Sohn MH. Correlation between spirometry and impulse oscillometry in children with asthma. Acta Paediatr. 2008;97(1):51-4.
20. Mansur AH, Manney S, Ayres JG. Methacholine-induced asthma symptoms correlate with impulse oscillometry but not spirometry. Respir Med. 2008;102(1):42-9.
21. Larsen GL, Morgan W, Heldt GP, Mauger DT, Boehmer SJ, Chinchilli VM, Lemanske RF, Jr., Martinez F, Strunk RC, Szefler SJ, Zeiger RS, Taussig LM, Bacharier LB, Guilbert TW, Radford S, Sorkness CA, Childhood Asthma R, Education Network of the National Heart L, Blood I. Impulse oscillometry versus spirometry in a long-term study of controller therapy for pediatric asthma. J Allergy Clin Immunol. 2008;123(4):861-7.
22. Schweitzer C, Vu LT, Nguyen YT, Chone C, Demoulin B, Marchal F. Estimation of the bronchodilatory effect of deep inhalation after a free run in children. Eur Respir J. 2006;28(1):89-95.
23. Evans TM, Rundell KW, Beck KC, Levine AM, Baumann JM. Impulse oscillometry is sensitive to bronchoconstriction after eucapnic voluntary hyperventilation or exercise. J Asthma. 2006;43(1):49-55.
24. Evans TM, Rundell KW, Beck KC, Levine AM, Baumann JM. Airway narrowing measured by spirometry and impulse oscillometry following room temperature and cold temperature exercise. Chest. 2005;128(4):2412-9.
25. Arets HG, van der Ent CK. Measurements of airway mechanics in spontaneously breathing young children. Paediatr Respir Rev. 2004;5(1):77-84.
26. Hogg JC, Williams J, Richardson JB, Macklem PT, Thurlbeck WM. Age as a factor in the distribution of lower-airway conductance and in the pathologic anatomy of obstructive lung disease. N Eng J Med. 1970;282(23):1283-7.
27. Klug B, Nielsen KG, Bisgaard H. Observer variability of lung function measurements in 2-6-yr-old children. Eur Respir J. 2000;16(3):472-5.
28. Goldman MD, Carter R, Klein R, Fritz G, Carter B, Pachucki P. Within- and between-day variability of respiratory impedance, using impulse oscillometry in adolescent asthmatics. Pediatr Pulmonol. 2002;34(4):312-9.
29. Houghton CM, Woodcock AA, Singh D. A comparison of plethysmography, spirometry and oscillometry for assessing the pulmonary effects of inhaled ipratropium bromide in healthy subjects and patients with asthma. Br J Clin Pharmacol. 2005;59(2):152-9.

Manuscript received December 18, 2009; accepted for publication, March 24, 2010.

Jung-Won Park

Department of Internal Medicine, Yonsei University
College of Medicine
Sudaemungu Shinchondong 134
Seoul, Republic of Korea 120-752
E-mail: parkjw@yuhs.ac

 © 2010 Esmon Publicidad